SPATIAL AND TEMPORAL VARIATIONS IN NUTRIENT DYNAMICS IN *POKKALI* SOILS OF KERALA

By

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(2016-21-021)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **“Spatial and temporal variations in nutrient dynamics in *Pokkali*soils of Kerala.”** is a bona-fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis, entitled **"Spatial and temporal variations in nutrient dynamics in *Pokkali* soils of Kerala."**is a record of research work done independently by **Mrs.Silpa P.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

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Silpa, P.

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INTRODUCTION

1. INTRODUCTION

The *Pokkali* soils belong to fine loamy, mixed, iso-hyperthermic acid family of sulfaqueptic trpofluents as per Soil Taxonomy. These are formed from lacustrine and alluvial deposits (Varghese *et al.,* 1970). The *Pokkali* tract *(Typic Sulfaquents)* represents the low lying coastal saline areas, situated near the estuaries of streams and rivers not far from the sea, and extends from 9°00 to 10°40'N Latitude and 76°00' to 77°30' E Longitude where no other type of agriculture would ordinarily be possible other than cultivation of *Pokkali* rice (Dominic and Jithin, 2012). This is due to the frequent ingression of tidal water from the sea that results in perennial problems of salinity and high acidity. *Pokkali* fields are reported to be highly fertile with pest and disease incidence below threshold level. Manuring and plant protection operations are hence not necessary for this farming system. The rice produced from this area is purely organic (Vanaja, 2013). The other characteristics of this land include water logging, poor drainage system and tidal action throughout the year.

The major land uses present in the *Pokkali* tracts are paddy alone, paddy-shrimp, shrimp alone, mangroves and fallow land. At present, farmers are not interested in paddy alone land use system as it not profitable. The paddy-shrimp cultivation is a classic example of sustainable agri – aqua integration providing a means of rural livelihood. The rice cultivation is carried out in *Pokkali* tract during June to early November when the fields are in low saline phase and shrimp farming takes over from mid-November to mid-April (high saline phase).

There are about 4000 hectares of paddy fields under *Pokkali* cultivation in Ernakulam district, while in Alappuzha and Thrissur the extent is nearly 3000 ha and 2000 ha respectively (Joy, 2013). In Kerala, traditional and extensive shrimp culture is in practice and the total area under traditional farming system is 12,986.6 ha, of which 84% is under *Pokkali* fields (Pillai *et.al*, 2002). According to Dominic and Jithin (2012),the total area under *Pokkali* has tremendously decreased from 25,000 ha a few decades back, to a mere 8,500 ha of which only 5,500 ha alone is in fact under rice cultivation. The rest is either left fallow or used only for prawn farming. Unavailability of farm hands, especially for harvesting, is the main cause for the decline.

Even though this soil is fertile, deficiency and toxicity of certain nutrients have been reported in *Pokkali* soils at random and it is difficult to generalise as the reports are mostly contradictory. Shylaraj *et al.* (2013) reported deficiencies of phosphorus, micro nutrients and poor nutrient status in *Pokkali soil*. Koruth *et al.* (2014) reported that 94 percent of the soils in *Pokkali* land were having medium to high organic carbon content. Sixty percent of samples were having high phosphorus status and 32 percent medium status. Sixty eight percent of samples were having high potassium status and 13 percent medium status. The secondary nutrient calcium was adequate in 79 percent of the soils. Hundred percent deficiency of magnesium and 100 percent sufficiency of sulphur was another characteristic reported in *Pokkali* tract. The micro nutrients zinc, copper and boron were 100 percent adequate. In contrast to observation of Koroth *et al* (2014), Bhindhu (2017) reported sufficiency of magnesium in *Pokkali* tract and Joseph (2014) noticed copper deficiency in all land use systems. Sea water intrusion in *Pokkali* field plays a major role in bringing about variations in nutrient dynamics in *Pokkali* soil.

Koruth *et al.* (2014) observed that available phosphorus, potassium, iron and aluminium were higher during high saline phase (November to April) than low saline phase (June to early November) and available calcium, magnesium, sulphur, zinc, copper, manganese and boron were higher during low saline phase.

Only very few studies have been carried out on fractionation of nutrients in *Pokkali* soil. Santhosh (2013) revealed that boron fraction in *Pokkali* soil followed the order; total B > residual B > organic B > oxide bound B > specifically adsorbed B. Aryalekshmi (2016) investigated on silicon (Si) fractions in different soil types in Kerala and reported highest amount of mobile and organic silicon in *Pokkali* soil compared to *Kuttanad*, *Kole*, sandy and lateritic soils. The clay mineral surface was observed to act as a major source of mobile Si and high quantity of organic carbon also was found to exert a direct effect on organic silicon in *Pokkali* soil. Distribution of different silicon fractions in *Pokkali* soil followed the order; total Si>residual Si>amorphous Si>organic Si>occluded Si>mobile Si>adsorbed Si. Bhindu (2017) carried out fractionation studies on calcium and magnesium in *Pokkali* soil. She pointed out that water soluble Ca was the second largest and water soluble Mg was the third largest Mg fraction in *Pokkali* soil which emphasized the tidal influence on very high calcium and magnesium availability in *Pokkali* soil. John(2019) performed on carbon and nitrogen fractions in wetlands of Kerala and she observed that the lowest hot water extractable carbon and permanganate oxidizable carbon were recorded in *Pokkali* soil.

She also reported highest amino acid nitrogen (organic fraction) in *Pokkali* land. Nideesh (2019) studied on different carbon pools *viz.,* total, passive, active and slow carbon and on total, organic and inorganic fractions of nitrogen, sulphur and phosphorus for the purpose of studying the soil taxonomy and organic carbon nutrient interaction in selected wetland soils of Kerala. The findings of the above researchers could not explain the reasons for nutrient variations manifested in *Pokkali* soils as *Pokkali* soils were only one area of their research programmes.

Very few investigations have so far been carried out on adsorption studies of nutrients in *Pokkali* soil. Aryalekshmi (2016) mentioned that *Pokkali* soils adsorbed highest percentage of Si applied to the soil at 25^0C and 40^0C and she concluded that *Pokkali* soils may not have reached its maximum adsorption potential at the levels of Si added to the soil. Desorption of calcium and magnesium in *Pokkali* soil was recorded by Bhindhu (2017) irrespective of change in temperature and this was attributed to the high content of soluble salts and exchangeable aluminium in the soil. The knowledge on pattern of adsorption and related thermodynamic parameters of other nutrients in this soil are altogether lacking.

Here, the study on seasonal variations in nutrient dynamics in *Pokkali* soils has got importance. Physical, chemical and biological properties of *Pokkali* soil was examined and recorded bimonthly. Water samples from field and brackish water also collected and analysed to know the tidal influence on soil properties. Selected nutrients viz, P and Cu were subjected to fractionation and adsorption study in October (low saline phase) and April (high saline phase) months to know the influence of varying soil pH and salinity on nutrient dynamics. This investigation will help in answering the reasons for the changes in available nutrient status in different seasons in *Pokkali* soil. On these background, a systematic study focussing entirely on *Pokkali* soils of Kerala has hence been designed to gather information on its nutrient dynamics in relation to spatial and temporal variations with the following objectives in view:

- Collection and characterisation of *Pokkali* soil and water samples bimonthly from five different land uses.
- Quantification of nutrients, phosphorus and copper existing in different forms and their contribution to available pool.

- To unravel the influence of land use, brackish water inundation, rainfall and soil temperature on nutrient availability and dynamics.
- Understanding pattern of phosphorus and copper adsorption i*n Pokkali* soil and related thermodynamic parameters.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The *Pokkali* tract *(Typic Sulfaquents)* represents the low lying coastal saline areas situated below the mean sea level (Dominic and Jithin, 2012).There are about 9000 hectares of paddy fields under *Pokkali* cultivation in Ernakulam, Alappuzha and Thrissur districts (Joy, 2013).*Pokkali* fields are waterlogged with poor drainage and are subject to the frequent ingression of tidal water from the sea and result in perennial problems of salinity and high acidity hence the name acid saline *Pokkali* soil. The *Pokkali* system enters to the high saline phase during November to April with the onset of N-E monsoon (October to November) causing high salinity level in the soil. During June to early November, this system will come under the low saline phase as copious S-W monsoon (June to September) washes the excess salt from the field.

Though *Pokkali* tracts are high in fertility status, they are low in productivity due to salinity resulting from sea water inundation. There is a drastic fluctuation in the available forms of nutrients during the high saline and low saline phases. This study is looking towards the dynamic seasonal variation in soil properties throughout the year, and the reasons and factors influencing these variations.

The most pertinent literature with respect to the present investigation on characterization of *Pokkali* soils, nutrient fractionation and adsorption giving special reference to phosphorus and copper on soil are reviewed hereunder.

2.1. Characterization of *Pokkali* soil

Limited numbers of studies are present on characterization of *Pokkali* soil. The available literature related to this investigation are updated and given under the following sub headings.

2.1.1. Physical properties of *Pokkali* soil

The study conducted by Varghese *et al.* (1970) on profile characteristics of *Pokkali* soils of Vytila revealed that soil texture became finer and soil colour intensity increased with depth of soil. The soils of *Pokkali* fields are deep, dark or pale bluish black in colour, impervious in nature and clayey in texture that forms cracks on drying and turn sticky on wetting (Padmaja *et al.,* 1994).

Joseph (2014) reported that bulk density of *Pokkali* soil varied from 0.23to 1.45 Mg m^{-3} in different land use systems (paddy alone, paddy-shrimp, shrimp alone, mangrove and fallow land) of *Pokkali* tract. Significant difference in bulk density was noticed among different land uses. The lowest bulk density was recorded in fallow land use system and highest was in shrimp alone land use system.

2.1.2. Chemical properties of *Pokkali* soil

2.1.2.1. Soil reaction (pH)

Wetland soils of Kerala could be arranged as *Kari >Pokkali >Karapadom >Vellayani >Kayal >Kole >Wayanad >Pattambi >Kaipad >Karamana >Kattampally >Chitoor*, based on severity of acidity. All the wetlands reached above a pH of 5.5 within two weeks of submergence except *Pokkali*, *Kari*, *Kayal* and *Kole* lands (Bhaskaran and Varghese, 2009).

Beena *et al.* (2017) reported that the pH of the *Pokkali* soil varied from 2.72 to 4.2 and the soils are classified as acid saline. The soil is extremely acidic due to intermittent submergence and aeration. Aeration of the soil leads to oxidation of sulphides to sulphuric acid, which rapidly increases the soil acidity.

Joseph (2014) observed thatsoilreaction was highest during harvest stage (September), compared to the mound preparation stage (April) of *Pokkali* rice cultivation.

The inbuilt acidity of *Pokkalis*oil becomes more dominant, when the salinity is washed away (Padmaja *et al.*, 1994). But Hindar *et al.,* (1994) reported that direct addition of Na^+ ion containing solution resulted in an exchange of Na^+ ion with H^+ and Al^{3+} ions, causing acidification. Earlier studies in wetland soils and sediments have reported a decrease in pH with increasing salt concentration (Khattak *et al.,* 1989). Later, Harriman *et al.,* (1995) also reported the same.

2.1.2.2. Electrical conductivity (EC)

Inundation of sea water into *Pokkali* tract contributed significant amount of soluble salts in soil and hence increased the electrical conductivity (Beena *et al*., 2017). Most of the *Pokkali* soils have EC higher than 14 dSm^{-1}(Varghese *et al.,* 1970). The salinity of *Pokkali* fields decreased rapidly up to the month of August and maintained till the end of December to January. This variation was due to the freshwater influx by rainfall and through estuaries (Vanaja, 2013). Mohan and Sreelatha (2016) also observed that electrical conductivity decreased from mound preparation to harvest stage of the *Pokkali* rice cultivation. During summer months (January – May), the electrical conductivity of *Pokkali* soil ranged between 12-24 dSm^{-1} and the average salt content got reduced upto 1.8% (Kuruvila, 1974).

2.1.2.3. Redox potential (Eh)

The oxidation-reduction potential (redox potential) is a measure of the ratio of oxidized to reduced forms in a solution. Redox potential is used as an indicator of the oxygenation status and the content of biogenic forms and toxins in the soil environment and sediments (Ewelina and Danuta, 2015). The low potentials (0.2 to -0.4 V) of submerged soils and sediments reflect the reduced state and the high potentials (0.8 to 0.3 V) of aerobic media, their oxidized condition. When an aerobic soil is submerged, its Eh decreases during the first few days and reaches a minimum; then it increases, attains a maximum, and decreases again asymptotically to a value characteristic of the soil, after 8-12 weeks of submergence (Ponnamperuma, 1972).

Redox potential is determined from the concentration of oxidants and reductants in the environment. The wetland soils are characterized by the limited presence of electron acceptors and the abundant supply of electron donors. The reductants in these soils include organic matter, various organic compounds and reduced inorganic compounds, *viz.* NH^{4+}, Mn^{2+}, CH_4 and H_2. The oxidation reduction status of different redox couples can be understood from the redox potential of the soil.

2.1.2.4. Nutrient status

In *Pokkali soils*, the content of oxidizable organic matter increased during the first 10 days and is maintained thereafter (Samikutty, 1997). Koruth *et al.* (2014) reported that *Pokkali* soils had medium to high organic carbon whereas Mohan and Sreelatha (2016) pointed out that the organic carbon content of thesesoils was found to be high during mound preparation and harvest stage of paddy. Saseedharan *et al.* (2012)

conducted an experiment on rice-fish-prawn rotational farming system and revealed that soil organic carbon content remained high after fish harvest and remained to be the same even after the prawn harvest, implying high fertility status of *Pokkali* soil. Beena *et al.* (2017) revealed that the *Pokkali* soil is rich in organic matter, which ranged from 2.04 to 3.57 per cent.

Ponnamperuma (1972) studied the changes occurring in submerged soils. Almost all the nitrate present in a soil disappeared within a few days of submergence, the bulk of it being lost as N_2. The potassium content in wetland soil was increased with advancement in submergence. There was a steep increase in iron content in the *Pokkali* soils upto 30 days of submergence and it was maintained thereafter. Aluminium and manganese content was increased upto 10 days and then dropped down. The supply of nutrients like P, K, Ca, Mg, Fe, Mn, Si, Cu and Mo was high due to submergence.The strong affinity of phosphorus to iron and aluminium oxides and hydroxides in highly weathered tropical soils limits P availability in tropics. But Snyder (2002) opined that, availability of P is more in flooded condition. This is due to the release of P fixed by Fe oxides and hydroxides into more available forms,with the reduction of Fe^{3+}.The amount of P released into the soil solution depends on soil characteristics involved in reduction processes 1) abundance of Fe oxides and their crystallinity 2) soil organic matter content and its microbial availability as electron donors 3) total P content and its forms and 4) soil pH neutralization as a result of soil flooding, which increases the P availability by increasing the solubility of Fe and Al-P compounds in acid soils (Chacon *et al.,* 2005.

Sasidharan *et al.* (2012) studied the effect of spatial and temporal integration of rice, fish and prawn on chemical characteristics of *Pokkali* soil in Vytila. Available soil P after the fish and prawn harvest were medium and for available K it was high. Available Na content increased significantly after the prawn harvest, presumably reflecting the changes in water salinity levels. He concluded that although no direct effect of the components, *viz.* paddy, fish and prawn on pH, electrical conductivity, organic carbon content, available phosphorus, available potassium, and available sodium of the soil were noted, seasonal variations in water quality and consequent changes in soil properties were evident.

Mohan and Sreelatha (2016) examined the nutrient dynamics of *Pokkali* soil during the two different stages of cultivation namely mound preparation on April and harvest stage on September.Comparing the two stages, organic carbon and available nitrogen were more at mound preparation stage. This might be due to the slower breakdown of soil organic matter and plant residues in submerged soil. This resulted in slow nitrogen mineralization in *Pokkali* soil. The available nutrients namely P, K, Ca, S, Fe, and B followed an increasing trend from mound preparation to harvest stage. The available Na and Al also followed the same trend. This variation can be mainly attributed to the tidal flows and submerged conditions prevailing in the fields. Available Zn, Mn and Cu did not show any significant difference between the two stages.

Bhindu (2017) observed high content of Ca and Mg in lowland *Pokkali* which can be related to high electrical conductivity indicating the presence of soluble salts due to marine influence. She also noted that aluminium was the dominant cation in lowland followed by magnesium.

Koruth *et al*. (2014) reported high solubility of Fe in *Pokkali* soil resulted in Mg deficiency. There was no solubility of Al and no toxic effect when the soil pH was more than 5.5. The same was reported by Joseph (2014). All other nutrients like P, K, Ca, S, Zn, Cu, Fe and Mn were presented sufficiently indicating high fertile status of *Pokkali* soils.

Joseph (2014) studied on quality assessment of *Pokkali* soils under different land uses (paddy alone, shrimp alone, paddy-shrimp, mangrove and fallow land). She concluded that the mean value of nitrogen came under medium fertility status even though organic carbon was high. All the nutrients except Cu was high at all the sites of sample collection under different land use systems. Copper was reported deficient in all these sites. The available status of Fe, Mn, B and S were in the toxic levels in all land uses under the study.

Santhosh (2013) reported a higher quantity of exchangeable sodium in *Pokkali* soils. The order of dominance of exchangeable cations in *Pokkali* soils was reported by Aryalekshmi (2016), which was Ca = Na >Al >Mg >K >Fe.

2.1.3. Biological properties

Fungi are active usually in aerobic conditions and their growth is inhibited in wetland environment, being anaerobic along with a shift in pH from acidic to neutral. The decrease in microbial activity leads to a decline in the rate of microbial mediated reactions (Inglett *et al.,* 2005). Pramila and Chandrika (2001) reported the occurrence of large number of *Pseudomonas sp.* during monsoon months in *Pokkali* soil. The tidal influx is also helpful for the growth of a broad spectrum of beneficial microbes (Ranga, 2006). Even though the *Pokkali* soil was very saline, remarkable activity of bacteria, fungi and actinomycetes were observed and the population of fungi were positively correlated with organic matter of soil (Beena *et al.* 2017). Koruth *et al.* (2014) reported that native flora of *Azospirillum* and P solubilizers were present in the *Pokkali* soil while native K solubilizers wereabsent.

The soil microbial biomass, an important soil indicator plays an efficient role in the formation of organic pool by decomposing organic matter and by controlling the nutrient dynamics in the soil (Kara and Bolat, 2008). Microbial biomass is reduced under saturated conditions of the soil (Inglett *et al.,* 2005). Beena *et al.* (2017) revealed that microbial biomass carbon in the *Pokkali* soil varied from 125.2 to 260.3 μg TPF g^{-1} soil. Kirtika *et al.* (2018) pointed out that microbial biomass carbon was drastically affected by the cropping systems and seasons. Temporal variation in microbial biomass carbon has been accounted due to variations in microclimatic conditions of the soil and the circumstances existing for vegetation growth. The soil biomass is significantly correlated with activity of dehydrogenase in soil (Garcia*et al.,* 2000).

Among all enzymes in the soil environment, dehydrogenases are one of the most important, and are used as an indicator of overall soil microbial activity (Salazar*et al.,*2011). Several environmental factors, including soil moisture, oxygen availability, oxidation reduction potential, pH, organic matter content, depth of the soil profile, temperature, season of the year, heavy metal contamination and soil fertilization or pesticide use can significantly affect dehydrogenase activity in the soil environment because they occur intracellular in all living microbial cells (Yuan and Yue, 2012). The investigation by Agnieszka and Zofia (2012) demonstrated that optimal pH range for dehydrogenase enzyme was between 5.5-5.73 and activity of this enzyme was positively correlated with total organic carbon and soil temperature. The dehydrogenase activity in the flooded soil was found to be higher than non-flooded soil, emphasizing that flooded condition favours dehydrogenase activity (Beena *et al.,* 2017).

2.2. Water quality in *Pokkali* tract

Shylaraj *et al.* (2013) reported a mean pH value of 7.10 from the water samples in *Pokkali* land. They also reported a mean EC value of 11.70 dS m^{-1}. Total soluble salt (TSS) in the water samples ranged from 1100.82 mg L^{-1} to 7404.82 mgL^{-1} (Joseph, 2014). Krishnani *et al.* (2011) studied on water characterization of traditional paddy and shrimp fields of Kerala. They noticed that water parameters like salinity, ammonia and nitrite values were marginally higher during extensive shrimp culture than during paddy crop. However, pH, chemical oxygen demand, phosphates and total phosphorous were not significantly different between the paddy cultivation and shrimp culture.

During high saline phase, there was no heavy metals in the water source of *Pokkali* tract except for Nickel which was more than 0.2 mgl^{-1}, the tolerance limit for irrigation water while the concentration of lead, arsenic, boron, aluminium, zinc, copper, iron and manganese were less (Joseph, 2014; Koruth *et al*., 2014). The pesticide residue of organo phosphorus, organo chlorine and synthetic pyrethroid compounds were not detected in the water samples during both high and low saline phases (Koruth *et al*., 2014).

2.3. Nutrient forms in *Pokkali* soil and their transformation

Nutrient elements are converted from unavailable to available forms through a wide variety of transformation processes.Elements in soil may be distributed among many components of the soil and may be associated with them in different ways. The nature of this association has often been referred to as fractionation (Ramos *et al.,* 1994). Studies conducted on nutrient fractionation in *Pokkali* soil are very few. So far, Santhosh (2013), Aryalekshmi (2016), Bhindhu (2017) and John (2019) had conducted fractionation studies on boron, silicon, calcium and magnesium, and carbon and nitrogen respectively in *Pokkali* soil. The different pools of carbon and the total,organic and inorganic factions of nitrogen,phosphorus and sulphur were studied by Nideesh

(2019). Research works related to fractionation of phosphorus and copper in submerged soil are discussed hereunder.

2.3.1. Phosphorus (P)

Soil phosphorus chemistry is complex with numerous forms of phosphorus present and the possible transformations that phosphorus may undergo depending on the physical, chemical, and biological environment. An understanding of soil P forms and the transformations that affect phosphorus availability can be useful when making decisions about how to improve soil P availability for crop production (Halajnia *et al.,* 2009).

Phosphorus is found in soils in inorganic forms and organic forms and according to the degree of stability or solubility, these allow different degree of bioavailability of P. Inorganic P is present in solution and gets fixed through the adsorption phenomenon, with oxides of Fe and Al. This process establishes either weak adsorption (labile P) or strong adsorption (moderately labile P).When this inorganic P precipitated with Al, Fe and Ca, it establishes insoluble forms (non-labile P) (Yang and Post, 2011). Organic P is formed by phosphate ions, which are bonded to C moieties and its lability is directly related to the decomposition susceptibility of the organic moiety to which the phosphate is bonded (Condron *et al*., 2005). Inorganic P and organic P differ in their rates of P release. It is necessary to separate them into different biologically meaningful pools. This can be accomplished by sequentially fractionating soil P into different inorganic and organic pools (Mesfin, 2007).

Stumm and Morgan (1970) concluded that the increase in concentration of water soluble P when acid soils are submerged resulted from (a) hydrolysis of Fe (III) and Alphosphates, (b) release of P held by anion exchange on clay and hydrous oxides of Fe (III) and Al,and (c) reduction of Fe (III) to Fe (II) with liberation of sorbed and chemically bonded P. The first two reactions were due to the pH increase brought about by soil reduction.

It was determined that when soil pH becomes near to neutral, water soluble and plant available P increased compared to its value measured at native pH (Magnus *et al.,* 2018). The study conducted by Deejay *et al.* (2017) pointed out that increase in pH of top soil and sub soil following flooding might influence the P release over time. He concluded that the increase of available P during flooding is due to three main mechanisms (1) phosphorus release via the microbially mediated reductive dissolution of Fe^{3+} oxides (2) phosphorus release during soil organic matter mineralization and (3) solubility of Fe phosphate due to increasing pH.

Birru (2000) revealed that limited availability of soil P to plants in intensively weathered and sesquioxide rich acidic soils might be attributed to high degree of P fixation and its precipitation as iron and aluminum phosphates.

Geetha (2015) revealed the major fractions contributing to available P under flooded condition in lateritic soil were Fe-P, Al-P and sesquioxide occluded P.

2.3.2. Copper (Cu)

The bioavailability and phytotoxicity of copper present in soil is closely related to its distribution in the different chemical forms (Lagomarsino *et al*., 2010). These chemical forms comprise soluble and exchangeable form, organic matter bound, carbonate bound, Mn-oxide, amorphous Fe-oxide, crystalline Fe-oxide associated metal forms, and residual fraction or metal ions fixed to silicate structures (Fathi *et al.,* 2014). The water soluble and exchangeable forms are considered readily mobile and available to plants, while metal incorporated into crystalline lattices of clays appear relatively inactive. The other forms precipitated as carbonate, occluded in Fe, Mn and Al oxides or complexed with organic matter could be considered relatively active or firmly bound, depending upon the actual combination of physical and chemical properties of soil (Diagboya *et al*., 2015).

The solubility of Cu increases immediately due to desorption of sesquioxide occluded Cu under submergence. But this solubilised Cu immediately get precipitated as CuS in acid sulphate soils and as $Cu\ (OH)_2$ with increase in pH. The formation of carbonates and bicarbonates of Cu decreases the solubility of Cu, ultimately leading to a decrease in its availability under submergence in both acidic as well as alkaline conditions (Das, 2015).

Soil pH is the main factor controlling Cu availability for plants. Cu concentration increased as the soil pH dropped due to the dissolution of insoluble Cu compounds at pH lower than 5. At pH values higher than 6, Cu could be either adsorbed on the surfaces of Fe and Al oxides or precipitated in hydroxyl forms (Gilmar *et al*., 2015).

According to Adriano (2013) the affinity of copper decreases in the chain Mn oxides > organic matter > Fe oxides > clay minerals, however some other studies have attributed a main influence to organic colloids or clay minerals. Vitezslav and Miroslav (2018)believed the high affinity of organic matter to copper is due to its high sorption capacity, as well its ability to chelation. Copper has a tendency to form stronger inner-sphere complex with soil organic matter (Boudesocque *et al*., 2007) as compared to alkali earth metals which usually forms weaker outer-sphere complex (Tessier *et al.,* 1979).

2.4. Adsorption of phosphorus and copper on *Pokkali* soil

Adsorption is one of the most important chemical processes in soils that determine the quantity of plant nutrients retained on soil surfaces and, therefore, affect transport of nutrients and regulate the concentration of nutrients in soil solution. Adsorption of nutrients on soil depend on a number of different factors like the chemical nature of the nutrient, the characteristics of the soil, and climatic factors such as rainfall, temperature, sunlight and wind (Dandanmozd and Hosseinpur, 2010) Not many studies have been conducted so far in *Pokkali* soil on the adsorption and desorption of nutrients except for that on silicon adsorption by Aryalekshmi (2016) and the desorption of Ca and Mg by Bhindhu (2017). The available literature on adsorption of phosphorus and copper are reviewed hereunder.

.2.4.1. Phosphorus

Adsorption describes the removal of phosphate ions from solution to soil components (Abedin and Saleque, 1998). As an equilibrium process the amount of P adsorbed is determined largely by the solution P concentration (Syers *et al,* 1973). The magnitude and rate of P sorption mainly depend upon the properties of soils and phosphate sources.

The isotherms can be described as the equilibrium relationship between amount of adsorbed and dissolved nutrient concentration at constant temperature in quantitative terms (Olsen and Watanabe, 1957). The study conducted by Rashmi *et al* (2015) illustrated that P sorption isotherm in relation to soil properties can be used as a tool of P management in sustainable crop production. Moazed *et al.* (2010) pointed out that Langmuir adsorption isotherm had better match with phosphorus adsorbed data and has maximum R-square. The Langmuir adsorption isotherm equation (Langmuir, 1918) was developed to describe gas adsorption onto clean solids. It is precisely obeyed only for uniform adsorbent surfaces without lateral interactions, implying a constant free energy of adsorption (Brunauer *et al.*, 1967).

Bereket (2017) showed that Freundlich model could be considered as the best model for the description of the P adsorption characteristics of the soils. In the Freundlich adsorption isotherm equation, the affinity terms are distributed approximately log normally implying heterogeneity of adsorbing sites. Freundlich model have been reported to give the best fit in many areas of the world (Muindi *et al.*, 2015).

Temkin isotherm contains a factor that explicitly takes in account the adsorbent–adsorbate interactions. By ignoring the extremely low and large value of concentrations, the model assumes that heat of adsorption (function of temperature) of all molecules in the layer would decrease linearly rather than logarithmic with coverage (Temkin and Pyzhev, 1940).

Analysis of relationship between phosphorus adsorption maximum and soil attributes revealed that adsorption maximum positively correlated with clay content, exchangeable P, exchangeable acidity and aluminium saturation and negatively correlated with pH and electrical conductivity in acid soils (Muindi *et al.,* 2015). Tripathi and Praveen (2000) suggested that organic matter content and cation exchange capacity had positive impact on adsorption maxima. It was possibly due to P bonding to organic matter by replacing the organic hydroxyl group and anion exchange sites present on organic matter (Harter, 1969).

2.4.2. Copper (Cu)

Adsorption is one of the most important processes that affect the bioavailability of Cu in the soil. This is because it affects the concentration of Cu ions and complexes in soil solution (Adriano, 2013).

Chokor (2017) emphasized that the adsorption isotherm of Cu was fitted to the Freundlich and Langmuir equations with the Freundlich giving a better fit. Correlation between the curve adsorption parameters and the soil attributes indicated that the pH, cation exchange capacity, organic matter and MnO variables had the best influence on Cu retention in soil (Deyvison *et al.* 2016). The significant correlation of Cu adsorption with CEC showed that more exchange sites on soil minerals were available for Cu as CEC increases (Shaheen *et al.,* 2013). Ramadan *et al.* (2018) noticed that copper ions form strong coordination complexes with organic matter and Cu is mainly adsorbed on the specific sites in an acid soil.

Ramadan *et al.* (2018) studied on Cu and Zn adsorption on soil and interpreted the parameter 1/n in the Freundlich isotherm. Parameter 1/n in the Freundlich isotherm measured the adsorption intensity of Zn and Cu ions on the tested soils. The high 1/n value of Cu (0.68) in comparison to Zn (0.59) indicated the preferential sorption of Cu than Zn. In Freundlich data, when the value of 1/n becomes less than 1, it indicates that the sorption process was normal and sorption process is favorable (Mohan and Karthikeyan, 1997). Hameed *et al.* (2008) and Dada *et al.* (2012) reported that adsorption process with $1/n > 1$ is a cooperative adsorption process. Cooperative adsorption is adsorption where adsorbed adsorbate has an effect on the adsorption of new adsorbate molecules (Liu*et al.,* 2002). Ramadan *et al.* (2018) also concluded that the maximum K*f* (Freundlich isotherm constant) value of Cu (2.29 L kg^{-1}) was greater than that of Zn (1.28 L kg^{-1}) confirming the greater adsorption tendency of Cu than Zinc.

Adsorption reaction of Cu was favourable and spontaneous on soil's variable charges soil, as indicated by negative values of the free energy variation (ΔG). With the increase in the pH, the ΔG became more negative as a result of the increase in the driving force for the adsorption reaction to take place, especially in the 4-5 pH range (Ernesto *et al*., 2008).

2.4.3. Factors affecting P and Cu adsorption on soil

Phosphorus adsorption capacity of soil is not only influenced by Fe and Al oxides but also by exchangeable calcium and magnesium, soil texture, porosity, pH, ionic strength and hydraulic conductivity (Bubba *et al.,* 2003). It has been reported that land utilization type influences P adsorption capacity (Amapu *et al.,* 2000).The adsorption of copper on soil solid phase is influenced by the pH, cation exchange capacity, $CaCO_3$, clay, organic matter, free iron and manganese content of the soils (Joshi, 1995). The major factors affecting P and Cu adsorption on soil are explained below.

2.4.3.1. Soil reaction

Soil reaction is the key factor affecting P adsorption. Phosphate precipitates with Al and Fe and is adsorbed by Al and Fe oxides in acid soils (Moazed *et al.,* 2010). Bolan *et al.* (1988) reported that an increase in pH from 5.2 to 8.2decreased the adsorption of P. The decrease in P adsorption with increasing pH can be justified with increased amounts of Al and Fe, as their hydroxides at lower pH, leaving practically no Al and Fe to react with P at higher pH levels(Fan, 1993). Also, Sanchez and Uehara (1980) suggested that P sorption decreased with an increase in pH because of higher negativity of surface charge. Higher Ca to Al and Fe ratios lead to formation of insoluble Ca-P as pH increases (Amel and Sirelkhatim, 2012).

Soil pH is the primary factor that governs Cu adsorption and availability. Cavallaro and McBride (1980) reported that in soils with pH less than 2.5, Cu competed with protons for adsorption sites. However, at pH over 4.5, more charged sites were available for Cu, due to the decrease in competition for protons, while at pH between 4.0 and 6.0, Fe and Al oxides were the main causes of fixation and solubilization. Ernesto *et al.* (2008) also observed that copper adsorption was found to be high even under highly acid soil conditions, but the process was intensified with the decrease in the hydrogen ionic concentration. He proved that, at pH 3.5, 70-80% of the total Cu added was adsorbed on soil. Over pH 5.0, all Cu initially added disappeared from the soil solution.

2.4.3.2. Fe and Al oxide

Phosphorus is adsorbed by Al and Fe in acid to near neutral soils (Rashmi *et al.,* 2015) and the degree of P adsorption depends on the crystallinity of Fe and Al oxides. Amorphous Fe oxides adsorb more P than crystalline Fe and Al hydrous oxides, which is much more than crystalline aluminosilicates and Ca carbonate (Ryden and Pratt, 1980). Accordng to Agbenin and Tiessen(1994) the noncrystalline component has greater surface area and hence greater P fixation. The poorly crystalline Fe and Al oxides were reported to correlate well with P sorption in soils (Logonathan and Hedley, 1997).

Copper is also specifically adsorbed on oxides of Al, Fe and Mn (Diagboya *et al.*, 2015). Specific adsorption of Cu is not dependent on cation exchange sites but mainly on the colloidal surfaces like organic matter, manganese oxide, aluminum oxide, iron oxide etc. (Vitezslav and Miroslav, 2018). Deyvison *et al* (2016) reported that adsorption of Cu positively correlated with pH, cation exchange capacity, organic matter and Mn oxide content in the soil.

2.4.3.3. Clay content

Many investigations revealed that alumino-silicate clay minerals play an important role in P sorption by soils. On tropical soils with low pH, the 1:1 lattice clay increases the number of adsorption sites and, thereby, increases P adsorption. Phosphate adsorption sites occur on kaolinite, gibbsite, goethite and pseudo boehmite (Muljadi *et al.,* 1966). Phosphorus adsorption occurs at the edge face of kaolinite involving the OH in kaolinite and hydrated sesquioxides. Among the layer silicate clays, 1:1 type clays have a greater phosphate retention capacity than 2:1 type clays (Amel and Sirelkhatim, 2012).

Qunaibit *et al.* (2005) reported that the concentration of copper ions in the soil solution is relatively low; the major part is bound on clay minerals.Vitezslav and Miroslav (2018) concluded that clay minerals have major influence on Cu than Fe and Mn oxdes.

2.4.3.4. Organic matter

Numerous scientists opined that the addition of organic matter decrease phosphate fixation by soil and, thereby, increase the availability of P (Moazed *et al.*, 2010). Some data suggested that organic molecules might block sorption sites on Al and Fe oxides, and thereby reduce P sorption (Hue, 1990). It is also possible that organic matterreduces positive charge on variable charge surfaces and this decreases the attraction of P to the soil surface. The negatively charged sites in organic matter and P ions can compete for sorption sites on hydrous oxides of Al and Fe (Hakim, 2002). Phosphorus retention process by organic matter involves a substitution of P ions for hydroxyl ions in organic matter (Sanyal and De Datta, 1991).

Copper has a very high affinity to organic material and the bond between the organic material and copper is much stronger than with other heavy metals. The high affinity of organic matter to copper is due to its high sorption capacity and the high chelation ability (Adriano, 2013). Copper present in the soil solution is most often bonded to dissolved organic carbon (Vitezslav and Miroslav, 2018). The results of the study by Ernesto *et al.* (2008) indicated that highly weathered soils having organic and mineral constituents could reduce the Cu concentration in the soil solution by adsorption mechanisms. Increase in the pH, generally decreases the quantity of Cu organically complexed in the soil solution (Alva *et al*., 2004).

2.4.3.5. Soil temperature

Phosphate sorption was found to increase with increasing temperature (Jia Zhong and Xiao Lan, 2011). This is consistent with the results of Jin *et al.* (2005) and Zhang and Huang (2011). Silva Rossi *et al.* (2016) also noticed that the temperature effect on sorption kinetics of P in soil was greater for 25 °C than for 10 °C. Additionally, Zhang and Huang (2011) observed approximately 1.3 times increase in phosphate sorption on marine sediments for every 10 °C increase in temperature at different salinity treatments. The possible explanation for the increasing phosphate adsorption on soil with increasing temperature was that the bonding energy of phosphorus sorption in soil and precipitation rates increases with the increase in temperature (Reddy and DeLaune, 2008).

Shuang *et al.* (2014) studied on effect of temperature on adsorption of copper on soil. They conducted the experiment at three different temperatures of 10°C, 25°C, and 35°C and observed that the adsorption increased with the increase in temperature. This is because of the increase in adsorption energy of Cu (II) with an increase in temperature which enables its easy contact with the sites, thereby improving its adsorption efficiency.

Materials and Methods

3. Materials and Methods

The present investigation entitled "Spatial and temporal variations in nutrient dynamics in *Pokkali* soils of Kerala" was conducted at Radio Tracer Laboratory, College of Horticulture, Kerala Agricultural University during 2017 to 2019. This study includes soil sample collection and laboratory experiments to achieve the objectives of the project. Laboratory investigations were conducted to characterize *Pokkali* soils and to study the dynamics of nutrients undertaking fractionation and adsorption studies. The materials used and methods adopted are summarized below.

3.1. Details of location

The study was carried out in five land uses *viz.,* paddy alone, paddy-shrimp, shrimp alone, mangrove and fallow land in selected four Panchayaths of Ernakulam district. Initial survey was conducted in *Pokkali* tracts and it was seen that no farmers were having paddy cultivation alone for the reason that it was less profitable as against shrimp farming. So the land uses, *viz.* paddy-shrimp, shrimp, mangrove and fallow land were selected in three Panchayaths, *viz.* Ezhikkara, Kottuvally and Kadamakudy and three plots in Rice research station, Vytila also selected for the land use paddy alone. The details of location are summarized in the table 1.

Table 1. Location of study

Location/Panchayath	Land use systems	N latitude	E longitude
Ezhikkara	Paddy-shrimp	N10°06.643'	E076°13.646'
	Shrimp alone	N10°06.796'	E076°12.993'
	Mangrove	N10°06.327'	E076°13.340'
	Fallow	N10°06.643'	E076°13.646'
Kottuvally	Paddy-shrimp	N10°06.153'	E076°14.713'
	Shrimp alone	N10°06.002'	E076°14.354'
	Mangrove	N10°05.444'	E076°15.452'
	Fallow	N10°06.153'	E076°14.713'
Kadamakudy	Paddy-shrimp	N10°03.310'	E076°14.986'
	Shrimp alone	N10°03.821'	E076°15.239'
	Mangrove	N10°03.502'	E076°14.890'
	Fallow	N10°03.869'	E076°15.348'
RRS, Vyttila	Paddy alone (a)	N09°58.438'	E076°19.395'
	Paddy alone (b)	N09°58.584'	E076°19.352'
	Paddy alone (c)	N09°58.657'	E076°19.411'

Plate 1. Sampling locations in *Pokkali* tract

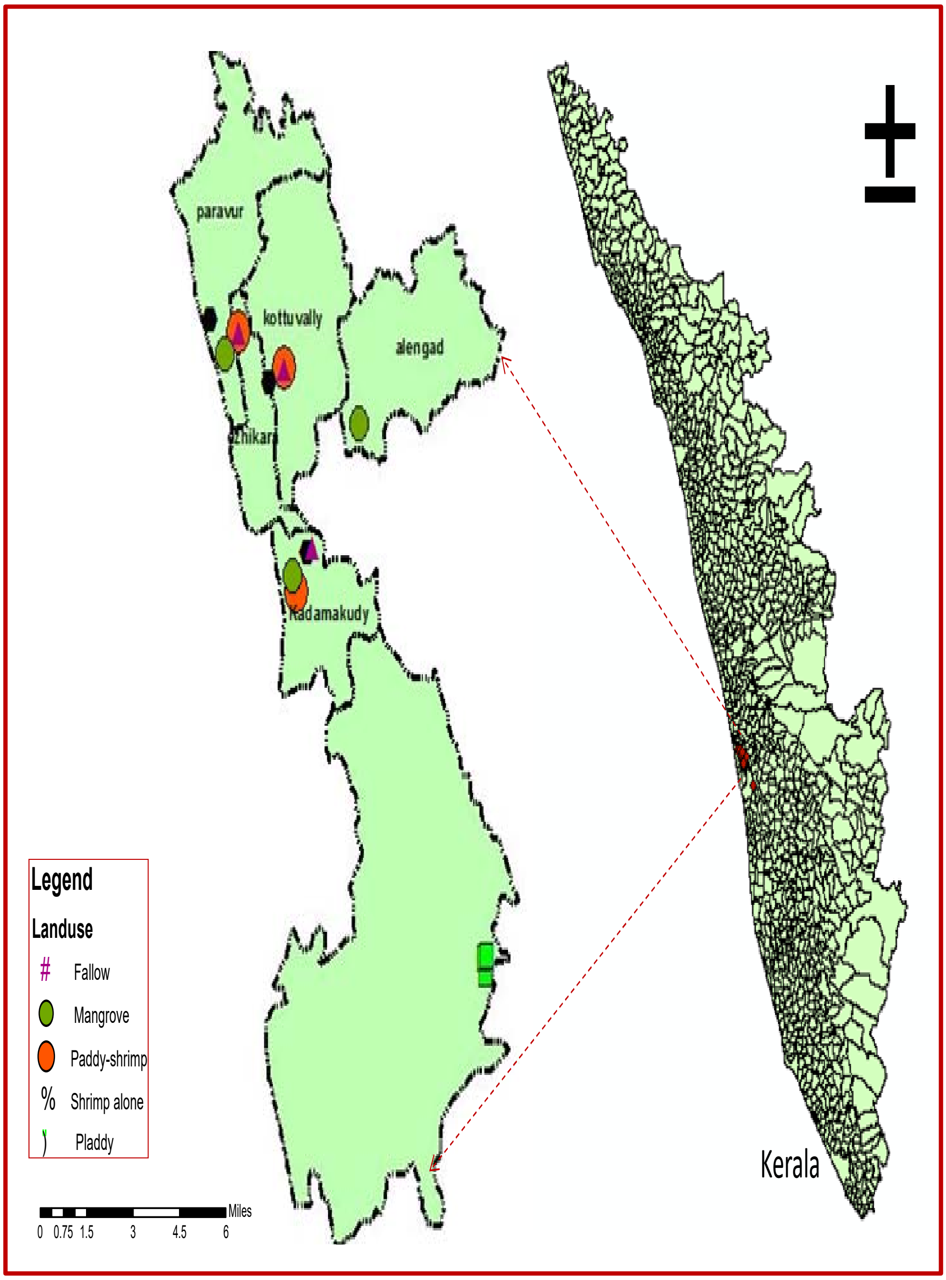


Plate 2. Different land uses in *Pokkali* tract

1) Paddy-shrimp

2) Shrimp alone

3) Mangroves

4) Fallow land

5) Paddy alone

3.2. Collection of samples

Soil samples were collected from a depth of 0-20 cm using core method from land uses of selected four Panchayaths in Ernakulum district (table1 and plates 1 and 2). Soil samples of both lowland and upland were collected at bimonthly interval (June to April) so as to overlap the sampling time with high tide and low tide phases as well as with rainy and dry season (total:180 samples). The collected samples were immediately sealed in polythene covers after collection and used. Water samples were also collected from both field and brackish water inundated to *Pokkali* tract in plastic bottles (total: 180 samples). Relative humidity, soil temperature and redox potential were recorded during soil sample collection. Geographical co-ordinates of sampling sites were recorded using GPS.

3.3 Characterization of soil and water samples

Collected soil samples were characterized in order to study the dynamics of nutrients. Wet analysis was followed for wetland soils whereas it was done based on dry weight basis for upland soil samples. Water samples were also analysed from the same sites.

3.3.1. Result expression for wet analysis

Moisture content of the wetland soil samples were estimated gravimetrically. Soil samples were weighed (W_1) and kept in the hot air oven at a temperature of 105°C until a constant weight had been achieved. Then, the samples were weighed (W_2) again and the percentage moisture content (%) was calculated using the equation,

$$\text{Per cent moisture content (\%)} = [(W_1-W_2)/W_1] \times 100$$

3.3.2. Physical properties

3.3.2.1. Texture

The particle size distribution of the soil sample was determined by International pipette method outlined by Robinson (1922).Twenty grams of soil samples were weighed in a 500 ml beaker and kept on a hot plate after pouring 10 ml portion of 30% of hydrogen peroxide for destroying organic matter. This process was continued until the large bubbles were ceased to ensure complete destruction of organic matter. Then, 8 ml, 1N NaOH was added and stirred well for effective dispersion of soil particles. Samples were moved into a spoutless cylinder (1000 ml capacity) and held undisturbed. Twenty ml of suspension was pipetted out based on sedimentation time to estimate percentage distribution of the clay and silt fractions. The weight of sand particles was estimated by repeated washing of the sediments followed by oven drying. The particle size distribution of soil samples were expressed in percentage.

3.3.2.2. Bulk density (BD)

Soil samples were collected using a core sampler from 1-20 cm depth and dried to a constant weight in an oven at 105°C. The bulk density of soil samples were calculated as the ratio of the mass of the dry soil to the total volume of soil (Dakshinamurti and Gupta, 1968) and the unit was expressed in Mg m^{-3}.

3.3.2.3. Soil temperature

In situ soil temperature of the both upland and wetland soils were determined by using a soil thermometer and expressed the temperature as °C.

3.3.3. Physico-chemical properties

3.3.3.1. Soil pH

The pH of 1:2.5 soil water suspension was estimated using a pH meter (Jackson, 1958). It is a measure of hydrogen ion activity of the soil water system and indicates whether the soil is acidic, neutral or alkaline in reaction.

3.3.3.2. Electrical conductivity (EC)

Electrical conductivity in soil water system is a measure of concentration of soluble salts and extent of salinity in the soil. It was measured in the supernatant liquid of the soil water suspension (1:2.5) used for pH estimation using a conductivity meter (Jackson, 1958). Electrical conductivity was expressed as dSm^{-1}.

3.3.3.3. Redox potential (RP)

In situ redox potential of the wetland system was expressed with the redox meter (Model RM 1K TOA) to the depth of 15cm. Redox potential was measured in mV.

3.3.4. Chemical properties

3.3.4.1. Organic carbon

Organic carbon of the soil was estimated by wet digestion method (Walkley and Black, 1934; Nelson and Sommers, 1982) and reported as per cent organic carbon.

3.3.4.2. Total nitrogen (TN)

Total nitrogen of the soil samples were estimated in CHNS analyzer (Model: Elementar'svario EL cube).The total nitrogen was expressed as percentage.

3.3.4.3. Available phosphorus (Av P)

Available phosphorus in the soil samples showing acidic pH was extracted using Bray's no1 reagent (Bray and Kurtz, 1945) and those showing neutral to alkaline pH was extracted with 0.5 M sodium bicarbonate ($NaHCO_3$) solution (Olsen *et al*, 1954). The concentration of phosphorus in the samples was estimated calorimetrically by reduced molybdate ascorbic acid blue colour method (Watanabe and Olsen, 1965) using spectrophotometer (Model: Systronics 169). Available P was expressed in mg kg^{-1}.

3.3.4.4. Available potassium (Av K)

Neutral normal ammonium acetate was used to extract available potassium in the soil samples. Potassium content in the extract was estimated by flame photometry (Jackson, 1958). Available K was expressed in $mgkg^{-1}$.

3.3.4.5. Available calcium (Av Ca)and magnesium (Av Mg)

Available calcium and magnesium in the soil samples was extracted using neutral normal ammonium acetate and its content in the extract was estimated by atomic absorption spectrophotometer (Model: Perkin Elmer-PinAAcle 500). Available Mg was expressed in $mgkg^{-1}$

3.3.4.6. Available sulphur (Av S)

Available sulphur in the soil sample was extracted by using 0.15% $CaCl_2$ solution (Tabatabai, 1982) and estimated by turbidimetry (Massoumi and Cornfield,

1963) using a spectrophotometer (Model: Systronics 169). Available S was expressed in mgkg^{-1}.

3.3.4.7. Available micronutrients (Av Fe, Av Mn, Av Znand Av Cu)

Available micronutrients in the soil samples showing acidic pH were extracted using 0.1 M HCl (Sims and Johnson, 1991) and soil samples of neutral to alkaline pH were extracted with 0.005M DTPA and 0.01M $CaCl_2.2H_2O$ buffered at pH 7.3 by 0.1 M triethanolamine (TEA) (Lindsay and Norvell, 1978). The filtrate was collected and analysed for Fe, Cu, Mn and Zn using Atomic Absorption Spectrophotometer (Model: Perkin Elmer-PinAAcle 500). Available micronutrients were expressed in mgkg^{-1}.

3.3.4.8. Available boron

Available boron in soil sample was extracted with hot water (Gupta,1972) and estimated colorimetrically by azomethane –H using spectrophotometer (Model: Systronics169). Available B was expressed in mgkg^{-1}.

3.3.4.9. Available heavy metals (Av Pb, Av Cd, Av Ni, Av Cr, Av Hg, Av As and Av Co)

Available heavy metal in the soil samples were extracted using 0.1 M HCl (Sims and Johnson, 1991). Four gram of soil with 40 ml of 0.1 M HCl was shaken for 5 minutes. It was filtered through Whatman No.1 filter paper and the filtrate was collected and analysed for Pb, Cd, Ni, Cr, Hg, As and Co by using Perkin Elmer ICP-OES (Inductively coupled plasma optical emission spectrometer). For the estimation of As, a pre reduction step was carried out. Exact 20 ml of the extract was placed in a polypropylene tube. To this 2 ml of a 5% solution of KI and ascorbic acid and 6 ml of concentrated HCl was added. The mixture was allowed to sit for 20 minutes. The tube was brought to 50 ml mark with double distilled water and the sample was subjected to take reading in ICP-OES (Model: Perkin Elmer -Optima 8000). Available heavy metals were expressed in mgkg^{-1}.

3.3.4.10. Exchangeable (ex) cations and cation exchange capacity (CEC)

The wet soil samples collected during October and April and also the upland soils subjected for estimation of CEC by the method proposed by Hendershot and

Duquette (1986). Barium chloride solution of 0.1 Molar was used for replacing the cations (Ca, Mg, Na, K, Al, Fe, Mn, Cu and Zn) present in the exchangeable sites in the soil and the cations in the extract were estimated. Four gram of soil sample with 40 ml of 0.1 M $BaCl_2$ in a centrifuge tube was shaken for 2 hours and filtered through Whatman No 42 filter paper. Filtrate was used for the estimation of all the above mentioned elements in the ICP-OES (Inductively coupled plasma optical emission spectrometer) (Model: Perkin Elmer -Optima 8000). In hydromorphic saline soils, high content of water soluble cations (Ca, Mg, Na, and K) which would also get extracted and wrongly interpreted as exchangeable cations. So this method was modified by substracting water soluble cations from exchangeable fractions. The sum of exchangeable cations was expressed in cmol (p^+) kg^{-1}.

Water soluble fractions were estimated by the modified procedure of Baruah *et al.* (2011). Five grams of soil sample with 25 ml deionized water was centrifuged at 4000 rpm for 30 minutes. The supernant solution was decanted and residue was rinsed with 25ml of deionized water followed by shaking, and centrifugation for the complete speciation.

3.3.4.11. Anion exchange capacity (AEC)

Ten grams of the soil samples were leached with 100 ml $BaCl_2$ –TEA followed by leaching with 100 ml $CaCl_2.2H_2O$ solution. The Ca saturated soil samples were dried at 45°C. Then the dried Ca saturated soil samples were taken in a conical flask with 20 ml 0.01M phosphoric acid and shaken for 30 minutes. It was allowed to stand for 24 hours and again shaken for 30 minutes. The suspension was centrifuged and the supernatant solutions were decanted. The phosphorus content in extract was estimated using ICP-OES (Inductively coupled plasma optical emission spectrometer) (Model: Perkin Elmer -Optima 8000). AEC was expressed as cmol(-) kg^{-1} (Baruah and Borthakur, 1997).

3.3.5. Biological properties

3.3.5.1. Population of nitrogen fixing bacteria

Population of nitrogen fixing bacteria was counted after serial dilution (10^{-3}) of 1 g soil and pouring 1 ml of soil solution from the dilution of 10^{-3} to the petric plate by pour plating method. Jensons agar medium was used as growing media for nitrogen fixing bacteria. Enumeration of nitrogen fixing bacteria was taken on third day from the pour plating. Population of nitrogen fixing bacteria was expressed in colony forming unit (CFU).

3.3.5.2. Dehydrogenase enzyme activity

Dehydrogenase enzyme activity was estimated colorimetrically using spectrophotometer based on the reduction of 2, 3, 5 –triphenyltetrazolium chloride (TTC) to the creaming red coloured triphenyl formazan (TPF). Dehydrogenase enzyme activity was expressed in µg TPF$g^{-1}day^{-1}$ (Klein *et al.*, 1971).

3.3.5.3. Microbial biomass carbon

Microbial biomass carbon in soil was estimated by chloroform fumigation and extraction method. Five sets of 10 g soil samples were taken and one set kept in an oven for the determination of moisture gravimetrically at 105°C. Two sets of samples were kept in vaccum desiccator containing ethanol free chloroform for 24 hours, after the creation of vaccum using a vaccum pump. The other two sets of samples were kept unfumigated. Organic carbon was extracted from these fumigated and unfumigated samples using 0.5M potassium sulphate. 0.2 M potassium dichromate, concentrated sulphuric acid and orthophosphoric acid were added to this 10 ml extract and kept on a hot plate at 100°Cfor half an hour under refluxing condition. After that, 250 ml water was added and titrated against standard ferrous ammonium sulphate to determine microbial biomass carbon (Jenkinsin and Powlson, 1976). Microbial biomass carbon was expressed in mgkg^{-1}.

3.3.6. Characterization of water samples

Water samples from the field and source water (nearby brackish water inundated to *Pokkali* tract) were also collected from each land uses.The samples were kept in labelled plastic containers for further studies. The methods of analysis were entitled in table 2.

Table 2. Methods used for the characterization of water samples

Sl. No.	Particulars	Method
1	pH	Potentiometric method using pH meter (Jackson, 1958)
2	EC	Conductivity meter (Jackson, 1958)
3	Total soluble solid (TSS)	Derived from the value of electrical conductivity (EC) using the formula, TSS (mg/L) = EC x 640
4	Water soluble potassium and sodium	Flame photometer (Model:Systronics flame photometer 128)
5	Water soluble calcium and magnesium	AAS (Model: Perkin Elmer-PinAAcle 500)
6	Water soluble sulphate	Turbidimetric method (Chesnin and Yien,1951)
7	Water soluble nitrate	Distillation followed by titration
8	Water soluble chloride	Mohr's titration method (Belcher *et al*, 1957)
9	Water soluble borate and phosphate	ICP-OES(Model: Perkin Elmer -Optima 8000)
10	Water soluble carbonate and bicarbonate	Acidimetric titration method (Richards, 1954)
11	Heavy metals (Pb, Cd, Ni, Cr, Hg, As and Co)	ICP-OES (Model: Perkin Elmer -Optima 8000)

3.4. Weather parameters

The data on average rainfall (table 64) for all the locations except for RRS, Vyttila was recorded from the website NASA POWER, https://power.Iarc.nasa.gov/. For RRS, Vyttila, average rainfall was recorded from rain gauge located in RRS, Vyttila. Relative humidity (table 65) was also recorded using a whirling psychrometer (model) during soil sample collection.

Experiment 2

3.5. Fractionation study

Soil samples from 15 locations collected during October and April were selected and subjected to fractionation study of phosphorus and copper.

3.5.1. Fractionation of phosphorus (P)

Fractions of soil inorganic phosphorus were extracted by sequential extraction method proposed by Peterson and Corey (1966) (Table 3). Organic P was estimated separately by the procedure proposed by Saunders and Williams (1955). Total P was analyzed by perchloric acid digestion method by Jackson (1958). Residual phosphorus was estimated by subtracting all inorganic fractions and organic fractions from total P.

3.5.1.1. Sequential extraction of inorganic P fractions

3.5.1.1.1. Soluble P (So-P)

One gram of soil was taken in a 100 ml centrifuge tube. To this 50 ml of 1 M NH_4Cl solution was added and shaken for 30 minutes. The tubes with the extract were then centrifuged. The solution was decanted into another tube.

3.5.1.1.2. Aluminium bound P (Al-P)

The soil residue in the centrifuge was added with 0.5 M NH_4F and shaken for 1 hour. Then the tube was centrifuged and the solution was decanted. The soil residue was washed twice with 25 ml saturated NaCl and these two extracts were combined together and made up the volume.

3.5.1.1.3. Iron bound P (Fe-P)

To the soil residue, 50ml 0.1 M NaOH was added and shaken for 17 hours. The solution was centrifuged and decanted. The residue was again washed twice with 25 ml saturated NaCl solution and centrifuged and decanted. The volume was made upto 100 ml by mixing these two extracts.

3.5.1.1.4. Occluded P (Oc-P)

To the soil residue, 40 ml of 0.3 M citrate solution and 5 ml of 1M $NaHCO_3$ solution were added and heated in a water bath to 80°C. To this, 1g of $NaS_2O_4.2H_2O$ was added with rapid stirring and the heating was continued at 85°C for 15 minutes. The solution was decanted into another flask after centrifugation. The soil residue was washed with 25 ml of saturated NaCl. This was centrifuged and the supernant solution wasdecanted to the above flask.

3.5.1.1.5. Calcium bound P (Ca-P)

To the soil residue, 50 ml 0.25 M H_2SO_4 was added and shaken for 1 hour on a shaker. The solution was centrifuged and decanted into another flask. The soil residue was washed twice with 25 ml saturated NaCl, centrifuged and decanted. This was decanted to the above flask and the volume was made upto 100 ml.

3.5.1.2. Extraction of organic P (Or-P)

Two grams of soil was weighed into porcelain crucible and kept in a muffle furnace at 550°C for 1 hour. After cooling the sample, removed the samples to a centrifuge tube and 50 ml of 0.5M H_2SO_4 was added. The samples were shaken for 16 hours and decanted after centrifugation. Two grams of the same samples was separately taken which were not ignited and continued the same procedure above. Organic P was estimated by subtracting the P content in non-ignited samples from ignited samples.

3.5.1.3. Extraction of total P (To-P)

Total content of phosphorus was determined on a separate sample by digesting one gram of soil sample with 70% $HClO_4$ following the procedure of Jackson (1958). On cooling, 5 ml of 5N HCl was added to the digested mixture followed by filtration and washing with distilled water until 100 ml of filtrate was collected.

3.5.1.4. Estimation of P fractions

Extracts of the P fractions were subjected to aspiration in ICP-OES (Model: Perkin Elmer -Optima 8000) for the estimation of P content in it.

3.6. Sequential extraction of copper fractions

Soil samples were subjected to sequential fractionation method outlined by Iwasaki and Yoshikawa (1990) which is the modified form of the fractionation scheme of Miller *et al.* (1986). The method was originally proposed for sequential fractionation of zinc. This method was used in the present study for the fractionation of copper (table 4). The reagents used and chemical forms solubilized from 1.5 g of soil samples are listed below.

3.6.1. Water soluble fraction (WaS)

Soil samples were shaken for 16 hours with 25 ml distilled water and supernatant decanted after centrifugation for 2 minutes at 3000 rpm.

Table 3. Sequential extraction of inorganic P fractions

Sl. No	P fractions	Reagents used for the extraction of 1g soil	Extraction method
1	Soluble P	• 50 ml of 1 M NH_4Cl	• Shaking for 30 min followed by centrifugation (at 4000 rpm for 15 minutes) = Extract A
2	Aluminium bound P	• 0.5 M NH_4F • 25 ml saturated NaCl	• Shaking for 1 hour followed by centrifugation (at 4000 rpm for 15 minutes) • Washing of soil residue twice Combination of two extracts = Extract B
3	Iron bound P	• 50ml 0.1 M NaOH • 25 ml saturated NaCl	• Shaking for 17 hour followed by centrifugation (at 4000 rpm for 15 minutes) • Washing of soil residue twice Combination of two extracts = Extract C
4	Occluded P	• 40 ml of 0.3 M citrate solution and 5 ml of 1M $NaHCO_3$ • 1g of $NaS_2O_4.2H_2O$ • 25 ml saturated NaCl	• Heat in a water bath to 80°C • Continuous stirring in the water bath to 85°C for 15 minutes followed by centrifugation • Washing of soil residue twice Combination of two extracts = Extract D
5	Calcium bound P	• 50 ml 0.25 M H_2SO_4 • 25 ml saturated NaCl	• Shaking for 1 hour followed by centrifugation (at 4000 rpm for 15 minutes) • Washing of soil residue twice Combination of two extracts = Extract E

3.6.2. Exchangeable fraction (Ex)

The exchangeable fraction was extracted from the residue of previous extraction by shaking for two hours with 15 ml of 0.5 M Ca (NO_3), centrifuging and decanting the supernatant.

3.6.3. Specifically adsorbed (Pb displaceable) fraction (SpA)

The residue from $BaCl_2$ extraction was shaken for 2 hours with 25 ml of 0.05 M $Pb(NO_3)_2$ and 0.5 M CH_3COONH_4 at pH 6, and the supernatant was collected after centrifugation.

3.6.4. Acid soluble fraction (AcS)

The acid soluble fraction was extracted with 25 ml CH_3COOH (2.5 per cent) by shaking the residue for 2 hours, and supernatant collected after centrifugation.

3.6.5. Manganese oxide occluded fraction (MnO)

The soil residue from the previous extraction was treated with 50 ml of 0.1 M NH_2OH HCl at pH 2, shaken for 0.5 hours and the supernatant was collected.

3.6.6. Organic matter occluded fraction (OrM)

Organic matter occluded fraction was extracted from the residue using 50 ml of 0.1 M $K_4P_2O_7$ at pH 10, by shaking for 24 hours. The supernatant was collected after centrifuging at 3000 rpm for 2 minutes.

3.6.7. Amorphous iron oxide occluded fraction (AmFeO)

The soil residue was added with 50 mL of 0.1 M $H_2C_2O_4$ and 0.175 M $(NH_4)_2C_2O_4$ at pH 3.25, kept in dark for 4 hours, centrifuged and decanted.

3.6.8. Crystalline iron oxide occluded fraction (CrFeO)

The residue from previous extraction was treated with 50 mL of 0.1 M $H_2C_2O_4$ and 0.175 M $(NH_4)_2C_2O_4$ and 0.1 M ascorbic acid, kept for 30 minutes in boiling water bath for extracting crystalline iron oxide occluded fraction. The supernatant was collected, after centrifuging for estimation.

3.6.9. Residual fraction (ReF)

The total of the above fractions (section 3.6.1 to 3.6. 8) were subtracted from the total content estimated as per 3.5.1.3 and expressed as residual fraction.

3.6.10. Estimation of Cu fractions

All the above extracts were analyzed for the different fractions of copper using ICP-OES (PerkinElmer - model Optima 8000).

Table 4. Sequential extraction of copper

Sl. No	Fractions of copper	Reagents used for the extraction of 1.5 g soil	Extraction method
1	Water soluble fraction	25 mL distilled water	Shaking for 16 hours followed by centrifugation (2 minutes at 3000 rpm)
2	Exchangeable fraction	15 ml of 0.5 M Ca (NO_3)	Shaking for 2 hours followed by centrifugation (2 minutes at 3000 rpm)
3	Specifically adsorbed (Pb displaceable) fraction	25 ml of 0.05 M $Pb(NO_3)_2$ and 0.5 M CH_3COONH_4 at pH 6	Shaking for 2 hours followed by centrifugation (2 minutes at 3000 rpm)
4	Acid soluble fraction	25 ml CH_3COOH (2.5 per cent)	Shaking for 2 hours followed by centrifugation (2 minutes at 3000 rpm)
5	Manganese oxide occluded fraction	50 mL of 0.1 M NH_2OH HCl at pH 2	Shaking for 0.5 hours followed by centrifugation (2 minutes at 3000 rpm)
6	Organic matter occluded fraction	50 mL of 0.1 M $K_4P_2O_7$ at pH 10	Shaking for 24 hours followed by centrifugation (2 minutes at 3000 rpm)
7	Amorphous iron oxide occluded fraction	50 mL of 0.1 M $H_2C_2O_4$ and 0.175 M $(NH_4)_2C_2O_4$ at pH 3.25	Keep in dark for 4 hours followed by centrifugation(2 minutes at 3000 rpm)
8	Crystalline iron oxide occluded fraction	50 mL of 0.1 M $H_2C_2O_4$ and 0.175 M $(NH_4)_2C_2O_4$ and 0.1 M ascorbic acid	Keep for 30 minutes in boiling water bath followed by centrifugation(2 minutes at 3000 rpm)

Experiment 3

3.7. Adsorption studies

The subset of five soil samples were selected based on various textural classes of the lowland soil (clay, clay loam, sandy clay loam, loam and silt loam) in October and April months for adsorption studies of phosphorus and copper.

3.7.1. Phosphorus

Five grams soil was weighed out in to 250 mL conical flasks. 50 mL of different P concentrations (0, 10, 20, 40, 80 and 100 mg l^{-1}) were added to the flask. The solutions were prepared using KH_2PO_4 in 0.01M $CaCl_2$. Shaking period of 1 h was given for equilibration (Geetha, 2008). The concentration of P in the equilibrium solution was estimated using ICP-OES (Model: Perkin Elmer-Optima 8000).

3.7.2. Copper

2.0 g of soil was weighed out in to 50 ml of centrifuge tube with 20 ml different Cu stock solution (0, 5, 10, 20, 30, 40, 50 mg L^{-1}). The stock solution was prepared by dissolving 0.121 g $Cu(NO_3)_2$, in 500 ml of the electrolyte solution. The supporting electrolyte solution, 0.01 mol L^{-1} $CaCl_2$, was prepared by dissolving 1.10 g $CaCl_2$ in 1 L of ultrapure water. The mixtures were shaken on a rotary shaker for 24 hours and then centrifuged (Baghernejad*et al.,* 2015). The supernatant was analyzed by ICP-OES (Model: Perkin Elmer-Optima 8000).

3.7.3. Quantity (Q) – Intensity (I) relations

The Q (amount of adsorbate adsorbed per unit quantity of adsorbent) and I (equilibrium concentration) parameters were calculated from the data of adsorption experiments conducted with the increasing concentration of particular element added to the soil. Q-I curves were prepared for each soil by plotting the amount of adsorbate adsorbed (qe) on Y axis and the equilibrium concentration (C_e) in the soil solution on X axis. Slope of the Q-I curve was considered as buffer power. Maximum amount adsorbed/desorbed was also expressed. Intercepts and slopes were computed from the best fit curves using regression analysis. The slope of the curve is the parameter which explains the buffer power (nutrient supplying power of soil). The simple linear equation $\Delta Q = bC + K$ was used to obtain the best curve, where b is the buffer power (slope of the curve) and K is the intercept.

3.7.4. Adsorption isotherms

The isotherm usually describes the adsorption system with some important information from which we can develop an equation representing the results and we can use the equation for interpreting some parameters of adsorption. Adsorption data was fitted into three isotherms via. Langmuir, Freundlich and Tempkin.

3.7.4.1. Langmuir adsorption isotherm

$q_e = q_m K_L\ Ce/(1+K_L C_e)$

Linear form can be expressed as $C_e/q_e = (1/(q_{max}*K_L))+((1/q_{max})*C_e)$

Where qe(mg kg^{-1}) is the quantity adsorbed at equilibrium, Ce(mg L^{-1}) is the equilibrium concentration of solute, qm (mg kg^{-1}) is the maximum amount of adsorbate that can be adsorbed, K_L(L mg^{-1}) is constant related to binding strength. While plotting the Langmuir adsorption isotherm for P adsorption, qe was converted into mg of P adsorbed per one gram of soil in order to get more precise linear equation.

3.7.4.2. Freundlich adsorption isotherm

$q_e = K_F\ C_e^{1/n}$

Linear form can be expressed as log qe= log K_F + (1/n) log C_e where q_e (mg kg^{-1}) is the quantity adsorbed at equilibrium, C_e (mg L^{-1}) is the equilibrium concentration of solute, K_F and 1/n are empirical constants. K_F (mg kg^{-1}) (L $kg^{-1})^{1/n}$ is the Freundlich adsorption constant, the amount adsorbed at unit concentration. It is characteristic for the adsorbent and the adsorbate adsorbed.

3.7.4.3. Tempkin adsorption isotherm

$qe = (RT/b) \ln (K_T C_e)$

A linear form of the Tempkin isotherm can be expressed as

$q_e = (RT/b) \ln K_T + (RT/b) \ln C_e$

Where qe (mg kg^{-1}) is the quantity adsorbed at equilibrium, Ce (mg L^{-1}) is the equilibrium concentration of solute, K_T (L kg^{-1}) is Tempkin adsorption constant and b (J mol^{-1}) is constant related to heat of adsorption. Constants of different adsorption isotherms were calculated from the slope and intercept values of respective linear equations of isotherm

3.7.5. Thermodynamic parameters

Thermodynamic parameters were calculated from the variation of the thermodynamic equilibrium constant, K^0 (Biggar and Cheung, 1973).

$K^0 = as/ae = \gamma s\ Cs/\gamma eC_e$ …………………………………….……………… (1.1)

Where, as = activity of adsorbed solute ae = activity of solute in equilibrium

Cs = μg of solute adsorbed per m L of solvent in contact with the adsorbed surface

Ce = μg of solute adsorbed per m L of solvent in equilibrium

γs = activity coefficient of adsorbed solute

γe = activity coefficient of solute in equilibrium solution

Cs was calculated according to the following equation (Fu *et al.*, 1948)

$Cs = ((\rho_1/M_1)\ A_1)/\ (S/N(x/m)) - (A_2/M_2x10^6\ )$…………………….……. (1.2)

ρ1 = density of solvent (density of water g cc^{-1})

M_1 and M_2 molecular weights of solvent and solute respectively (g mol^{-1})

A_1 and A_2 = respective cross sectional areas of solvent and solute molecule ($cm^2 molecule^{-1}$)

N = Avogadro‘s number (6.023 x 10^{23} molecules mol^{-1})

S = surface area of adsorbent (cm^2 g^{-1})

x/m = specific adsorption (μg g^{-1}) The cross sectional areas (cm^2) of the solvent and solute molecules were estimated from the following equation (Kodera and Onishi, 1959)

$A = 1.091 \text{ x } 10^{-16}\ [(M \text{ x } 10^{24})/\ (N \text{ x } \rho)]^{2/3}$ …………………………… (1.3)

Where, M and ρ represent the molecular weight and density respectively

3.7.5.1. Surface area of soils

About 1.1g of calcium saturated soil samples were taken in shallow small weighing cans and dried to a constant weight over P_2O_5 in evacuated dessiccator. Approximately 3 ml of ethylene glycol monoethyl ether (EGME) was added to each of the dried sample to form mineral absorbate slurry. The slurry was allowed to equilibrate for at least one hour and then kept in evacuated desiccators. The samples were first weighed one hour after the evacuation, then at successively longer time intervals until a constant weight was attained (Carter *et al.,* 1965). 2.86 x 10^{-4} g of EGME was required to form a monolayer of 1 m^2. The surface area of the soil was then calculated based on the amount of EGME retained using the following equation:

S (m^2 g^{-1}) = (1 m^2 / 2.86 x 10^{-4}) x amount of EGME retained (g)/weight of soil taken (g) ………………………………………………………………………… (1.4)

In equation (1.2) since S/N (x/m) >> A_2/M_2 x 10^6, the equation is reduced to

$C_s = (\rho 1/M_1)\ A_1/\ (S/N(x/m))$ …………………………………………… (1.5)

This can be used to calculate microgram of solute adsorbed per mL of solvent in contact with the adsorbed surface, ie., C_s in g mL^{-1}.

At lower concentration, activity coefficient approaches unity and hence

$C_s/C_e = K^0$

Values of K^0 were obtained by plotting log (C_s/C_e) Vs C_s and extrapolating to zero.

The standard free energy (ΔG0) was calculated from

$\Delta G^0 = -RT \ln K0$ ………………………………………………………. (1.6)

The standard enthalpy (ΔH^0) was obtained from the integrated form of the Vant Hoff equation,

$\ln K^0_2/ K^0_1 = -\ \Delta H^0 /R\ [(1/T_2) - (1/T_1)]$ …………………………………… (1.7)

The standard entropy (ΔS^0) was calculated from

$\Delta S^0 = (\Delta H^0 - \Delta G^0) / T$ ……………………………………………………….. (1.8)

3.8. Statistical analysis

The data generated from experiment 1 were analysed as factorial CRD with six different levels of months and fifteen different levels of locations. To know the specific effect of land uses on nutrient dynamics, factorial analysis was done with six different levels of months and five different levels of land use systems. Correlation studies were carried out by the method suggested by Panse and Sukatme (1978). Two factorial analysis, correlation studies and path analysis were carried out using OPSTAT package (Sheoran *et al*., 1998). Linear form adsorption isotherms were prepared in microsoft excel.

3.9. Preparation of spatio-temporal maps

Spatio-temporal changes for soil properties in the form of maps were prepared using ArcGIS software. The spatial location of data points with the location details is entered and the attribute of the data point is updated with the spatial and seasonal soil characteristics. The point data is converted to surface using IDW interpolation technique. Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable.

Results

4. Results

The present investigation was taken up to study the spatial and temporal variation in nutrient dynamics of *Pokkali* soils of Kerala. For achieving this objective the data generated from various experiments as detailed in chapter 3 were subjected to statistical analysis and the results emanated are detailed in this chapter. To compare the specific land use effect on soil properties including pH, EC, redox potential, available nutrient status and biological properties irrespective of the locations, mean values of each land use systems from different locations were summarized and given as sub tables next to main table.

Experiment no.1.

4.1. Characterization of soil samples

Surface (0-15cm) soil samples were collected at bimonthly intervals from lowlands and uplands of the same locations from *Pokkali* areas with different land uses *viz.* paddy-shrimp, shrimp alone, mangrove and fallow land from Ezhikkara, Kottuvally and Kadamakudy, and paddy alone land use from RRS-Vyttila. A total of 180 soil samples were collected and characterized keeping the moisture status as in field following wet analysis for lowland soil samples and dry analysis for upland soil samples (air dried and sieved through 2 mm sieve) with respect to physical, chemical and biological properties as detailed in chapter 3.

4.1.1. Physical properties

4.1.1.1.Soil texture

The data on soil texture provided in table 5 and it revealed that highest clay (60%), silt (27%) and sand (70%) fractions were reported in paddy alone land use from RSS - Vyttila, fallow land from Kottuvally and fallow land from Kadamakudy respectively in lowland soil. At the same time, upland soil showed highest clay (38%) silt (19%) and sand (85%) percentage in paddy-shrimp from Kottuvally, paddy alone from RRS-Vyttila and paddy shrimp from Kadamakudy in that order. Textural differences were observed in lowland and upland soils of the same location. Totally, five textural classes (clay loam, clay, silt loam, loam and sandy clay loam) in lowland and six textural classes (sandy loam, loam, sandy clay loam, sandy clay, clay loam and loamy sand) in upland soils could be identified.

Table 5. Soil texture of land uses from different locations

Locations	Land use	Lowland soil				Upland soil			
		Sand (%)	Silt (%)	Clay (%)	Texture	Sand (%)	Silt (%)	Clay (%)	Texture
Ezhikkara	Paddy – Shrimp	65	10	25	Clay loam	71	14	15	Sandy loam
	Shrimp alone	61	10	29	Clay loam	70	15	15	Loam
	Mangrove	53	7	40	Clay	68	6	26	Sandy clay loam
	Fallow	69	8	23	Clay loam	82	2	16	Sandy loam
Kottuvally	Paddy – Shrimp	53	2	45	Clay	60	2	38	Sandy clay
	Shrimp alone	52	20	28	Clay loam	75	10	15	Sandy loam
	Mangrove	48	11	41	Clay	54	15	31	Clay loam
	Fallow	60	28	12	Silt loam	75	10	15	Sandy loam
Kadamakudy	Paddy – Shrimp	55	25	20	Loam	85	10	5	Loamy sand
	Shrimp alone	53	26	21	Loam	71	10	19	Sandy loam
	Mangrove	62	14	24	Clay loam	70	9	21	Sandy clay loam
	Fallow	70	8	22	Sandy clay loam	73	9	18	Sandy loam
RRS, Vyttila	Paddy alone (a)	35	6	59	Clay	50	19	31	Clay loam
	Paddy alone (b)	34	6	60	Clay	53	15	32	Clay loam
	Paddy alone (c)	31	11	58	Clay	56	16	28	Clay loam

Clay loam textured soil was observed in lowland soils of paddy-shrimp, shrimp alone, and fallow land in Ezhikkara, shrimp alone in Kottuvally, mangrove in Kadamakudy, upland soils of mangrove in Kottuvally and paddy alone land uses in RRS- Vyttila. Clayey soil was identified in lowland soils of paddy alone land use from RRS- Vyttila, paddy-shrimp from Kottuvally and mangroves from Ezhikkara and Kottuvally. Loamy soil was found in lowland soils of paddy-shrimp and shrimp alone land uses from Kadamakudy and upland soils of shrimp alone land use from Ezhikkara. Silt loam soil was noticed only in lowland soil of fallow land in Kottuvally. Sandy clay loam soil was observed in lowland soil of fallow land in Kadamakudy and upland soils of mangroves in Ezhikkara and Kadamakudy. Sandy loam soil was detected in upland soils of paddy-shrimp and fallow land in Ezhikkara, shrimp alone and fallow land in Kottuvally and Kadamakudy. Sandy clay soil was observed only in upland soil of paddy-shrimp in Kottuvally. The texture clay loam soil was detected in upland soils of mangrove in Kottuvally and paddy alone land uses in RRS, Vyttila were clay loam. Loamy sand soil was noticed in upland soil of paddy-shrimp land use in Kadamakudy. Upland soils were high in sand percentage compared to lowland soils which were dominant in clay content.

4.1.1.2. Bulk density

Bulk density of both lowland and upland soil was not found to be significantly different among the samples collected at different months and land uses (table 6a and 6b). An increase in bulk density was observed in both lowland and upland soil from low saline phase (June to October) to high saline (December to April). Mean value of bulk density of lowland and upland soil ranged from 0.69 (August) to 0.90 (April) Mg m^{-3} and 0.67 (June) to 0.88 Mg m^{-3} (April) respectively throughout the year. Among the land uses, highest bulk density in lowland (0.94 Mg m^{-3}) and upland (0.90 Mg m^{-3}) soil was found in fallow land use in Ezhikkara.

4.1.1.3 Soil temperature

Soil temperature measured during soil sample collection from each land uses using a soil thermometer was recorded in tables 7a and 7b. The minimum soil temperature recorded in lowland soil was 25°C in December in paddy-shrimp, shrimp alone and fallow land in Ezhikkara and shrimp alone in Kottuvally. Whereas the maximum temperature (35°C) reported was in paddy alone land uses in RRS, Vyttila on

Table 6a. Spatial and temporal variations in bulk density (Mg m^{-3}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.78	0.65	0.71	0.82	0.95	1.05	0.83
	Shrimp alone	0.68	0.54	0.61	0.75	0.69	0.73	0.67
	Mangrove	0.92	0.85	0.71	0.91	0. 94	1.14	0.91
	Fallow	0.95	0.82	0.96	0.85	0.98	1.09	0.94
Kottuvally	Paddy - Shrimp	0.65	0.55	0.67	0.63	0.78	0.81	0.68
	Shrimp alone	0.63	0.52	0.68	0.75	0.66	0.79	0.67
	Mangrove	0.87	0.75	0.84	0.74	0.91	0.95	0.84
	Fallow	0.53	0.62	0.57	0.63	0.74	0.86	0.66
Kadamakudy	Paddy - Shrimp	0.75	0.62	0.71	0.76	0.81	0.88	0.76
	Shrimp alone	0.64	0.62	0.57	0.68	0.71	0.82	0.67
	Mangrove	0.71	0.82	0.68	0.79	0.85	0.79	0.77
	Fallow	0.72	0.84	0.87	0.76	0.78	0.91	0.81
RRS, Vyttila	Paddy alone (a)	0.70	0.82	0.74	0.84	0.88	0.99	0.83
	Paddy alone (b)	0.69	0.74	0.72	0.68	0.88	0.94	0.78
	Paddy alone (c)	0.67	0.54	0.67	0.85	0.73	0.81	0.71
Mean		0.73	0.69	0.71	0.76	0.82	0.90	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		interaction			NS			

Table 6b. Spatial and temporal variations of bulk density (Mg m^{-3}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.65	0.52	0.64	0.69	0.72	0.79	0.67
	Shrimp alone	0.74	0.84	0.92	0.85	0.91	0.99	0.88
	Mangrove	0.86	0.82	0.79	0.89	0.91	0.92	0.87
	Fallow	0.78	0.89	0.95	0.82	0.94	0.99	0.90
Kottuvally	Paddy - Shrimp	0.54	0.62	0.71	0.68	0.77	0.89	0.70
	Shrimp alone	0.56	0.68	0.61	0.65	0.59	0.75	0.64
	Mangrove	0.62	0.75	0.81	0.91	0.97	1.06	0.85
	Fallow	0.54	0.69	0.65	0.78	0.86	0.91	0.74
Kadamakudy	Paddy - Shrimp	0.71	0.69	0.65	0.76	0.85	0.91	0.76
	Shrimp alone	0.62	0.74	0.68	0.73	0.78	0.80	0.72
	Mangrove	0.66	0.57	0.67	0.59	0.71	0.85	0.67
	Fallow	0.70	0.63	0.75	0.66	0.78	0.89	0.74
RRS, Vyttila	Paddy alone (a)	0.69	0.78	0.65	0.75	0.88	0.76	0.75
	Paddy alone (b)	0.65	0.74	0.69	0.70	0.72	0.81	0.72
	Paddy alone (c)	0.66	0.75	0.68	0.76	0.72	0.83	0.73
Mean		0.67	0.71	0.72	0.75	0.81	0.88	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		interaction			NS			

Table 7a. In situ measurement of soil temperature (°C) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	29.9	34.0	31	25	29	32	30.15
	Shrimp alone	30.0	32.5	31	25	29	32	29.91
	Mangrove	30.0	34.0	31	26	25	32	29.66
	Fallow	29.0	34.5	31	25	29	32	30.08
Kottuvally	Paddy - Shrimp	30.0	31.2	30	26	30	30	29.53
	Shrimp alone	31.0	32.0	30	25	30	30	29.66
	Mangrove	31.0	31.0	30	26	29	30	29.50
	Fallow	30.0	30.0	30	27	29	30	29.33
Kadamakudy	Paddy - Shrimp	29.0	32.0	30	30	30	30	30.16
	Shrimp alone	30.0	34.0	30	29	30	30	30.50
	Mangrove	29.0	31.0	30	29	30	30	29.83
	Fallow	30.0	31.0	30	30	30	30	30.16
RRS, Vyttila	Paddy alone (a)	31.0	30.0	29	31	35	35	31.83
	Paddy alone (b)	30.0	30.9	29	30	35	35	31.65
	Paddy alone (c)	31.0	30.1	29	30	35	35	31.68
Mean		30.06	31.88	30.06	27.60	30.33	31.53	-
CD (0.05)		Months			0.363			
		Locations/Land use			0.574			
		interaction			1.407			

Table 7b. In situ measurement of soil temperature (°C) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	28.2	32.0	31	29	28	32	30.03
	Shrimp alone	32.0	31.0	30	29	28	32	30.33
	Mangrove	36.0	31.0	30	29	29	32	31.16
	Fallow	28.0	31.0	31	29	30	32	30.16
Kottuvally	Paddy - Shrimp	30.0	33.0	31	29	30	33	31.00
	Shrimp alone	30.0	32.0	31	29	31	32	30.83
	Mangrove	30.0	28.5	28	29	31	31	29.58
	Fallow	30.0	34.0	31	29	32	32	31.33
Kadamakudy	Paddy - Shrimp	29.0	33.0	30	29	30	30	30.16
	Shrimp alone	29.5	38.0	30	29	30	31	31.25
	Mangrove	29.0	34.0	30	29	30	32	30.66
	Fallow	29.5	31.0	30	29	31	31	30.25
RRS, Vyttila	Paddy alone (a)	31.0	30.0	29	28	30	35	30.50
	Paddy alone (b)	31.0	31.0	31	28	30	35	31.00
	Paddy alone (c)	30.0	31.0	29	28	30	35	30.50
Mean		30.21	32.03	30.13	28.8	30.00	32.33	-
CD (0.05)		Months			0.363			
		Locations/Land use			0.574			
		Interaction			1.407			

April (summer). In-situ measurement of soil temperature in upland soil varied from 28°C (paddy alone land uses in RRS, Vyttila) to 35°C (paddy alone land uses in RRS, Vyttila) in December and April (summer) respectively.

4.1.2. Chemical properties

4.1.2.1. Soil reaction (pH)

The mean value of soil pH of lowland soil gradually increased from 6.34 to 7.42 towards the end of low saline phase (October) and then decreased during high saline phase especially in summer (Fabruary and April) (table 8a). Extremely acidic to slightly acidic soil pH (3.76 to 6.46) was noticed in the month of April. The mean value of soil reaction ranged from 6.00 to 7.06 (slightly acidic to neutral) and 6.22 to 6.68 (slightly acidic to neutral) in Ezhikkara and Kottuvally respectively. Whereas Kadamakudy and Vytila registered the mean value of soil pH which ranged from 5.77 to 5.93 (Moderately acidic) and 4.94 to 5.59 (very strongly acidic to moderately acidic) respectively. Table 8b revealed that the highest soil pH was recorded in shrimp alone land use (6.50) and the lowest was recorded in paddy alone land use (5.30).

All the upland soils of *Pokkali* tract were recorded with acidic pH irrespective of the seasons (table 8c). The mean value of upland soil pH ranged between 4.39 to 4.82. Among the land uses, the lowest soil pH (3.16) was observed in paddy alone (a) in RRS-Vytila. Ezhikkara, Kottuvally and Kadamakudy recorded soil pH of 4.01 to 4.57, 4.43 to 6.36 and 4.54 to 5.73 respectively.

4.1.2.2. Electrical conductivity (EC)

The data pertaining to electrical conductivity of lowland *Pokkali* soil is presented in table 9a. The mean value of electrical conductivity of lowland *Pokkali* soil was found to be increasing during high saline phase ranged from 2.03 to 6.25 dS m^{-1} in the month of December and April respectively and then decreased during low saline phase ranged from 3.62 to 1.80 dS m^{-1} in the month of June to October respectively. Among land uses, highest mean value of electrical conductivity (6.38 dS m^{-1}) as observed in mangroves from Kadamakudy and the lowest was 2.02 dS m^{-1} in the paddy alone land use (c) in RRS-Vyttila. Table 9b disclosed that electrical conductivity of the lowlands ranged from 2.16 (paddy alone) to 4.44 dS m^{-1} (paddy shrimp).

Similar to lowland soil, upland soil also showed the same trend in variation in electrical conductivity throughout the seasons (table 9c). The mean value of electrical conductivity ranged from 0.23 to 0.84 dS m^{-1} during low saline phase (June to October) and 0.67 to 2.24 dS m^{-1} during high saline phase (December to April). Fallow land use in Ezhikkara recorded highest mean value (2.07 dS m^{-1}) of electrical conductivity and shrimp alone land use in Kadamakudy showed lowest mean value (0.20 dS m^{-1}). All land uses recorded highest electrical conductivity in summer season (February and April).

Table 8a. Spatial and temporal variations of soil pH in lowlands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	5.91	6.15	7.85	5.95	6.48	5.64	6.33
	Shrimp alone	8.14	7.07	7.16	7.06	6.47	6.46	7.06
	Mangrove	6.17	7.15	7.75	5.53	5.57	3.85	6.00
	Fallow	6.90	6.03	7.08	6.42	6.05	3.8	6.05
Kottuvally	Paddy - Shrimp	5.80	7.09	7.60	5.6	6.52	5.01	6.27
	Shrimp alone	7.83	7.02	7.66	6.59	6.51	4.47	6.68
	Mangrove	7.37	6.44	7.45	5.74	5.32	5.01	6.22
	Fallow	6.77	6.91	7.61	6.57	6.42	5.78	6.67
Kadamakudy	Paddy - Shrimp	6.24	6.44	7.52	6.47	4.24	3.79	5.78
	Shrimp alone	6.63	6.8	7.35	5.25	4.70	3.90	5.77
	Mangrove	6.74	6.84	7.71	6.53	3.86	3.89	5.93
	Fallow	7.90	6.50	7.88	5.16	4.12	4.04	5.93
RRS, Vyttila	Paddy alone (a)	4.58	5.86	7.47	6.38	4.09	3.76	5.36
	Paddy alone (b)	4.66	6.06	6.68	6.46	5.27	4.39	5.59
	Paddy alone (c)	3.46	4.80	6.55	5.43	5.81	3.61	4.94
Mean		6.34	6.48	7.42	6.08	5.43	4.49	-
CD (0.05)		Months			0.441			
		Locations/Land use			0.697			
		Interaction			NS			

Table 8b. Temporal variations of soil pH in different land uses

Land Use	**Months**						**Mean**
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	5.98	6.56	7.66	6.01	5.75	4.81	6.13
Shrimp alone	7.53	6.96	7.39	6.30	5.89	4.94	6.50
Mangrove	6.76	6.81	7.64	5.93	4.92	4.25	6.05
Fallow	7.19	6.48	7.52	6.05	5.53	4.54	6.22
Paddy alone	4.23	5.57	6.90	6.09	5.06	3.92	5.30
Mean	6.34	6.48	7.42	6.08	5.43	4.49	
CD (0.01)	Months			0.650			
	Locations/Land use			0.593			
	interaction			1.453			

Table 8c. Spatial and temporal variation of soil pH in uplands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	4.45	4.26	4.48	3.91	3.3	3.67	4.01
	Shrimp alone	4.08	3.96	5.29	3.60	5.78	3.66	4.39
	Mangrove	4.55	5.14	4.03	4.91	4.64	4.15	4.57
	Fallow	4.84	4.58	4.65	4.05	3.83	3.64	4.26
Kottuvally	Paddy - Shrimp	6.51	6.43	6.01	6.75	6.16	6.32	6.36
	Shrimp alone	4.26	4.83	4.20	4.73	4.25	4.29	4.43
	Mangrove	6.04	5.67	4.70	4.96	5.23	5.70	5.38
	Fallow	6.21	5.78	5.02	4.80	3.82	3.96	4.93
Kadamakudy	Paddy - Shrimp	6.87	5.58	4.90	5.24	5.44	6.33	5.73
	Shrimp alone	4.93	3.19	5.69	4.85	4.65	4.75	4.68
	Mangrove	4.88	5.28	4.11	5.00	3.94	4.01	4.54
	Fallow	5.12	3.92	5.05	5.35	5.06	5.20	4.95
RRS, Vyttila	Paddy alone (a)	3.32	3.29	2.79	3.01	3.37	3.19	3.16
	Paddy alone (b)	3.36	3.83	3.88	3.18	3.41	3.78	3.57
	Paddy alone (c)	2.95	3.74	3.29	3.31	3.19	3.22	3.28
Mean		4.82	4.63	4.54	4.51	4.40	4.39	
CD (0.05)		Months			NS			
		Locations/Land use			0.535			

Table 9a. Spatial and temporal variations of electrical conductivity (dS m^{-1}) in lowlands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	3.69	2.53	3.21	3.17	8.47	8.24	4.89
	Shrimp alone	2.68	1.14	1.58	2.15	6.08	6.05	3.28
	Mangrove	2.65	2.60	1.49	2.91	6.36	7.68	3.95
	Fallow	3.22	2.50	1.04	2.49	6.94	6.32	3.75
Kottuvally	Paddy - Shrimp	4.37	2.66	1.60	1.95	7.00	7.86	4.24
	Shrimp alone	1.95	3.43	1.54	1.87	5.10	9.10	3.83
	Mangrove	1.90	1.17	1.59	1.91	6.07	4.23	2.81
	Fallow	3.97	2.47	1.34	1.18	4.89	7.87	3.62
Kadamakudy	Paddy - Shrimp	6.84	2.02	2.23	2.40	5.64	6.05	4.20
	Shrimp alone	5.13	5.84	1.52	2.26	5.64	7.87	4.71
	Mangrove	7.84	5.97	4.21	3.06	8.39	8.81	6.38
	Fallow	2.09	1.55	1.38	1.75	5.16	5.33	2.88
RRS, Vyttila	Paddy alone (a)	3.04	1.52	1.71	1.04	3.81	3.01	2.35
	Paddy alone (b)	2.74	1.09	1.34	0.92	3.65	2.81	2.09
	Paddy alone (c)	2.23	1.14	1.16	1.44	3.67	2.48	2.02
Mean		3.62	2.51	1.80	2.03	5.79	6.25	-
CD (0.05)		Months			0.323			
		Locations/Land use			0.511			
		Interaction			1.253			

Table 9b. Temporal variation of electrical conductivity (dS m^{-1}) in different land uses

Land Use	**Months**						**Mean**
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	4.97	2.40	2.35	2.51	7.04	7.38	4.44
Shrimp alone	3.25	3.47	1.55	2.09	5.61	7.67	3.94
Mangrove	4.13	3.25	2.43	2.63	6.94	6.91	4.38
Fallow	3.09	2.17	1.25	1.81	5.66	6.51	3.42
Paddy alone	2.67	1.25	1.40	1.13	3.71	2.77	2.16
Mean	3.62	2.51	1.80	2.03	5.79	6.25	
CD (0.05)	Months			1.224			
	Locations/Land use			1.117			
	interaction			2.736			

Table 9c. Spatial and temporal variations of electrical conductivity (dS m^{-1}) in uplands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.08	0.22	0.07	0.09	1.14	2.92	0.75
	Shrimp alone	1.97	0.74	0.12	0.53	4.85	2.84	1.84
	Mangrove	2.45	0.17	0.17	0.19	1.00	2.70	1.11
	Fallow	0.05	0.67	0.11	1.11	6.24	4.22	2.07
Kottuvally	Paddy - Shrimp	0.37	0.17	0.12	1.01	2.55	2.16	1.06
	Shrimp alone	1.15	0.66	0.88	0.31	1.09	3.74	1.30
	Mangrove	0.27	0.10	0.13	0.30	1.67	3.23	0.95
	Fallow	0.90	0.22	0.12	0.17	3.42	4.18	1.50
Kadamakudy	Paddy - Shrimp	0.91	0.20	0.10	0.13	0.18	0.99	0.42
	Shrimp alone	0.12	0.15	0.11	0.09	0.15	0.58	0.20
	Mangrove	1.39	1.19	0.14	3.97	1.57	1.72	1.66
	Fallow	0.14	0.15	0.11	0.10	1.53	1.21	0.54
RRS, Vyttila	Paddy alone (a)	0.39	0.17	0.25	0.87	1.18	0.95	0.63
	Paddy alone (b)	1.12	0.32	0.25	0.62	1.00	0.91	0.70
	Paddy alone (c)	1.30	0.31	0.81	0.48	0.64	1.20	0.79
Mean		0.84	0.36	0.23	0.67	1.88	2.24	
CD (0.05)		Months			0.117			
		Locations/Land use			0.185			
		Interaction			0.453			

4.1.2.3. Redox potential (RP)

Agradual decrease in redox potential in lowland soil was observed during low saline phasefrom June (-177 mV) to October (-300 mV) and an increase in redox potential was noticed during high saline phase from December (-274 mV) to April (-97 mV) (table 10a). Among land uses, paddy alone land uses from RRS, Vyttila recorded highest redox potential values ranged from 320 to 360 mV in April and lowest was reported as -360 mV in paddy-shrimp land use from Ezhikkara in the month of October.

Whereas the table 10b revealed that the highest redox potential in soil was showed in paddy alone (-75 mV) and that of lowest was in shrimp alone (-280 mV).

Table 10a. In situ measurement of redox potential (mV) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	-310	-320	-360	-320	-300	-280	-315
	Shrimp alone	-280	-300	-320	-290	-270	-270	-288
	Mangrove	-250	-270	-280	-280	-270	-240	-265
	Fallow	-280	-290	-310	-320	-300	-290	-298
Kottuvally	Paddy - Shrimp	-250	-260	-320	-330	-290	-270	-286
	Shrimp alone	-290	-300	-350	-345	-330	-280	-315
	Mangrove	-230	-250	-280	-250	-220	210	-170
	Fallow	-250	-260	-280	-250	-240	-240	-253
Kadamakudy	Paddy - Shrimp	-220	-240	-250	-210	-200	-200	-220
	Shrimp alone	-240	-280	-260	-220	-210	-200	-235
	Mangrove	-250	-260	-270	-280	-250	-220	-255
	Fallow	-240	-280	-310	-280	-250	-210	-261
RRS, Vyttila	Paddy alone (a)	160	-220	-300	-250	-160	320	-75
	Paddy alone (b)	120	-220	-320	-250	-150	350	-78
	Paddy alone (c)	150	-240	-300	-240	-160	360	-71
Mean		-177	-266	-300	-274	-240	-97	-
CD(0.05)		Months			0.363			
		Locations/Land use			0.514			
		Interaction			1.407			

Table 10b. Temporal variation of redox potential (m V) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	-260	-273	-310	-287	-263	-250	-274
Shrimp alone	-270	-293	-310	-285	-270	-250	-280
Mangrove	-243	-260	-277	-270	-247	-83	-230
Fallow	-257	-277	-300	-283	-263	-247	-271
Paddy alone	143	-227	-307	-247	-157	343	-75
Mean	-177	-266	-301	-274	-240	-97	
CD (0.05)	Months			53.617			
	Locations/Land use			48.945			
	interaction			119.891			

4.1.2.4. Organic Carbon (OC)

Organic carbon content in lowland soil did not show any significant difference between the seasons and among land uses (table 11a). The mean value of organic carbon in various months ranged from 2.62 % (October) to 3.02 % (June) and that for different land uses was from 2.52 (paddy-shrimp in Kadamakudy) to 3.31 % (shrimp alone in Kottuvally).

Like lowland soil, upland soil also did not show any significant difference in organic carbon among the seasons (table 11b). Whereas the mean values of organic carbon in land uses showed significant variation. The highest mean value (3.13 %) of organic carbon was observed in paddy shrimp land use in Ezhikkara and lowest (1.79 %) was noticed in paddy shrimp land use in Kadamakudy.

4.1.2.5. Total Nitrogen (TN)

The data pertaining to the total nitrogen content of lowland soil is given in the table 12a. There was no significant variation in total nitrogen content throughout the seasons as well as in different land uses. The mean value of total nitrogen varied from 0.161 % (August) to 0.170 % (April) among the seasons and 0.132 % (fallow land in Ezhikkara) to 0.232 % (shrimp alone in Ezhikkara) among land uses.

The temporal variation of total nitrogen content of upland soil was not significantly different (table 12b). But the spatial variation had marked difference. The highest and lowest mean values of total nitrogen in upland soils were reported as 0.312 % (paddy shrimp in Kottuvally) and 0.122 % (paddy shrimp in Kadamakudy) respectively.

4.1.2.6. Available Phosphorus (av.P)

The data on available phosphorus of lowland soil revealed a high status of available P. Gradual increase in mean value of available P was reported during low saline phase from June (75.55 kg ha^{-1}) to October (134.33 kg ha^{-1}) and sudden decrease in mean value of available P was observed from December (118.29 kg ha^{-1}) to April (74.21 kg ha^{-1}) during high saline phase (table 13a). While considering the land uses, available P ranges from 122.08 to 206.82 $kgha^{-1}$, the highest being recorded in paddy alone land use (c) in RRS, Vyttila. Table 13b disclosed that available phosphorus in soil was highest in paddy alone land use (133.09 kg ha^{-1}) and lowest in shrimp alone land use (62.34 kg ha^{-1}).

All upland soil samples were reported to have high available P status (table 13c). The available P content in the upland soil was found to be non-significant throughout the seasons. But it was reported as significant among the locations. Soil samples from RRS-Vyttila (paddy alone) showed higher mean value of available P (135.11 kg ha^{-1}, 134.31 kg ha^{-1} and 137.87 kg ha^{-1} in plot a, b and c respectively) compared to other locations.

Table 11a. Spatial and temporal variations of organic carbon (%) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	3.23	2.06	2.59	3.10	3.98	3.14	3.02
	Shrimp alone	3.21	2.59	2.30	2.94	2.85	3.13	2.84
	Mangrove	3.21	2.12	1.47	2.14	3.45	3.12	2.59
	Fallow	3.26	2.85	1.79	2.89	3.26	2.83	2.81
Kottuvally	Paddy - Shrimp	2.19	3.62	3.66	3.92	3.90	2.10	3.23
	Shrimp alone	3.96	2.26	3.70	2.48	3.99	3.48	3.31
	Mangrove	1.83	2.74	2.36	3.12	2.57	3.18	2.63
	Fallow	2.52	3.46	2.23	3.76	2.49	3.18	2.94
Kadamakudy	Paddy - Shrimp	3.34	3.45	2.06	1.99	2.12	2.14	2.52
	Shrimp alone	2.99	1.69	1.45	1.98	2.79	3.34	2.37
	Mangrove	2.84	3.03	3.52	2.89	3.41	3.38	3.18
	Fallow	2.62	3.64	2.98	3.17	2.45	2.63	2.92
RRS, Vyttila	Paddy alone (a)	3.01	3.52	3.23	2.45	2.59	2.41	2.87
	Paddy alone (b)	3.92	2.84	2.60	3.68	2.42	3.34	3.13
	Paddy alone (c)	3.16	3.46	3.38	3.36	2.91	3.13	3.23
Mean		3.02	2.89	2.62	2.92	3.01	2.97	
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

Table 11b. Spatial and temporal variations of organic carbon (%) in uplands

Locations	Land use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2.69	3.62	3.52	3.14	3.21	2.60	3.13
	Shrimp alone	1.72	1.51	2.43	1.56	2.32	1.94	1.91
	Mangrove	2.59	1.72	2.12	1.62	2.24	1.71	2.00
	Fallow	1.47	2.19	1.98	2.52	1.99	1.82	2.00
Kottuvally	Paddy - Shrimp	2.04	3.66	3.25	2.05	3.32	2.13	2.74
	Shrimp alone	2.07	3.01	3.16	2.01	3.56	2.49	2.72
	Mangrove	1.99	2.45	3.46	2.96	2.56	3.01	2.74
	Fallow	2.17	1.51	2.14	1.65	1.85	2.39	1.95
Kadamakudy	Paddy - Shrimp	1.50	1.59	2.12	1.35	2.22	1.95	1.79
	Shrimp alone	3.01	2.27	1.62	2.43	3.15	2.89	2.56
	Mangrove	2.18	1.91	2.13	2.35	3.12	1.79	2.25
	Fallow	3.09	3.95	3.56	2.51	2.99	2.41	3.08
RRS,Vyttila	Paddy alone (a)	3.49	2.93	3.08	2.87	2.51	1.92	2.80
	Paddy alone (b)	2.18	1.85	2.54	1.62	2.31	2.20	2.12
	Paddy alone (c)	3.04	2.42	3.13	3.23	3.41	2.58	2.97
Mean		2.35	2.44	2.68	2.26	2.72	2.26	
CD (0.05)		Months				NS		
		Locations/Land use				0.525		
		Interaction				NS		

Table 12a. Spatial and temporal variations of total nitrogen (%) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.160	0.140	0.150	0.150	0.220	0.170	0.165
	Shrimp alone	0.290	0.250	0.260	0.250	0.160	0.180	0.232
	Mangrove	0.160	0.150	0.140	0.160	0.170	0.160	0.157
	Fallow	0.150	0.140	0.110	0.130	0.140	0.120	0.132
Kottuvally	Paddy - Shrimp	0.130	0.110	0.110	0.120	0.210	0.190	0.145
	Shrimp alone	0.210	0.230	0.180	0.190	0.190	0.150	0.192
	Mangrove	0.160	0.150	0.230	0.160	0.190	0.250	0.190
	Fallow	0.140	0.180	0.200	0.140	0.120	0.150	0.155
Kadamakudy	Paddy - Shrimp	0.140	0.130	0.180	0.150	0.180	0.140	0.153
	Shrimp alone	0.190	0.180	0.190	0.160	0.100	0.180	0.167
	Mangrove	0.140	0.150	0.220	0.180	0.130	0.190	0.168
	Fallow	0.180	0.150	0.120	0.160	0.190	0.170	0.162
RRS, Vyttila	Paddy alone (a)	0.150	0.140	0.190	0.150	0.210	0.180	0.170
	Paddy alone (b)	0.170	0.160	0.190	0.180	0.170	0.180	0.175
	Paddy alone (c)	0.110	0.160	0.160	0.150	0.120	0.140	0.140
Mean		0.165	0.161	0.175	0.162	0.167	0.170	
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

Table 12b. Spatial and temporal variations of total nitrogen (%) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.140	0.120	0.180	0.150	0.140	0.160	0.148
	Shrimp alone	0.170	0.160	0.160	0.140	0.210	0.180	0.170
	Mangrove	0.120	0.110	0.100	0.120	0.190	0.160	0.133
	Fallow	0.140	0.150	0.350	0.210	0.150	0.140	0.190
Kottuvally	Paddy - Shrimp	0.390	0.260	0.200	0.310	0.360	0.350	0.312
	Shrimp alone	0.110	0.220	0.350	0.310	0.140	0.210	0.223
	Mangrove	0.210	0.110	0.190	0.240	0.130	0.260	0.190
	Fallow	0.350	0.320	0.160	0.220	0.190	0.230	0.245
Kadamakudy	Paddy - Shrimp	0.100	0.130	0.120	0.140	0.130	0.110	0.122
	Shrimp alone	0.260	0.220	0.210	0.240	0.190	0.250	0.228
	Mangrove	0.290	0.250	0.160	0.180	0.180	0.210	0.212
	Fallow	0.260	0.250	0.250	0.210	0.220	0.190	0.230
RRS, Vyttila	Paddy alone (a)	0.180	0.150	0.280	0.270	0.220	0.240	0.223
	Paddy alone (b)	0.190	0.140	0.180	0.160	0.200	0.180	0.175
	Paddy alone (c)	0.200	0.180	0.210	0.240	0.230	0.270	0.222
Mean		0.207	0.185	0.207	0.209	0.192	0.209	
CD (0.05)		Months			NS			
		Locations/Land use			0.057			
		Interaction			NS			

Table 13a. Spatial and temporal variations of available phosphorus (kg ha^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	86.28	101.49	117.91	101.27	88.85	97.71	98.92
	Shrimp alone	72.82	110.32	113.50	110.69	76.34	71.02	92.45
	Mangrove	48.34	75.08	79.14	70.36	26.50	29.01	54.74
	Fallow	105.6	160.05	191.42	161.59	104.54	82.13	134.23
Kottuvally	Paddy - Shrimp	93.90	170.96	198.04	183.99	99.12	75.41	136.90
	Shrimp alone	57.41	48.16	75.97	64.18	40.88	27.19	52.30
	Mangrove	95.22	102.30	124.63	103.73	70.00	53.38	91.54
	Fallow	99.25	146.34	139.90	122.35	126.16	122.4	126.08
Kadamakudy	Paddy - Shrimp	55.15	165.76	198.40	149.59	143.36	131.3	140.60
	Shrimp alone	25.11	45.17	54.95	49.59	42.94	35.89	42.28
	Mangrove	50.20	50.58	99.12	86.17	26.13	27.15	56.56
	Fallow	37.71	93.90	126.18	121.70	31.55	29.12	73.36
RRS, Vyttila	Paddy alone (a)	47.78	85.30	106.21	108.79	107.42	92.36	91.31
	Paddy alone (b)	118.5	121.54	182.74	169.39	156.17	116.9	144.23
	Paddy alone (c)	139.8	175.64	206.82	170.96	167.15	122.0	163.74
Mean		75.55	110.17	134.33	118.29	87.14	74.21	-
CD (0.05)		Months			13.254			
		Locations/Land use			20.957			
		Interaction			51.333			

Table 13b. Temporal variation of available phosphorus (kg ha^{-1}) in different land use

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	78.44	146.07	171.45	144.95	110.44	101.48	125.47
Shrimp alone	51.78	67.88	81.47	74.82	53.39	44.70	62.34
Mangrove	64.59	75.99	100.96	86.75	40.88	36.51	67.61
Fallow	80.87	133.43	152.50	135.21	87.42	77.90	111.22
Paddy alone	102.05	127.49	165.26	149.71	143.58	110.47	133.09
Mean	75.55	110.17	134.33	118.29	87.14	74.21	
CD (0.05)	Months			32.048			
	Locations/Land use			29.256			
	interaction			71.661			

Table 13c. Spatial and temporal variations of available phosphorus (kg ha^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	88.85	74.65	68.12	107.33	79.32	101.4	86.63
	Shrimp alone	76.34	52.08	53.20	45.11	57.37	63.64	57.96
	Mangrove	22.67	27.91	45.49	37.00	40.79	47.98	36.97
	Fallow	27.22	54.95	61.87	56.92	71.99	68.30	56.87
Kottuvally	Paddy - Shrimp	68.31	89.41	75.78	84.37	79.79	86.28	80.66
	Shrimp alone	23.14	25.57	35.65	45.11	41.71	36.76	34.66
	Mangrove	27.64	34.99	45.11	50.42	59.16	53.42	45.12
	Fallow	77.32	103.80	129.73	108.91	115.67	126.1	110.2
Kadamakudy	Paddy - Shrimp	125.5	105.27	114.24	103.03	110.13	127.4	114.2
	Shrimp alone	43.10	26.03	18.84	35.01	51.12	76.50	41.76
	Mangrove	64.56	46.10	56.69	50.65	61.91	56.92	56.14
	Fallow	99.30	89.41	79.33	75.78	86.04	81.18	85.17
RRS, Vyttila	Paddy alone (a)	133.5	124.12	117.89	153.48	146.29	135.3	135.11
	Paddy alone (b)	139.5	148.24	131.31	119.10	125.33	142.2	134.31
	Paddy alone (c)	131.3	144.77	128.79	128.05	148.13	146.1	137.87
Mean		76.56	76.49	77.47	80.02	84.98	89.99	-
CD (0.05)		Months			NS			
		Locations/Land use			17.475			
		Interaction			NS			

4.1.2.7. Available Potassium (av.K)

Results revealed that all soil samples showed high available K status (table 14a). Generally, a trend of decline in the mean value of available K from 955.91 (June) to 636.51 kgha^{-1} (October) was found during low saline phase (June to October). Later, an increase in available K was observed during high saline phase (December to April). Highest mean value of available K was noticed in April (1275.3 kg ha^{-1}). Among land uses, fallow land in Ezhikkara and mangrove in Kottuvally recorded highest (1427.58 kg ha^{-1}) and lowest (795.72 kg ha^{-1}) mean values of available K. While considering the specific land use effect, table 14b revealed that the highest K was observed in paddy-shrimp land use (1137.35 kg ha^{-1}) and that of lowest was in fallow land (900.04 kg ha^{-1}).

Upland soils were high (>275 kg ha^{-1}) in K status. Gradual increase in the mean value of available K status was noticed throughout the seasons ranging from 199.02 kg ha^{-1} (June) to 253.37 kg ha^{-1} (April) (table 14c). The mean value of available K among land uses ranged from 76.59 kg ha^{-1} (paddy-shrimp in Kadamakudy) to 681.05 kg ha^{-1} (paddy-shrimp in Kottuvally).

4.1.2.8. Available Calcium and Magnesium (av.Ca and Mg)

Available calcium in lowland soil was determined and furnished in table 15a. All soil samples showed high in available calcium status. The highest available calcium was recorded in summer (April) and it ranged from 610.05 to 1505.42 mg kg^{-1} and the lowest available Ca was reported in October (406.78 to 1535.03 mg kg^{-1}) which was on par with the values in June (326.59 to 1183.88 mg kg^{-1}) and in August (433.02 to 1333.84 $mgkg^{-1}$). The mean values of available calcium in land uses ranged from 418.68 mg kg^{-1} (paddy alone (b) in RRS-Vyttila) to 1422.23 mg kg^{-1} (mangrove in Kadamakudy). Table 15b revealed that available calcium was recorded highest in paddy shrimp (1129.42 mg kg^{-1}) and that of lowest was in paddy alone (557.50 mg kg^{-1}).

Available calcium assessed in the upland soil indicated that there was no significant variation throughout the seasons (table 15c). Among land uses, paddy alone land use (c) in RRS-Vyttila and paddy-shrimp in Kadamakudy marked lowest (195.22 mg kg^{-1}) and highest (800.90 mg kg^{-1}) mean values of calcium respectively.

The data on available Mg (table 16a) revealed very high Mg status in lowland *Pokkali* soil. High saline phase was recorded with higher mean values of available Mg ranging from 1016.60 (December) to 1365.22 mg kg^{-1} (February)than low saline phase which was registered with mean values of available Mg from 557.76 (June) to 881.17 (August) mg kg^{-1}. Spatial variation in available Mg was reported to be significant among land uses and the mean values of available Mg ranged from 711.73 mg kg^{-1} (shrimp alone in Ezhikkara) to 1432.90 mg kg^{-1} (mangrove in Kadamakudy). Table 16b revealed that available magnesium was recorded highest in mangrove land use (1269.81 mg kg^{-1}) and that of lowest was in paddy alone land use (695.94 mg kg^{-1}).

Available Mg of upland soil are presented in table 16c. Seasonal variation in available Mg was found to be non-significant. All upland soil was reported to be deficient in Mg. The highest available Mg was reported in shrimp alone land use in Ezhikkara which ranged from 166.50 to 285.50 mg kg^{-1}.

4.1.2.9. Available Sulphur (av.S)

Pokkali lowland soil contained available S in very high quantity. Mean value of available sulphur was found to be decreasing from June (2459.32 mg kg^{-1}) to October

(1711.18 mg kg^{-1}) in low saline phase and then increased from December (1962.81 mg kg^{-1}) to April (284.73 mgkg^{-1}) during high saline phase (table 17a). The lowest mean value of available sulphur was 1070.40 mg kg^{-1} (paddy alone land use, b in RRS-Vyttila) and the highest was 2996.65 mg kg^{-1} (mangrove in Kadamakudy). Table 17b revealed that available magnesium was recorded lowest in paddy alone land use (1491.42 mg kg^{-1}) and highest in mangrove land use (2806.18 mg kg^{-1}).

The data pertaining to the available sulphur content of upland soils revealed a gradual increase in mean value of available sulphur throughout the season and it ranged from 299.58 (June) to 476.64 mg kg^{-1} (April) (table 17c). Among land uses, the mean values of available sulphur ranged from 281.03 mg kg^{-1} (paddy shrimp in Kottuvally) to 429.04 mg kg^{-1} (Mangrove in Kadamakudy).

Table 14a. Spatial and temporal variations of available potassium (kg ha^{-1}) in Lowlands.

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	754.2	665.6	404.1	598.4	1280.0	1499.3	866.9
	Shrimp alone	1002.3	651.8	423.0	495.3	991.3	1539.3	850.5
	Mangrove	1277.3	905.2	918.9	1163.0	1394.1	1526.5	1197.5
	Fallow	1374.3	1319.5	789.1	1493.9	1768.8	1820.1	1427.6
Kottuvally	Paddy - Shrimp	1449.6	1163.6	993.4	1230.3	1886.6	1814.9	1423.1
	Shrimp alone	778.5	720.0	451.2	773.1	895.6	1020.6	773.2
	Mangrove	443.8	370.1	417.8	623.1	861.4	937.5	609.0
	Fallow	1124.8	756.6	600.6	495.9	863.4	933.0	795.7
Kadamakudy	Paddy - Shrimp	881.5	930.0	739.0	1342.5	1347.2	1492.3	1122.1
	Shrimp alone	1514.5	1380.1	1334.2	1699.0	1741.0	1702.3	1561.9
	Mangrove	1124.8	974.9	723.2	900.1	986.2	1237.8	991.2
	Fallow	525.0	322.8	377.1	362.0	657.4	616.5	476.8
RRS, Vyttila	Paddy alone (a)	637.3	469.1	473.6	856.9	962.2	1035.7	739.1
	Paddy alone(b)	522.4	662.0	447.6	520.2	745.2	866.9	627.4
	Paddy alone (c)	928.4	944.2	455.0	729.1	1232.3	1086.9	896.0
Mean		955.9	815.7	636.5	885.5	1174.2	1275.3	-
CD (0.05)		Months			50.009			
		Locations/Land use			70.071			
		Interaction			193.683			

Table 14b. Temporal variation of available potassium (kg ha^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	1028.46	919.71	712.17	1057.05	1504.57	1602.17	1137.35
Shrimp alone	1098.43	917.30	736.13	989.13	1209.28	1420.74	1061.83
Mangrove	948.61	750.07	686.65	895.39	1080.56	1233.94	932.54
Fallow	1008.01	799.63	588.93	783.93	1096.53	1123.19	900.04
Paddy alone	696.02	691.74	458.71	702.08	979.91	996.50	754.16
Mean	955.91	815.69	636.52	885.52	1174.17	1275.31	
CD (0.05)	Months			362.802			
	Locations/Land use			331.192			
	interaction			811.250			

Table 14c. Spatial and temporal variation of available potassium (kg ha^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	123.76	116.03	136.08	158.70	179.67	173.42	147.94
	Shrimp alone	189.28	159.71	172.37	193.98	226.24	213.49	192.51
	Mangrove	142.80	137.42	146.27	174.16	123.09	135.18	143.15
	Fallow	284.97	332.95	370.50	279.10	350.78	307.78	321.01
Kottuvally	Paddy - Shrimp	483.35	633.92	504.11	779.63	823.20	862.06	681.05
	Shrimp alone	175.84	141.68	116.82	126.00	173.26	157.36	148.49
	Mangrove	136.08	144.03	142.80	144.26	156.02	144.26	144.57
	Fallow	131.60	133.73	144.82	132.50	184.24	240.69	161.26
Kadamakudy	Paddy - Shrimp	67.76	76.83	50.18	68.32	85.68	110.77	76.59
	Shrimp alone	181.44	188.83	156.69	195.55	246.92	211.97	196.90
	Mangrove	392.58	442.18	521.70	536.70	268.69	381.92	423.96
	Fallow	126.00	128.60	125.35	164.30	203.06	247.61	165.82
RRS, Vyttila	Paddy alone (a)	128.37	168.52	161.39	176.96	190.40	134.51	160.03
	Paddy alone(b)	220.68	184.20	258.14	253.46	233.48	252.09	233.67
	Paddy alone (c)	200.75	217.17	234.42	220.75	183.01	227.38	213.91
Mean		199.02	213.72	216.11	240.29	241.85	253.37	-
CD (0.05)		Months			30.098			
		Locations/Land use			47.589			
		Interaction			116.569			

Table 15a. Spatial and temporal variations of available calcium (mg kg^{-1}) in lowlands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	701.2	721.0	805.0	1224.2	1296.3	1168.2	986.0
	Shrimp alone	327.0	433.0	445.8	433.0	549.5	662.7	498.7
	Mangrove	760.8	814.8	851.9	776.4	806.2	822.0	805.4
	Fallow	606.8	621.0	741.3	972.3	1410.3	1120.9	912.1
Kottuvally	Paddy - Shrimp	900.1	949.0	757.0	938.2	1871.3	1925.4	1223.5
	Shrimp alone	1069.5	1066.5	1305.2	1513.2	1913.5	1505.4	1395.6
	Mangrove	485.9	492.3	771.4	1011.5	1112.6	854.7	788.1
	Fallow	416.1	545.0	866.7	746.2	1195.3	1486.6	876.0
Kadamakudy	Paddy - Shrimp	1107.1	1049.1	929.4	1403.7	1400.9	1182.5	1178.8
	Shrimp alone	704.8	579.8	474.9	900.0	1293.9	1486.2	906.6
	Mangrove	1183.9	1333.8	1535.0	1565.2	1620.5	1294.9	1422.2
	Fallow	367.6	472.4	406.8	550.7	640.8	580.7	503.2
RRS, Vyttila	Paddy alone (a)	326.6	508.5	648.3	632.3	765.9	881.2	627.1
	Paddy alone(b)	327.4	481.1	448.2	461.7	470.5	323.2	418.7
	Paddy alone (c)	328.6	586.0	600.0	728.3	907.2	610.1	626.7
Mean		686.6	749.4	742.3	894.0	1134.7	1060.3	-
CD (0.05)		Months			79.795			
		Locations/Land use			126.168			
		Interaction			309.046			

Table 15b. Temporal variation of available calcium (mg kg^{-1}) in different land uses

Land Use	**Months**						**Mean**
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	902.84	906.37	830.45	1188.70	1522.84	1425.35	1129.42
Shrimp alone	700.41	693.11	741.95	948.73	1252.32	1218.12	925.77
Mangrove	810.17	880.33	1052.79	1117.71	1179.75	990.52	1005.21
Fallow	463.49	546.11	671.60	756.39	1082.11	1062.75	763.74
Paddy alone	327.50	525.20	565.52	607.42	714.54	604.79	557.50
Mean	640.88	710.22	772.46	923.79	1150.31	1060.31	
CD (0.05)	Months			319.033			
	Locations/Land use			291.236			
	interaction			713.380			

Table 15c. Spatial and temporal variations of available calcium (mg kg^{-1}) in uplands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	274.0	215.1	169.5	216.3	248.3	287.8	235.2
	Shrimp alone	237.0	283.0	182.3	188.8	232.0	225.0	224.7
	Mangrove	467.0	469.5	404.8	344.2	437.3	459.5	430.4
	Fallow	492.6	515.8	437.5	445.3	556.5	565.3	502.2
Kottuvally	Paddy - Shrimp	171.3	192.6	256.3	263.2	223.6	256.3	227.2
	Shrimp alone	188.9	215.3	270.0	295.6	251.2	269.8	248.5
	Mangrove	483.5	400.5	417.8	655.3	551.8	608.5	519.6
	Fallow	281.3	268.8	207.8	271.5	299.8	226.5	259.2
Kadamakudy	Paddy - Shrimp	816.1	861.3	822.3	636.8	830.3	838.8	800.9
	Shrimp alone	341.3	305.0	330.1	436.8	458.0	460.5	388.6
	Mangrove	516.6	372.5	325.6	528.3	598.3	551.5	482.1
	Fallow	752.8	745.0	732.3	600.0	680.0	674.0	697.3
RRS, Vyttila	Paddy alone (a)	115.0	274.5	226.8	270.0	283.0	241.4	235.1
	Paddy alone (b)	100.8	148.5	196.0	229.5	282.0	290.0	207.8
	Paddy alone (c)	149.5	192.8	183.8	176.3	238.5	230.5	195.2
Mean		359.1	364.0	344.1	370.5	411.3	412.3	-
CD (0.05)		Months			NS			
		Locations/Land use			120.152			
		Interaction			NS			

Table 16a. Spatial and temporal variations of available magnesium (mg kg^{-1}) in lowlands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	560.1	631.4	816.1	1291.5	1666.2	1293.6	1043.2
	Shrimp alone	487.3	915.0	414.2	494.4	635.9	1323.7	711.7
	Mangrove	520.1	1335.2	1265.5	1195.3	1581.0	1642.5	1256.6
	Fallow	756.3	1213.3	1087.7	1415.2	1544.2	1324.6	1223.6
Kottuvally	Paddy - Shrimp	511.2	1299.7	994.6	1091.3	1723.4	1310.4	1155.1
	Shrimp alone	651.4	1387.4	1473.0	1196.5	1754.6	1394.5	1309.6
	Mangrove	398.8	669.1	729.3	1033.9	1982.9	1905.5	1119.9
	Fallow	988.4	1001.7	428.3	636.2	808.2	719.2	763.7
Kadamakudy	Paddy - Shrimp	856.2	1131.2	1467.3	1016.2	1503.6	1368.4	1223.8
	Shrimp alone	820.1	945.1	594.7	1101.2	1699.2	1077.4	1039.6
	Mangrove	910.2	1271.4	1584.2	1654.2	1546.0	1631.2	1432.9
	Fallow	508.6	779.9	709.6	577.4	993.7	916.9	747.7
RRS, Vyttila	Paddy alone (a)	115.6	694.8	593.2	982.5	780.0	1380.3	757.7
	Paddy alone (b)	108.5	585.3	514.2	682.7	810.6	585.0	547.7
	Paddy alone (c)	173.2	491.4	545.7	880.5	1448.7	1154.6	782.4
Mean		557.7	956.7	881.1	1016.6	1365.2	1268.5	-
CD (0.05)		Months			79.013			
		Locations/Land use			124.930			
		Interaction			306.014			

Table 16b. Temporal variation of available magnesium (mg kg^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	642.52	1020.79	1092.66	1132.97	1631.09	1324.15	1140.70
Shrimp alone	652.96	1082.48	827.29	930.69	1363.26	1265.18	1020.31
Mangrove	609.74	1091.91	1192.99	1294.49	1703.32	1726.42	1269.81
Fallow	751.12	998.30	741.85	876.27	1115.36	986.92	911.64
Paddy alone	132.44	590.49	551.04	848.60	1013.09	1039.95	695.94
Mean	557.76	956.79	881.17	1016.60	1365.22	1268.52	
CD (0.05)			Months	305.31			
			Locations/Land use	278.71			
			interaction	682.71			

Table 16c. Spatial and temporal variations of available magnesium (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	54.81	58.75	51.50	70.50	77.12	75.24	64.65
	Shrimp alone	202.31	166.50	235.25	222.50	285.50	247.50	226.59
	Mangrove	152.00	127.75	159.25	132.75	232.75	231.75	172.71
	Fallow	149.31	132.50	204.50	211.00	200.00	208.20	184.25
Kottuvally	Paddy - Shrimp	175.50	125.50	115.00	159.20	198.00	197.12	161.72
	Shrimp alone	275.00	275.00	295.00	261.75	208.00	13.52	221.38
	Mangrove	112.00	137.00	134.75	119.25	229.00	255.00	164.50
	Fallow	121.38	175.00	131.25	145.25	201.30	203.10	162.88
Kadamakudy	Paddy - Shrimp	43.13	22.34	36.75	42.25	59.25	37.75	40.25
	Shrimp alone	195.31	158.00	134.50	184.00	199.75	239.75	185.22
	Mangrove	199.56	163.50	240.00	235.00	206.75	235.00	213.30
	Fallow	282.30	231.20	158.50	147.00	196.75	260.25	212.67
RRS, Vyttila	Paddy alone (a)	54.38	57.00	33.00	49.50	59.00	62.25	52.52
	Paddy alone (b)	43.38	62.00	59.50	31.00	43.25	51.75	48.48
	Paddy alone (c)	83.19	86.50	92.75	87.00	92.25	91.75	88.91
Mean		142.90	131.90	138.77	139.86	165.91	160.66	-
CD (0.05)				Months	NS			
				Locations/Land use	89.860			
				Interaction	NS			

Table 17a. Spatial and temporal variations of available sulphur (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2494.1	2427.0	1296.2	1914.7	2067.5	2177.2	2062.8
	Shrimp alone	1831.7	1602.1	1314.1	1283.2	1704.2	2235.6	1661.8
	Mangrove	1750.8	2323.1	1384.1	1714.1	1867.1	2305.2	1890.8
	Fallow	2866.3	2387.1	1880.1	2221.5	2425.2	2328.6	2351.5
Kottuvally	Paddy - Shrimp	3362.5	2651.8	2666.5	2285.6	2796.4	3680.8	2907.3
	Shrimp alone	1050.9	1135.9	1487.3	1031.5	2011.7	2026.9	1457.4
	Mangrove	4506.8	4205.6	2325.6	3183.9	3019.7	3945.2	3531.1
	Fallow	4024.4	2057.8	2554.2	3160.2	2946.1	3193.1	2989.3
Kadamakudy	Paddy - Shrimp	2511.0	2656.1	2060.8	3351.2	4886.9	5102.6	3428.1
	Shrimp alone	2259.9	2452.1	1329.6	2305.2	2687.0	2536.3	2261.7
	Mangrove	2891.5	2568.0	2495.6	2585.3	3539.6	3899.8	2996.7
	Fallow	2858.5	1705.3	1251.3	1104.2	2247.9	2360.8	1921.4
RRS, Vyttila	Paddy alone (a)	2601.0	2108.5	1312.5	1460.6	2008.4	3049.7	2090.1
	Paddy alone(b)	776.0	718.2	1000.0	705.6	1444.5	1778.0	1070.4
	Paddy alone (c)	1103.7	1030.3	1309.8	1135.2	1552.6	1750.6	1313.7
Mean		2459.3	2135.3	1711.1	1962.8	2480.3	2824.7	-
CD (0.05)		Months			140.244			
		Locations/Land use			221.746			
		Interaction			545.164			

Table 17b. Temporal variation of available sulphur (mg kg^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	2789.25	2578.34	2007.81	2517.16	3250.27	3653.53	2799.39
Shrimp alone	1714.20	1730.09	1377.00	1539.99	2134.30	2266.32	1793.65
Mangrove	3049.74	3032.24	2068.45	2494.43	2808.79	3383.43	2806.18
Fallow	3249.81	2050.12	1895.19	2161.97	2539.69	2627.53	2420.72
Paddy alone	1493.61	1285.71	1207.42	1100.48	1668.49	2192.82	1491.42
Mean	2459.32	2135.30	1711.18	1962.81	2480.31	2824.73	
CD (0.05)	Months			721.203			
	Locations/Land use			658.365			
	interaction			1612.65			

Table 17c. Spatial and temporal variations of available sulphur (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	392.00	290.50	278.64	272.15	374.25	439.25	341.13
	Shrimp alone	406.00	381.00	389.21	388.12	358.75	443.50	394.43
	Mangrove	352.50	321.50	329.65	431.25	419.25	503.00	392.86
	Fallow	356.75	407.50	395.41	383.12	425.25	417.50	397.59
Kottuvally	Paddy - Shrimp	224.00	212.75	252.41	355.51	316.00	325.50	281.03
	Shrimp alone	333.00	254.50	370.12	381.24	434.50	460.32	372.28
	Mangrove	245.75	255.75	355.23	458.80	504.75	594.00	402.38
	Fallow	258.00	281.25	362.53	371.51	260.50	435.75	328.26
Kadamakudy	Paddy - Shrimp	291.75	209.50	280.52	285.64	298.50	388.50	292.40
	Shrimp alone	266.25	208.50	262.54	369.65	358.25	447.50	318.78
	Mangrove	340.75	337.50	378.45	479.52	483.75	554.25	429.04
	Fallow	263.75	351.25	378.52	374.52	583.50	551.50	417.17
RRS, Vyttila	Paddy alone (a)	172.75	173.75	265.12	274.13	514.00	604.00	333.96
	Paddy alone (b)	252.75	266.50	366.45	370.15	441.25	514.50	368.60
	Paddy alone (c)	337.75	281.00	269.12	372.15	482.50	470.50	368.84
Mean		299.58	282.18	328.93	371.16	417.00	476.64	-
CD (0.05)		Months			25.433			
		Locations/Land use			40.213			
		Interaction			98.501			

4.1.2.10. Available Iron (av.Fe)

Available Fe was found to be very high in lowland soils ranging from 1135.62 (October) to 2248.38 mg kg^{-1} (April) throughout the season (table 18a). A decreasing trend of mean values of available Fe from June (1741.09 mg kg^{-1}) to October (1135.62 mg kg^{-1}) and an increasing trend from December (1810.43 mg kg^{-1}) to April (2248.38 mg kg^{-1}) were clearly noticed. Fallow land in Kottuvally (736.24 mg kg^{-1}) and paddy-shrimp in Kadamakudy (2906.43 mg kg^{-1}) recorded the lowest and highest mean values of available Fe respectively among the land uses. Table 18b revealed that available iron was recorded lowest in fallow land use (1182.20 mg kg^{-1}) and highest in mangrove land use (2364.55 mg kg^{-1}).

Upland soils were also reported with high Fe status (table 18c). An increasing trend in mean values of available Fe content from June (310.09 mg kg^{-1}) to April (393.20 mg kg^{-1}) was observed. Among land uses, paddy alone land use (c) in RRS-Vyttila (820.71 mg kg^{-1}) showed the highest mean value of available Fe compared to other land uses.

4.1.2.11. Available Manganese (av.Mn)

The data on available manganese in lowland soil showed high status and it varied significantly throughout the season (table 19a). The mean values of available Mn varied from 9.18 mg kg^{-1} (June) to 16.11 mg kg^{-1} (April). Among land uses, paddy-shrimp land use in Kadamakudy (15.43 mg kg^{-1}) and paddy alone land use (b) in RRS-Vyttila (5.87 mg kg^{-1}) recorded the highest and lowest mean value of available manganese respectively. Table 19b revealed that available manganese ranged from 7.81 (paddy alone) to 12.91 mg kg^{-1} (mangrove).

Upland soils were also reported with high manganese content (table 19c). Mean values of available Mn was higher during high saline phase (4.30 to 6.56 mg kg^{-1}) than low saline phase (3.53 to 3.66 mg kg^{-1}). Among land uses, the highest mean value of available manganese was reported in shrimp alone in Kadamakudy (16.16 mg kg^{-1}).

4.1.2.12. Available Zinc (av.Zn)

Available Zn content in lowland soils was very high and the mean values followed an increasing trend from low saline phase (June to October) to high saline phase (December to April) (table 20a). Higher values of available Zn were reported in April (summer)which ranged from 7.58 to 413.45 mgkg^{-1} and the lower values reported in October ranged from 2.21 to 122.97 mg kg^{-1}.Among land uses, paddy-shrimp land use (178.42 mg kg^{-1}) in Kadamakudy and paddy alone land use (b) (3.62 mg kg^{-1}) in RRS, Vyttila recorded the highest and lowest mean values of available Zn respectively. Table 20b revealed that available manganese ranged from 12.62 (paddy alone) to 123.24 mgkg^{-1} (mangrove).

Upland soils showed an increasing trend in available Zn content throughout the season ranging from 6.38 mg kg^{-1}(June) to 10.70 mg kg^{-1} (April) (table 20c). Available Zn among land uses was found to be significantly different. The lowest mean value (2.11 mg kg^{-1}) of available Zn was registered in paddy alone land use (a) in RRS, Vyttila (a) and the highest mean value was reported in mangrove in Kadamakudy (16.61 mg kg^{-1}).

Table 18a. Spatial and temporal variations of available iron (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1670.3	966.0	1144.9	1652.4	1867.0	1778.7	1513.2
	Shrimp alone	1650.7	1645.9	1224.4	1493.0	1645.9	1760.8	1570.1
	Mangrove	2358.2	1910.8	1690.5	2577.0	2317.1	2923.1	2296.1
	Fallow	1736.0	1027.5	774.5	1021.1	1405.0	1736.0	1283.3
Kottuvally	Paddy - Shrimp	998.3	1202.2	1157.6	1092.0	1173.2	2202.3	1304.3
	Shrimp alone	2235.7	1585.8	1107.2	1976.0	2349.5	2804.2	2009.7
	Mangrove	2219.1	2045.8	159 4.9	2758.0	2569.2	2854.1	2340.2
	Fallow	878.0	522.6	387.3	863.8	737.5	1028.0	736.2
Kadamakudy	Paddy - Shrimp	2623.2	2688.8	2367.0	3158.5	3234.0	3366.8	2906.4
	Shrimp alone	1915.5	1791.3	1103.4	2230.0	2003.3	2269.5	1885.5
	Mangrove	2796.6	2110.2	1259.0	2362.9	2784.0	3551.0	2477.3
	Fallow	1331.0	1252.2	1066.0	1716.0	1827.5	1969.1	1526.9
RRS, Vyttila	Paddy alone (a)	1298.9	1200.2	956.1	1452.9	1569.3	1855.0	1388.7
	Paddy alone (b)	1301.7	981.3	446.1	1304.0	1216.3	1995.7	1207.5
	Paddy alone (c)	1102.6	1122.1	755.0	1498.5	1536.0	1631.0	1274.2
Mean		1741.0	1470.2	1135.6	1810.4	1882.3	2248.3	-
CD (0.05)		Months			59.01			
		Locations/Land use			93.31			
		Interaction			228.56			

Table 18b. Temporal variation of available iron (mg kg^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	1678.59	1619.07	1641.93	2037.11	2066.26	2405.01	1907.99
Shrimp alone	1933.99	1674.36	1145.05	1899.67	1999.60	2278.21	1821.81
Mangrove	2458.03	2022.29	1474.77	2565.99	2556.80	3109.43	2364.55
Fallow	1315.02	934.14	742.61	1200.36	1323.35	1577.72	1182.20
Paddy alone	1234.44	1101.23	719.08	1418.49	1440.56	1827.26	1290.18
Mean	1724.01	1470.22	1144.69	1824.32	1877.32	2239.53	
CD (0.05)	Months			428.3			
	Locations/Land use			390.98			
	interaction			957.70			

Table 18c. Spatial and temporal variations of available iron (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	140.5	145.0	179.0	123.8	176.3	150.5	152.5
	Shrimp alone	283.3	267.0	302.9	351.5	406.8	418.8	338.4
	Mangrove	246.1	204.0	257.8	267.6	296.2	299.6	261.9
	Fallow	147.8	149.5	271.2	355.2	354.6	374.2	275.4
Kottuvally	Paddy - Shrimp	279.8	254.1	243.5	281.4	259.9	242.2	260.2
	Shrimp alone	157.3	127.4	143.5	169.1	150.2	167.4	152.5
	Mangrove	224.5	200.8	228.4	188.5	203.1	230.4	212.6
	Fallow	229.4	312.0	315.3	333.8	325.8	332.1	308.1
Kadamakudy	Paddy - Shrimp	291.4	163.8	396.5	324.8	371.4	398.7	324.4
	Shrimp alone	142.6	133.5	111.5	159.3	140.3	163.3	141.8
	Mangrove	146.9	186.5	123.5	195.4	258.5	260.3	195.2
	Fallow	162.5	124.5	138.8	174.6	291.1	248.4	190.0
RRS, Vyttila	Paddy alone (a)	754.9	745.2	775.0	827.5	860.3	881.3	807.4
	Paddy alone (b)	657.9	717.5	801.0	786.8	765.0	825.0	758.9
	Paddy alone (c)	786.3	785.0	741.5	809.5	896.0	906.0	820.7
Mean		310.0	301.0	335.2	356.5	383.7	393.2	-
CD (0.05)		Months			26.393			
		Locations/Land use			43.731			
		Interaction			NS			

Table 19a. Spatial and temporal variations of available manganese (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	5.53	5.70	3.97	4.90	7.31	10.85	6.38
	Shrimp alone	10.99	6.12	3.62	11.84	15.60	16.95	10.85
	Mangrove	12.06	10.21	6.34	5.91	19.67	17.50	11.95
	Fallow	6.83	5.33	2.44	8.85	10.87	9.06	7.23
Kottuvally	Paddy - Shrimp	5.81	5.54	3.68	10.20	11.59	14.78	8.60
	Shrimp alone	7.38	9.15	4.43	7.65	11.54	18.24	9.73
	Mangrove	12.89	12.44	6.96	12.03	16.25	18.63	13.20
	Fallow	4.65	3.03	3.64	10.36	11.85	14.12	7.94
Kadamakudy	Paddy - Shrimp	14.34	15.66	11.83	11.93	19.90	18.91	15.43
	Shrimp alone	13.41	7.89	3.63	7.38	13.97	22.97	11.54
	Mangrove	16.60	14.72	4.87	5.87	17.82	21.66	13.59
	Fallow	12.67	10.51	8.52	12.21	11.89	13.05	11.48
RRS, Vyttila	Paddy alone (a)	7.41	9.25	2.07	10.18	14.98	14.55	9.74
	Paddy alone (b)	3.35	3.95	1.73	4.47	9.14	12.59	5.87
	Paddy alone (c)	3.84	7.70	1.09	4.26	12.20	17.80	7.82
Mean		9.18	8.48	4.59	8.54	13.64	16.11	-
CD (0.05)		Months			0.701			
		Locations/Land use			1.109			
		Interaction			2.716			

Table 19b. Temporal variation of available manganese (mg kg^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	10.02	8.35	7.20	7.46	14.00	13.78	10.14
Shrimp alone	10.59	7.72	3.89	8.96	13.70	19.39	10.71
Mangrove	13.85	12.46	6.06	7.94	17.91	19.26	12.91
Fallow	8.05	6.29	4.87	10.47	11.54	12.08	8.88
Paddy alone	4.87	6.97	1.63	6.30	12.11	14.98	7.81
Mean	9.48	8.36	4.73	8.23	13.85	15.90	
CD (0.05)	Months			3.011			
	Locations/Land use			2.749			
	interaction			6.734			

Table 19c. Spatial and temporal variations of available manganese (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1.13	0.96	1.65	1.62	1.05	1.35	1.29
	Shrimp alone	2.35	2.99	3.07	3.61	3.78	3.39	3.20
	Mangrove	3.76	3.18	2.35	3.30	4.14	4.95	3.61
	Fallow	2.83	2.2	2.14	2.64	4.45	4.09	3.06
Kottuvally	Paddy - Shrimp	2.08	2.58	1.19	1.97	1.07	2.06	1.83
	Shrimp alone	1.90	2.82	1.96	2.20	4.95	3.07	2.82
	Mangrove	2.57	1.36	1.95	3.10	4.61	4.73	3.05
	Fallow	1.67	1.62	1.32	2.41	2.77	2.39	2.03
Kadamakudy	Paddy - Shrimp	4.24	3.22	2.79	4.21	3.23	6.11	3.97
	Shrimp alone	12.83	13.74	16.75	17.39	17.43	18.79	16.16
	Mangrove	2.43	2.31	1.51	3.20	9.25	13.04	5.29
	Fallow	9.25	7.82	10.71	10.8	12.88	11.67	10.52
RRS, Vyttila	Paddy alone (a)	1.49	1.88	2.17	3.70	2.54	7.34	3.19
	Paddy alone (b)	2.69	2.23	2.05	2.39	4.52	7.11	3.50
	Paddy alone (c)	2.58	3.98	3.29	2.01	2.81	8.33	3.83
Mean		3.59	3.53	3.66	4.30	5.30	6.56	-
CD (0.05)		Months			0.182			
		Locations/Land use			0.287			
		Interaction			0.704			

Table 20a. Spatial and temporal variations of available zinc (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	18.3	13.0	9.9	10.4	12.6	15.9	12.9
	Shrimp alone	11.2	11.9	5.7	4.6	9.1	16.2	8.5
	Mangrove	32.3	26.6	16.4	18.2	33.9	37.2	25.5
	Fallow	10.9	7.8	5.8	10.7	27.7	31.3	12.6
Kottuvally	Paddy - Shrimp	39.1	24.5	8.2	7.7	22.6	50.6	20.4
	Shrimp alone	35.8	24.7	17.0	55.2	86.7	55.2	43.9
	Mangrove	107.0	102.8	120.6	126.0	158.7	217.4	123.0
	Fallow	39.7	35.7	26.3	23.2	41.4	46.5	33.3
Kadamakudy	Paddy - Shrimp	215.0	128.7	123.0	196.7	228.7	275.1	178.4
	Shrimp alone	111.4	74.0	28.5	78.4	312.3	413.5	120.9
	Mangrove	181.8	143.8	104.5	126.8	287.6	376.8	168.9
	Fallow	93.1	68.1	17.2	88.1	133.4	160.8	80.0
RRS, Vyttila	Paddy alone (a)	24.1	24.4	16.9	28.8	33.2	34.4	25.5
	Paddy alone (b)	1.9	3.3	2.2	4.3	6.5	10.9	3.6
	Paddy alone (c)	5.8	3.4	4.1	4.9	10.7	7.6	5.8
Mean		61.8	46.1	33.7	52.2	93.6	116.6	-
CD (0.05)		Months			0.702			
		Locations/Land use			1.110			
		Interaction			2.718			

Table 20b. Temporal variation of available zinc (mg kg^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	90.82	55.41	47.03	71.61	87.98	113.85	77.78
Shrimp alone	52.80	36.87	17.04	46.05	135.99	161.60	75.06
Mangrove	107.06	91.08	80.46	90.34	160.04	210.42	123.24
Fallow	47.87	37.20	16.41	40.64	67.50	79.52	48.19
Paddy alone	10.57	10.36	7.76	12.66	16.78	17.61	12.62
Mean	61.82	46.18	33.74	52.26	93.66	116.60	
CD (0.05)	Months			86.36			
	Locations/Land use			78.83			
	interaction			193.11			

4.1.2.13. Available Copper (av. Cu)

The highest mean value of available Cu in lowland soils was registered in summer (4.78 mg kg^{-1} inApril followed by 4.44 mg kg^{-1} inFebruary) and the lowest mean value of available Cu was reported in October (1.93 mg kg^{-1}) (table 21a). Among land uses, paddy alone land use in RRS-Vyttila recorded the highest mean value of available copper (5.34 mg kg^{-1}). Table 21b revealed that available copper was recorded highest in paddy alone (3.86 mg kg^{-1}) and that of lowest was in fallow land (2.61 mg kg^{-1}).

Table 20c. Spatial and temporal variations of available zinc (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	3.15	5.36	3.14	4.26	3.90	5.85	4.28
	Shrimp alone	5.20	4.99	1.54	3.30	8.14	6.25	4.90
	Mangrove	3.39	9.96	12.7	10.15	15.61	16.69	11.42
	Fallow	5.75	5.17	4.11	5.29	6.88	6.04	5.54
Kottuvally	Paddy - Shrimp	11.33	14.85	15.18	16.31	18.93	18.26	15.81
	Shrimp alone	7.07	8.02	9.64	9.29	12.26	12.05	9.72
	Mangrove	7.13	7.17	8.72	9.16	14.12	12.24	9.76
	Fallow	5.16	4.75	2.75	3.26	6.03	5.85	4.63
Kadamakudy	Paddy - Shrimp	10.84	12.30	11.96	12.11	13.21	15.19	12.60
	Shrimp alone	8.28	7.81	14.33	13.17	14.02	18.17	12.63
	Mangrove	15.56	14.03	13.28	18.6	19.25	18.93	16.61
	Fallow	5.76	4.53	4.02	4.44	5.72	9.17	5.61
RRS, Vyttila	Paddy alone (a)	1.49	1.80	1.50	2.52	1.55	3.82	2.11
	Paddy alone (b)	2.41	2.83	1.97	2.28	3.81	6.32	3.27
	Paddy alone (c)	3.15	3.59	3.39	3.95	3.35	5.65	3.85
Mean		6.38	7.14	7.22	7.87	9.79	10.70	-
CD (0.05)		Months			0.711			
		Locations/Land use			1.124			
		Interaction			2.752			

Temporal variation of available Cu in upland was not found to be significant during low saline phase (June-October) (table 21c). The highest mean value of available copper (2.24 mg kg^{-1}) was observed in summer (February). The land uses did not show significant variation in available copper and the mean values ranged from 1.10 mgkg^{-1}(paddy-shrimp in Ezhikkara) to 2.57 mg kg^{-1}(mangrove in Kotuvally).

4.1.2.14. Available Boron (av.B)

Available B content in lowland soils reported in table 22a showed an increasing trend in mean values from low saline phase (June to October) to high saline phase (December to April). The mean values of available B ranged from 3.94 (June) to 9.12 mgkg^{-1} (April). Among land uses, fallow land in Ezhikkara and paddy alone in RRS-Vyttila recorded the highest (11.64 mg kg^{-1}) and lowest (2.71 mg kg^{-1}) mean value of available B. Table 22b revealed that available boron was recorded highest in paddy shrimp land use (7.81 mg kg^{-1}) and the lowest was in paddy alone land use (3.12 mgkg^{-1})

Available B was reported as deficient in upland soils throughout the seasons (table 22c). The content ranged from 0.268 (October) to 0.389 mg kg^{-1} (April). Spatial and temporal variation in available B was found to be non significant in upland soil.

Table 21a. Spatial and temporal variations of available copper (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2.27	2.42	1.82	1.27	3.89	3.80	2.58
	Shrimp alone	2.22	2.27	1.38	1.98	2.16	3.54	2.26
	Mangrove	1.15	3.44	2.71	4.22	5.50	4.59	3.60
	Fallow	1.05	0.97	2.02	0.77	3.84	4.28	2.15
Kottuvally	Paddy - Shrimp	3.42	3.05	1.99	2.47	4.60	6.17	3.62
	Shrimp alone	1.66	0.49	0.71	0.99	2.05	4.13	1.67
	Mangrove	0.82	3.83	3.08	2.56	6.31	4.32	3.49
	Fallow	2.56	2.13	1.60	1.66	3.09	3.63	2.44
Kadamakudy	Paddy - Shrimp	2.35	3.83	2.62	2.54	3.41	4.23	3.16
	Shrimp alone	5.04	6.10	2.30	1.97	4.14	6.00	4.26
	Mangrove	3.68	2.68	3.15	3.69	4.55	7.53	4.21
	Fallow	4.45	2.51	1.31	1.67	4.65	4.74	3.22
RRS, Vyttila	Paddy alone (a)	6.30	5.25	1.82	2.40	8.93	7.35	5.34
	Paddy alone (b)	2.71	3.08	1.33	1.41	2.84	2.13	2.25
	Paddy alone (c)	3.63	3.62	1.04	3.66	6.67	5.23	3.97
Mean		2.89	3.04	1.93	2.22	4.44	4.78	-
CD (0.05)		Months			0.684			
		Locations/Land use			1.081			
		Interaction			2.648			

Table 21b. Temporal variation of available copper (mg kg^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	3.60	3.62	2.14	2.09	3.45	3.24	3.02
Shrimp alone	2.97	2.95	1.46	1.65	2.78	4.56	2.73
Mangrove	1.88	3.32	3.45	3.61	4.99	5.36	3.77
Fallow	2.96	3.02	1.64	1.37	3.54	3.12	2.61
Paddy alone	4.21	3.98	2.46	1.42	6.15	4.90	3.86
Mean	3.13	3.38	2.23	2.03	4.18	4.24	
CD (0.05)	Months			1.38			
	Locations/Land use			1.26			
	interaction			3.08			

Table 21c. Spatial and temporal variations of available copper (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1.07	1.24	1.09	0.96	1.18	1.08	1.10
	Shrimp alone	1.20	1.40	1.11	1.34	2.44	2.83	1.72
	Mangrove	1.48	1.26	1.01	2.01	3.55	3.18	2.08
	Fallow	1.27	1.32	1.09	1.31	1.89	2.06	1.49
Kottuvally	Paddy - Shrimp	1.53	1.50	2.47	2.68	2.41	2.79	2.23
	Shrimp alone	1.45	1.53	1.36	1.83	1.53	1.58	1.55
	Mangrove	2.04	2.78	2.11	2.71	2.93	2.82	2.57
	Fallow	1.23	1.41	1.43	1.50	1.84	1.91	1.55
Kadamakudy	Paddy - Shrimp	1.87	1.56	2.53	2.68	3.28	3.13	2.51
	Shrimp alone	1.23	1.40	1.55	1.59	1.81	1.98	1.59
	Mangrove	1.93	1.88	1.59	1.84	1.87	1.96	1.85
	Fallow	1.64	1.45	1.15	1.65	1.98	1.72	1.60
RRS, Vyttila	Paddy alone (a)	1.56	1.34	1.32	1.60	2.36	1.63	1.64
	Paddy alone (b)	1.50	1.64	1.34	1.42	1.89	1.95	1.62
	Paddy alone (c)	1.99	1.61	2.02	2.32	2.61	2.72	2.21
Mean		1.53	1.55	1.54	1.83	2.24	2.22	-
CD (0.05)		Months			0.592			
		Locations/Land use			NS			
		Interaction			NS			

Table 22a. Spatial and temporal variations of available boron (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	4.97	6.13	8.26	8.61	12.87	11.51	8.73
	Shrimp alone	3.42	1.98	3.05	1.01	4.42	9.06	3.82
	Mangrove	9.52	10.07	11.09	13.77	11.13	12.53	11.35
	Fallow	9.88	7.05	8.74	6.34	18.48	19.32	11.64
Kottuvally	Paddy - Shrimp	4.23	6.85	5.30	9.11	16.17	9.34	8.50
	Shrimp alone	5.39	6.63	6.99	9.49	14.58	11.67	9.13
	Mangrove	1.72	1.79	2.78	4.69	7.23	9.67	4.65
	Fallow	2.50	4.46	4.33	3.08	8.66	12.49	5.92
Kadamakudy	Paddy - Shrimp	5.97	5.17	6.65	5.94	6.10	7.32	6.19
	Shrimp alone	2.19	3.19	3.16	4.99	4.20	6.60	4.06
	Mangrove	3.56	3.04	4.98	4.32	5.82	5.34	4.51
	Fallow	1.96	2.74	2.18	3.02	5.03	4.81	3.29
RRS, Vyttila	Paddy alone (a)	1.51	2.07	2.64	3.62	4.06	5.06	3.16
	Paddy alone (b)	1.27	1.32	1.50	2.48	4.32	5.34	2.71
	Paddy alone (c)	0.98	2.04	1.94	3.68	5.50	6.76	3.48
Mean		3.94	4.30	4.91	5.61	8.57	9.12	-
CD (0.05)		Months			0.618			
		Locations/Land use			0.977			
		Interaction			2.393			

Table 22b. Temporal variation of available boron (mg kg^{-1}) in different land uses

Land Use	Months						Mean
	Jun	Aug	Oct	Dec	Feb	Apr	
Paddy - Shrimp	6.68	6.05	6.38	6.62	11.71	9.39	7.81
Shrimp alone	3.67	3.93	5.01	4.55	8.53	8.31	5.67
Mangrove	4.93	4.97	6.28	7.59	8.06	9.18	6.84
Fallow	5.13	4.75	5.08	3.79	10.72	12.21	6.95
Paddy alone	1.25	1.81	2.03	3.26	4.63	5.72	3.12
Mean	4.33	4.30	4.96	5.16	8.73	8.96	
CD (0.05)	Months			2.99			
	Locations/Land use			2.73			
	interaction			6.70			

Table 22c. Spatial and temporal variations of available boron (mgkg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.469	0.304	0.280	0.232	0.320	0.440	0.341
	Shrimp alone	0.412	0.413	0.142	0.476	0.440	0.485	0.395
	Mangrove	0.228	0.229	0.158	0.104	0.220	0.300	0.207
	Fallow	0.398	0.232	0.184	0.296	0.280	0.452	0.307
Kottuvally	Paddy - Shrimp	0.410	0.300	0.496	0.412	0.428	0.440	0.414
	Shrimp alone	0.455	0.467	0.130	0.402	0.440	0.480	0.396
	Mangrove	0.308	0.172	0.374	0.454	0.422	0.424	0.359
	Fallow	0.187	0.196	0.260	0.148	0.200	0.240	0.205
Kadamakudy	Paddy - Shrimp	0.115	0.105	0.158	0.130	0.174	0.152	0.139
	Shrimp alone	0.221	0.112	0.138	0.212	0.230	0.263	0.196
	Mangrove	0.399	0.459	0.412	0.490	0.420	0.400	0.430
	Fallow	0.386	0.221	0.144	0.398	0.480	0.400	0.338
RRS, Vyttila	Paddy alone (a)	0.267	0.321	0.420	0.408	0.462	0.485	0.394
	Paddy alone (b)	0.214	0.241	0.300	0.318	0.396	0.420	0.315
	Paddy alone (c)	0.392	0.229	0.426	0.470	0.460	0.460	0.406
Mean		0.324	0.267	0.268	0.330	0.358	0.389	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

4.1.2.15. Heavy metals

4.1.2.15.1. Available Nickel (av.Ni)

The data on available nickel content (table 23a) in lowland soils showed a decreasing trend from June to October during low saline phase and an increasing trend from December to April during high saline phase. The highest mean value of available nickel was reported in April (1.245mg kg^{-1}) followed by that in February (1.199 mgkg^{-1}). The lowest mean value of available Ni was observed in October (0.812 mg kg^{-1}).

Among land uses, the highest mean value of available nickel was reported in mangrove in Kadamakudy (2.382 mg kg^{-1}).

The available nickel in upland soils was reported in table 23b. The mean values of available nickel were not significantly different throughout the season. The highest nickel content was reported in mangrove in Kottuvally (0.587 mg kg^{-1}) and the lowest was recorded in paddy-shrimp in Ezhikkara (0.150 mg kg^{-1}).

4.1.2.15.2. Available Cadmium (av.Cd)

Available cadmium presented in the table 24a revealed that the highest mean value of available cadmium was observed during summer (1.80 mg kg^{-1} in February which was on par with the value 1.70 mgkg^{-1} reported in April). Among land uses, shrimp alone land use in Kadamakudy showed the highest mean value (7.109 mg kg^{-1}) of cadmium followed by mangrove in Kadamakudy (6.524 mg kg^{-1}). Available cadmium was reported as below the detectable limit in shrimp alone land use in Ezhikkara.

Available cadmium in upland soils was found to be non-significant throughout the seasons (table 24b). Paddy-shrimp and fallow land in Ezhikkara, shrimp alone and fallow land in Kottuvally, fallow land in Kadamakudy and paddy alone land uses (b and c) in RRS-Vyttila were reported with below detectable limit of available cadmium. All other land uses were observed with negligible amount of available cadmium in soil.

4.1.2.15.3. Available Chromium (av.Cr)

Temporal variation in available chromium in lowland soils was found to be non-significant (table 25a). The highest mean value of available chromium was reported in April (2.507 mgkg^{-1}). Among the land uses, available chromium ranged from 0.463 mg kg^{-1} (paddy alone land use, b in RRS-Vyttila) to 4.284 mg kg^{-1} (paddy-shrimp in Kadamakudy).

Available chromium of upland soils was found to vary significantly throughout the seasons and land uses (table 25b). The mean values ranged from 0.398 (April) to 0.493 mg kg^{-1} (June). The highest mean value (0.954 mg kg^{-1}) of available chromium was reported in paddy alone land use (a) in RRS-Vyttila and the lowest (0.257 mg kg^{-1}) was recorded in mangrove in Ezhikkara.

4.1.2.15.4. Available Lead (av.Pb)

Available lead in lowland and upland soils was quantified and the data indicated that that temporal variation in available lead was non-significant in both lowlands (table 26a) and uplands (table 26b). The mean values were got in the range of 0.093 (December) to 0.123 mg kg^{-1} (June and October) in lowlands and 0.098 (August) to 0.155 mg kg^{-1} (February) in uplands.

Among fifteen land uses of lowland soils, available lead was reported only in two land uses (Shrimp alone in Ezhikkara and mangrove in Kottuvally) for which the mean values ranged from 0.561 to 0.919 mg kg^{-1}.Whereas only three land uses (shrimp alone in Kottuvally and Kadamakudy and mangrove in Kottuvally) in uplands were detected with the available lead content which showed a range from 0.160 to 0.227 mg kg^{-1}. All other land uses were observed with below detectable limit of available lead content in soil.

4.1.2.15.5. Available Cobalt (av. Co)

Mean value of available cobalt in lowlands varied from 0.702 (August) to 0.786 mg kg^{-1} (April) across the seasons (table 27a). Among land uses, the highest and lowest mean value was recorded as 1.698 mg kg^{-1} and 0.109 mg kg^{-1} in shrimp alone land use in Kadamakudy and paddy alone land use (b) in RRS, Vyttila respectively.

A significant increment in available cobalt was evident from low saline phase (June to october) to high saline phase (December to April) in upland soils and the mean values ranged from 0.198 (June) to 0.279 mg kg^{-1} (April) (table 27b). Among land uses, paddy-shrimp land use in Kottuvally (0.580 mg kg^{-1}) registered the highest mean value of available cobalt and paddy-shrimp in Ezhikkara recorded the lowest mean value (0.038 mg kg^{-1}).

Table 23a. Spatial and temporal variations of available nickel (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.347	0.243	0.121	0.582	0.642	0.630	0.428
	Shrimp alone	0.521	0.486	0.454	0.549	0.534	0.612	0.526
	Mangrove	1.542	1.524	1.321	1.682	2.030	1.924	1.670
	Fallow	1.425	1.213	1.08	1.320	1.493	1.621	1.359
Kottuvally	Paddy - Shrimp	0.421	0.352	0.295	0.375	0.602	0.625	0.445
	Shrimp alone	0.385	0.251	0.123	0.295	0.412	0.513	0.330
	Mangrove	2.056	1.956	1.821	2.312	2.450	2.498	2.182
	Fallow	0.195	0.182	0.168	0.197	0.214	0.265	0.204
Kadamakudy	Paddy - Shrimp	1.954	1.890	1.842	1.743	1.963	2.135	1.921
	Shrimp alone	0.853	0.792	0.612	0.954	1.180	1.025	0.925
	Mangrove	2.361	2.221	2.132	2.346	2.718	2.514	2.382
	Fallow	0.456	0.432	0.415	0.482	0.489	0.611	0.479
RRS, Vyttila	Paddy alone (a)	1.689	1.512	1.498	1.860	2.013	2.391	1.827
	Paddy alone (b)	0.265	0.215	0.198	0.270	0.310	0.321	0.263
	Paddy alone (c)	0.861	0.842	0.102	0.877	0.943	0.998	0.770
Mean		1.022	0.940	0.812	1.056	1.199	1.245	-
CD (0.05)		Months			0.087			
		Locations/Land use			0.137			
		Interaction			NS			

Table 23b. Spatial and temporal variations of available nickel (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.130	0.124	0.162	0.152	0.163	0.17	0.150
	Shrimp alone	0.440	0.442	0.621	0.632	0.423	0.52	0.513
	Mangrove	0.370	0.342	0.362	0.315	0.385	0.36	0.356
	Fallow	0.080	0.185	0.162	0.143	0.251	0.29	0.185
Kottuvally	Paddy - Shrimp	0.240	0.261	0.253	0.274	0.185	0.135	0.225
	Shrimp alone	0.230	0.421	0.236	0.341	0.284	0.46	0.329
	Mangrove	0.600	0.652	0.641	0.598	0.531	0.5	0.587
	Fallow	0.280	0.256	0.216	0.234	0.198	0.16	0.224
Kadamakudy	Paddy - Shrimp	0.520	0.541	0.532	0.215	0.394	0.25	0.409
	Shrimp alone	0.470	0.462	0.631	0.513	0.526	0.5	0.517
	Mangrove	0.350	0.326	0.241	0.374	0.395	0.341	0.338
	Fallow	0.240	0.246	0.215	0.263	0.274	0.25	0.248
RRS, Vyttila	Paddy alone (a)	0.295	0.209	0.219	0.285	0.312	0.36	0.280
	Paddy alone (b)	0.270	0.254	0.261	0.284	0.296	0.27	0.273
	Paddy alone (c)	0.340	0.324	0.316	0.358	0.394	0.34	0.345
Mean		0.324	0.336	0.338	0.332	0.334	0.327	-
CD (0.05)		Months			NS			
		Locations/Land use			0.114			
		Interaction			NS			

Table 24a. Spatial and temporal variations of available cadmium (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.050	0.020	0.010	0.086	0.070	BDL	0.039
	Shrimp alone	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	Mangrove	0.254	0.210	0.090	0.240	0.310	0.280	0.231
	Fallow	0.044	0.020	0.010	0.050	0.060	0.080	0.044
Kottuvally	Paddy - Shrimp	0.328	0.290	0.240	0.310	0.370	0.360	0.316
	Shrimp alone	0.240	0.220	0.213	0.270	0.290	0.280	0.252
	Mangrove	4.410	4.260	4.350	4.439	4.720	4.850	4.505
	Fallow	0.035	0.020	0.010	0.060	0.070	0.080	0.046
Kadamakudy	Paddy - Shrimp	4.340	4.250	4.160	4.810	4.842	4.860	4.544
	Shrimp alone	7.140	6.920	6.840	7.160	7.350	7.243	7.109
	Mangrove	6.340	6.370	6.120	6.540	6.940	6.835	6.524
	Fallow	1.550	1.620	1.340	1.620	1.710	1.840	1.613
RRS, Vyttila	Paddy alone (a)	0.190	0.160	0.140	0.140	0.294	0.240	0.194
	Paddy alone (b)	BDL	0.010	BDL	0.030	BDL	BDL	0.007
	Paddy alone (c)	0.060	0.025	0.010	BDL	0.040	BDL	0.023
Mean		1.66	1.62	1.56	1.71	1.80	1.79	-
CD (0.05)		Months			0.030			
		Locations/Land use			0.048			
		Interaction			0.118			

Table 24b. Spatial and temporal variations of available cadmium (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	Shrimp alone	0.010	BDL	0.010	BDL	0.010	BDL	0.005
	Mangrove	0.040	0.010	0.010	0.030	0.020	0.040	0.025
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Kottuvally	Paddy - Shrimp	0.040	0.020	0.010	0.030	0.040	0.080	0.037
	Shrimp alone	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	Mangrove	0.050	0.020	0.040	0.010	0.030	0.040	0.032
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Kadamakudy	Paddy - Shrimp	0.060	0.050	0.040	0.020	0.040	0.020	0.038
	Shrimp alone	0.140	0.180	0.160	0.170	0.130	0.180	0.160
	Mangrove	0.160	0.140	0.130	0.180	0.150	0.180	0.157
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	BDL
RRS, Vyttila	Paddy alone (a)	0.060	0.030	0.010	BDL	0.020	BDL	0.020
	Paddy alone (b)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	Paddy alone (c)	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Mean		0.037	0.030	0.027	0.029	0.029	0.036	-
CD (0.05)		Months			NS			
		Locations/Land use			0.025			
		Interaction			NS			

Table 25a. Spatial and temporal variations of available chromium (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2.903	3.120	3.510	4.620	4.060	3.864	3.679
	Shrimp alone	1.720	1.860	2.640	3.950	4.320	5.046	3.256
	Mangrove	2.502	2.221	2.560	2.410	2.840	2.973	2.584
	Fallow	1.844	1.740	1.620	1.950	2.510	2.794	2.076
Kottuvally	Paddy - Shrimp	0.958	0.985	1.140	1.350	0.999	1.269	1.117
	Shrimp alone	0.571	0.610	0.420	0.590	0.540	0.612	0.557
	Mangrove	3.409	3.120	3.510	3.640	3.740	3.697	3.519
	Fallow	0.808	0.951	0.974	0.892	1.354	1.414	1.065
Kadamakudy	Paddy - Shrimp	4.255	4.360	4.340	4.220	4.250	4.276	4.284
	Shrimp alone	2.442	2.510	2.740	1.950	1.450	1.829	2.153
	Mangrove	2.960	2.620	3.050	2.980	3.980	4.121	3.285
	Fallow	1.330	1.326	1.520	1.420	1.840	1.302	1.456
RRS, Vyttila	Paddy alone (a)	1.487	1.250	1.630	1.840	1.670	1.973	1.642
	Paddy alone (b)	0.589	0.523	0.514	0.412	0.395	0.347	0.463
	Paddy alone (c)	1.065	1.520	1.340	1.840	2.160	2.087	1.669
Mean		1.923	1.914	2.101	2.271	2.407	2.507	-
CD (0.05)		Months			NS			
		Locations/Land use			1.041			
		Interaction			NS			

Table 25b. Spatial and temporal variations of available chromium (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.290	0.250	0.310	0.320	0.310	0.340	0.303
	Shrimp alone	0.240	0.210	0.260	0.280	0.340	0.370	0.283
	Mangrove	0.270	0.210	0.260	0.280	0.240	0.280	0.257
	Fallow	0.350	0.320	0.310	0.360	0.370	0.310	0.337
Kottuvally	Paddy - Shrimp	0.820	0.850	0.860	0.840	0.820	0.860	0.842
	Shrimp alone	0.270	0.240	0.260	0.280	0.240	0.270	0.260
	Mangrove	0.400	0.412	0.380	0.290	0.254	0.220	0.326
	Fallow	0.480	0.450	0.412	0.463	0.385	0.340	0.422
Kadamakudy	Paddy - Shrimp	0.580	0.520	0.560	0.650	0.610	0.650	0.595
	Shrimp alone	0.340	0.360	0.314	0.280	0.250	0.210	0.292
	Mangrove	0.331	0.310	0.350	0.280	0.360	0.380	0.335
	Fallow	0.420	0.410	0.360	0.390	0.290	0.210	0.347
RRS, Vyttila	Paddy alone (a)	1.220	1.130	0.904	0.950	0.840	0.680	0.954
	Paddy alone (b)	0.590	0.610	0.630	0.410	0.340	0.340	0.487
	Paddy alone (c)	0.790	0.690	0.510	0.420	0.460	0.510	0.563
Mean		0.493	0.465	0.445	0.433	0.407	0.398	-
CD (0.05)		Months			0.036			
		Locations/Land use			0.057			
		Interaction			0.141			

Table 26a. Spatial and temporal variations of available lead (mg kg^{-1}) in lowlands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	BDL	BDL	BDL	BDL	BDL	BDL	-
	Shrimp alone	0.477	0.420	0.640	0.510	0.630	0.686	0.561
	Mangrove	BDL	BDL	BDL	BDL	BDL	BDL	-
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	-
Kottuvally	Paddy - Shrimp	BDL	BDL	BDL	BDL	BDL	BDL	-
	Shrimp alone	BDL	BDL	BDL	BDL	BDL	BDL	-
	Mangrove	0.924	0.913	0.954	0.850	0.910	0.965	0.919
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	-
Kadamakudy	Paddy - Shrimp	BDL	BDL	BDL	BDL	BDL	BDL	-
	Shrimp alone	BDL	BDL	BDL	BDL	BDL	BDL	-
	Mangrove	BDL	BDL	BDL	BDL	BDL	BDL	-
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	-
RRS, Vyttila	Paddy alone (a)	BDL	BDL	BDL	BDL	BDL	BDL	-
	Paddy alone (b)	BDL	BDL	BDL	BDL	BDL	BDL	-
	Paddy alone (c)	BDL	BDL	BDL	BDL	BDL	BDL	-
Mean		0.700	0.666	0.797	0.680	0.770	0.825	-
CD (0.05)		Months		NS				
		Locations/Land use		0.144				
		Interaction		NS				

Table 26b. Spatial and temporal variations of available lead (mg kg^{-1}) in uplands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	BDL	BDL	BDL	BDL	BDL	BDL	-
	Shrimp alone	BDL	BDL	BDL	BDL	BDL	BDL	-
	Mangrove	BDL	BDL	BDL	BDL	BDL	BDL	-
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	-
Kottuvally	Paddy - Shrimp	BDL	BDL	BDL	BDL	BDL	BDL	-
	Shrimp alone	0.24	0.21	0.20	0.23	0.25	0.23	0.227
	Mangrove	0.16	0.14	0.13	0.17	0.18	0.18	0.160
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	-
Kadamakudy	Paddy - Shrimp	BDL	BDL	BDL	BDL	BDL	BDL	-
	Shrimp alone	1.68	1.12	1.54	1.63	1.89	1.12	1.497
	Mangrove	BDL	BDL	BDL	BDL	BDL	BDL	-
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	-
RRS, Vyttila	Paddy alone (a)	BDL	BDL	BDL	BDL	BDL	BDL	-
	Paddy alone (b)	BDL	BDL	BDL	BDL	BDL	BDL	-
	Paddy alone (c)	BDL	BDL	BDL	BDL	BDL	BDL	-
Mean		0.139	0.098	0.125	0.135	0.155	0.102	-
CD (0.05)		Months		NS				
		Locations/Land use		0.209				
		Interaction		NS				

Table 27a. Spatial and temporal variations of available cobalt (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.518	0.551	0.530	0.570	0.590	0.540	0.550
	Shrimp alone	0.463	0.510	0.620	0.490	0.540	0.640	0.544
	Mangrove	1.396	1.320	1.250	1.450	1.440	1.620	1.413
	Fallow	0.505	0.560	0.620	0.710	0.930	0.910	0.706
Kottuvally	Paddy - Shrimp	0.356	0.320	0.340	0.350	0.280	0.390	0.339
	Shrimp alone	0.159	0.150	0.130	0.170	0.124	0.240	0.162
	Mangrove	0.700	0.650	0.610	0.520	0.680	0.710	0.645
	Fallow	0.176	0.140	0.130	0.080	0.070	0.064	0.110
Kadamakudy	Paddy - Shrimp	1.594	1.520	1.630	1.450	1.610	1.666	1.578
	Shrimp alone	1.728	1.710	1.690	1.640	1.720	1.700	1.698
	Mangrove	1.426	1.250	1.340	1.180	1.190	1.142	1.255
	Fallow	0.555	0.550	0.370	0.430	0.390	0.492	0.464
RRS, Vyttila	Paddy alone (a)	0.661	0.750	0.710	0.920	0.830	0.996	0.811
	Paddy alone (b)	0.093	0.120	0.080	0.150	0.080	0.129	0.109
	Paddy alone (c)	0.407	0.430	0.520	0.620	0.410	0.550	0.490
Mean		0.716	0.702	0.705	0.715	0.725	0.786	-
CD (0.05)		Months			0.001			
		Locations/Land use			0.002			
		Interaction			NS			

Table 27b. Spatial and temporal variations of available cobalt (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.030	0.010	0.060	0.040	0.020	0.070	0.038
	Shrimp alone	0.300	0.350	0.410	0.520	0.570	0.550	0.450
	Mangrove	0.120	0.150	0.170	0.260	0.210	0.250	0.193
	Fallow	0.040	0.060	0.140	0.180	0.150	0.190	0.127
Kottuvally	Paddy - Shrimp	0.590	0.540	0.520	0.620	0.580	0.630	0.580
	Shrimp alone	0.120	0.160	0.140	0.250	0.290	0.330	0.215
	Mangrove	0.250	0.210	0.320	0.360	0.320	0.360	0.303
	Fallow	0.070	0.040	0.030	0.070	0.040	0.060	0.052
Kadamakudy	Paddy - Shrimp	0.140	0.120	0.140	0.120	0.150	0.180	0.142
	Shrimp alone	0.320	0.350	0.340	0.360	0.390	0.370	0.355
	Mangrove	0.330	0.320	0.340	0.310	0.330	0.380	0.335
	Fallow	0.090	0.080	0.190	0.240	0.220	0.250	0.178
RRS, Vyttila	Paddy alone (a)	0.410	0.460	0.420	0.510	0.560	0.530	0.482
	Paddy alone (b)	0.080	0.090	0.130	0.140	0.170	0.120	0.122
	Paddy alone (c)	0.080	0.090	0.140	0.160	0.180	0.150	0.133
Mean		0.200	0.198	0.202	0.233	0.276	0.279	-
CD (0.05)		Months			0.001			
		Locations/Land use			0.001			
		Interaction			0.003			

4.1.2.15.6. Available Arsenic (av. As)

Mean value of available arsenic in lowland soil ranged from 0.106 (October) to 0.194 mg kg^{-1} (April) (table 28a) throughout the season. Among land uses, fallow land (0.290 mg kg^{1}) in Ezhikkara recorded the highest arsenic content. Available arsenic in upland soils also exhibited an increasing trend with the advancement of season (table 28b). The mean values ranged from 0.043 (June) to 0.073 mg kg^{-1} (April). Among land uses, the highest mean value was registered by paddy alone land use, b (0.077 mg kg^{-1}) in RRS-Vyttila.

4.1.2.15.7. Available Mercury (av.Hg)

The mean values of available Hg (0.004) remained unchanged during low saline phase where as an increase in mean values could be observed in February (0.006 mg kg^{-1}) followed by April (0.007 mg kg^{-1}) (table 29a). Paddy alone land uses (a and b) in RRS-Vyttila and fallow land in Ezhikkara recorded lowest (0.001 mg kg^{-1}) and highest (0.017 mg kg^{-1}) mean values of available mercury respectively. Available Hg was absent in fallow land in Kottuvally. The highest mean value of available Hg (0.013 mg kg^{-1}) in upland soils was reported in summer (April) (table 29b). Among the land uses, the highest value (0.024 mg kg^{-1}) of available Hg was noticed in paddy alone land use (b) in RRS-Vyttila.

Table 28a. Spatial and temporal variations of available arsenic (mg kg^{-1}) in lowlands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.050	0.040	0.020	0.060	0.040	0.092	0.050
	Shrimp alone	0.090	0.145	0.020	0.060	0.090	0.164	0.095
	Mangrove	0.210	0.250	0.270	0.280	0.250	0.291	0.259
	Fallow	0.290	0.240	0.110	0.280	0.320	0.300	0.290
Kottuvally	Paddy - Shrimp	0.160	0.140	0.120	0.170	0.180	0.172	0.157
	Shrimp alone	0.040	0.030	0.020	0.050	0.060	0.082	0.047
	Mangrove	0.040	0.030	0.010	0.060	0.090	0.082	0.052
	Fallow	0.040	0.020	0.010	0.040	0.060	0.050	0.038
Kadamakudy	Paddy - Shrimp	0.140	0.090	0.070	0.180	0.210	0.219	0.151
	Shrimp alone	0.210	0.150	0.130	0.190	0.217	0.202	0.183
	Mangrove	0.213	0.180	0.130	0.221	0.240	0.240	0.204
	Fallow	0.200	0.140	0.120	0.204	0.210	0.240	0.186
RRS, Vyttila	Paddy alone (a)	0.133	0.120	0.122	0.140	0.160	0.150	0.137
	Paddy alone (b)	0.240	0.224	0.214	0.321	0.320	0.330	0.275
	Paddy alone (c)	0.260	0.250	0.228	0.280	0.360	0.310	0.281
Mean		0.154	0.136	0.106	0.169	0.187	0.194	-
CD (0.05)		Months			0.014			
		Locations/Land use			0.022			
		Interaction			0.054			

Table 28b. Spatial and temporal variations of available arsenic (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.020	0.023	0.010	BDL	BDL	0.018	0.012
	Shrimp alone	0.040	0.030	0.080	0.050	0.060	0.082	0.057
	Mangrove	0.050	0.060	0.040	0.070	0.080	0.072	0.062
	Fallow	0.010	0.030	0.070	0.050	0.020	0.025	0.034
Kottuvally	Paddy - Shrimp	0.080	0.050	0.040	0.030	0.070	0.090	0.060
	Shrimp alone	0.050	0.060	0.030	0.040	0.070	0.056	0.051
	Mangrove	BDL	BDL	0.020	0.010	0.010	0.009	0.008
	Fallow	0.030	0.040	0.010	0.050	0.020	0.013	0.027
Kadamakudy	Paddy - Shrimp	0.010	0.020	0.040	0.030	0.010	0.041	0.025
	Shrimp alone	0.010	0.050	0.030	0.040	0.010	0.015	0.026
	Mangrove	0.050	0.060	0.070	0.040	0.040	0.068	0.055
	Fallow	0.010	0.060	0.040	0.020	0.050	0.052	0.039
RRS, Vyttila	Paddy alone (a)	0.090	0.070	0.140	0.160	0.150	0.178	0.131
	Paddy alone (b)	0.064	0.050	0.021	0.084	0.150	0.094	0.077
	Paddy alone (c)	0.124	0.220	0.254	0.241	0.314	0.284	0.240
Mean		0.043	0.055	0.060	0.061	0.070	0.073	
CD (0.05)		Months			0.007			
		Locations/Land use			0.011			
		Interaction			0.026			

Table 29a. Spatial and temporal variations of available mercury (mg kg^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.010	0.011	0.021	0.020	0.024	0.029	0.019
	Shrimp alone	0.004	0.005	0.002	0.004	0.006	0.006	0.005
	Mangrove	0.001	0.001	0.002	0.001	0.002	0.002	0.002
	Fallow	0.015	0.017	0.016	0.017	0.018	0.018	0.017
Kottuvally	Paddy - Shrimp	0.008	0.007	0.006	0.005	0.009	0.009	0.007
	Shrimp alone	0.002	0.003	0.001	0.003	0.004	0.004	0.003
	Mangrove	0.001	0.002	0.001	0.001	0.003	0.004	0.002
	Fallow	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Kadamakudy	Paddy - Shrimp	0.005	0.004	0.003	0.002	0.006	0.007	0.004
	Shrimp alone	0.004	0.004	0.003	0.002	0.004	0.005	0.004
	Mangrove	0.001	0.001	0.002	0.002	0.001	0.002	0.002
	Fallow	0.003	0.003	0.004	0.004	0.003	0.004	0.004
RRS, Vyttila	Paddy alone (a)	0.001	0.001	BDL	0.002	0.002	0.001	0.001
	Paddy alone (b)	0.001	BDL	0.001	0.002	BDL	0.002	0.001
	Paddy alone (c)	0.002	0.001	BDL	0.002	0.001	0.003	0.002
Mean		0.004	0.004	0.004	0.004	0.006	0.007	-
CD (0.05)		Months			0.001			
		Locations/Land use			0.002			
		Interaction			NS			

Table 29b. Spatial and temporal variations of available mercury (mg kg^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.011	BDL	0.010	0.010	BDL	0.010	0.007
	Shrimp alone	0.009	0.005	0.007	0.008	0.008	0.009	0.008
	Mangrove	0.015	0.016	0.019	0.018	0.018	0.019	0.018
	Fallow	BDL	0.010	0.011	0.020	0.010	0.011	0.010
Kottuvally	Paddy - Shrimp	0.010	0.010	0.020	0.015	0.017	0.014	0.014
	Shrimp alone	0.010	0.010	0.010	0.011	0.010	0.012	0.011
	Mangrove	0.010	0.020	0.010	0.010	0.001	0.009	0.010
	Fallow	BDL	0.001	0.001	BDL	BDL	0.001	0.001
Kadamakudy	Paddy - Shrimp	0.014	0.016	0.016	0.015	0.010	0.016	0.014
	Shrimp alone	0.012	0.013	0.012	0.010	0.020	0.013	0.013
	Mangrove	0.011	0.012	0.011	0.010	0.010	0.012	0.011
	Fallow	0.020	0.012	0.011	0.010	0.010	0.011	0.012
RRS, Vyttila	Paddy alone (a)	0.020	0.010	0.020	0.019	0.017	0.019	0.018
	Paddy alone (b)	0.020	0.023	0.021	0.025	0.026	0.026	0.024
	Paddy alone (c)	0.004	0.005	0.005	0.006	0.006	0.006	0.005
Mean		0.011	0.011	0.012	0.012	0.011	0.013	-
CD (0.05)				Months	0.001			
				Locations/Land use	0.001			
				Interaction	0.003			

4.1.2.16. Exchangeable cations and cation exchange capacity

4.1.2.16.1. Exchangeable sodium

Exchangeable sodium in lowland soil (table 30a) was found to be significantly varying across the seasons and the mean values ranged from 372.93 (October) to 588.47 (April) mg kg^{-1}. Spatial variation of exchangeable sodium was also found to be significant. Fallow land in Kadamakudy (290.70 mg kg^{-1}) and shrimp alone in Kottuvally (618.94 mg kg^{-1}) showed the lowest and the highest mean values of exchangeable sodium respectively.

Upland soils showed a non-significant variation in exchangeable sodium across the seasons (table 30b). The mean values of exchangeable sodium varied from 174.66 (August) to 175.01 mg kg^{-1} (October and April). Among land uses, the highest and lowest values of exchangeable sodium was reported in mangrove in Kadamakudy, ranging from 365.1 to 367.40 mg kg^{-1} and fallow land in Kottuvally, ranging from 97.40 to 99.90 mg kg^{-1} respectively.

4.1.2.16.2. Exchangeable potassium

Mean values of exchangeable potassium in lowland soils (table 31a) was found to be decreasing significantly from June (62.35 mg kg^{-1}) to October (30.55 mg kg^{-1})

during low saline phase. Later, a significant increment was noticed from December (46.19 mg kg^{-1}) to April (89.68 mg kg^{-1}) during high saline phase. Among land uses, significant variation in exchangeable potassium was observed and the highest mean value was noticed in shrimp alone in Kottuvally (79 mg kg^{-1}) and the lowest was reported in mangrove in Kadamakudy (45.10 mg kg^{-1}).

Temporal variation in exchangeable potassium in upland soils was reported to be non-significant (table 31b). Exchangeable K in land uses were reported that it is significantly varying and the mean values ranged from 16.97 (paddy-shrimp in Kottuvally) to 73.46 mg kg^{-1} (mangrove in Kadamakudy).

4.1.2.16.3. Exchangeable calcium

A significant increase in exchangeable Ca from June to October (255.67 to 381.07 mg kg^{-1}) during low saline phase and a decrease from December to April (285.56 to 188.09 mg kg^{-1}) during high saline phase was noticed in lowland soils (table 32a). Spatial variation of exchangeable Ca was also found to be significant. Fallow land in Kottuvally (216.40 mg kg^{-1}) and fallow land in Kadamakudy (152.48 mg kg^{-1}) showed the highest and lowest mean values of exchangeable Ca respectively.Upland soils showed a non-significant variation in exchangeable Ca throughout the seasons (table 32b). The highest mean value was recorded in fallow land in Ezhikkara (185.18 mg kg^{-1}) and the lowest value was noticed in shrimp alone in Kadamakudy (71.19 mg kg^{-1}).

4.1.2.16.4. Exchangeable magnesium

Exchangeable magnesium in lowland soil (table 33a) was found to be significantly varying across the seasons and the mean values ranged from 163.94 (April) to 586.60 mg kg^{-1} (October). Spatial variation of exchangeable magnesium was also found to be significant. Shrimp alone in Ezhikkara (488.10 mg kg^{-1}) and shrimp alone in Kadamakudy (184.68 mg kg^{-1}) showed the highest and lowest mean values of exchangeable magnesium respectively.

Upland soils did not have any significant variation in exchangeable magnesium acrcoss the seasons (table 33b). Among land uses, the highest (96.71 mg kg^{-1}) and lowest mean values (16.23 mg kg^{-1}) of exchangeable magnesium was reported in shrimp alone in Kotuvally and paddy alone land use in RRS-Vyttila (a) respectively.

Table 30a. Spatial and temporal variation in exchangeable sodium (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	554.00	456.00	470.0	499.00	511.00	620	518.33
	Shrimp alone	595.00	548.20	456.0	478.00	522.10	660	543.22
	Mangrove	488.00	336.10	222.0	335.00	354.90	490	371.00
	Fallow	356.00	468.40	240.0	282.00	299.60	378	337.33
Kottuvally	Paddy - Shrimp	599.90	385.47	390.0	363.00	372.40	692	467.13
	Shrimp alone	696.40	522.89	520.0	599.00	626.50	748	618.94
	Mangrove	521.40	426.30	222.0	230.00	264.70	650	385.73
	Fallow	545.20	447.20	321.8	356.00	355.60	562	431.30
Kadamakudy	Paddy - Shrimp	645.00	621.00	500.2	534.00	554.70	660	585.83
	Shrimp alone	645.00	641.00	575.2	498.00	512.40	675	591.10
	Mangrove	546.00	421.00	375.2	374.00	395.60	501	435.47
	Fallow	389.00	312.00	100.6	262.31	285.30	395	290.70
RRS, Vyttila	Paddy alone (a)	585.30	494.00	475.8	498.56	520.10	650	537.33
	Paddy alone (b)	464.00	378.00	354.6	398.00	404.10	562	426.78
	Paddy alone (c)	564.00	494.00	370.5	401.00	465.30	583	479.63
Mean		546.28	463.44	372.93	407.19	429.62	588.47	-
CD (0.05)		Months			1.737			
		Locations/Land use			2.747			
		interaction			6.728			

Table 30b. Spatial and temporal variation in exchangeable sodium (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	161.20	160.30	162.50	160.75	162.30	160.4	161.24
	Shrimp alone	184.20	184.60	186.30	185.20	183.90	185.6	184.97
	Mangrove	170.30	171.20	171.54	170.62	171.80	172.9	171.39
	Fallow	184.50	184.80	185.30	185.70	184.90	184.3	184.92
Kottuvally	Paddy - Shrimp	305.60	306.75	308.40	307.10	308.60	309.1	307.59
	Shrimp alone	142.60	142.80	141.70	143.60	143.90	144.2	143.13
	Mangrove	139.60	138.50	138.20	138.50	137.84	138.0	138.44
	Fallow	99.70	99.10	99.50	98.30	97.40	99.90	98.98
Kadamakudy	Paddy - Shrimp	146.30	146.70	145.50	145.60	146.78	145.4	146.05
	Shrimp alone	132.50	132.68	130.50	131.40	130.70	131.4	131.53
	Mangrove	367.40	365.20	367.20	367.10	366.50	365.1	366.42
	Fallow	124.30	123.60	125.90	125.40	124.80	125.0	124.83
RRS, Vyttila	Paddy alone (a)	164.20	164.80	165.30	166.70	165.60	165.1	165.28
	Paddy alone (b)	132.50	132.40	131.89	131.50	133.50	132.8	132.43
	Paddy alone (c)	165.30	166.40	165.40	164.30	165.40	166.0	165.47
Mean		174.68	174.66	175.01	174.78	174.93	175.0	-
CD (0.05)		Months			NS			
		Locations/Land use			5.860			
		interaction			NS			

Table 31a. Spatial and temporal variation in exchangeable potassium (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	78.20	63.24	50.1	55.60	60.21	92.0	72.10
	Shrimp alone	64.20	55.13	41.3	54.60	55.24	86.0	60.30
	Mangrove	55.40	42.13	22.4	42.10	36.40	82.0	54.35
	Fallow	52.10	41.26	21.7	35.80	45.70	88.4	51.00
Kottuvally	Paddy - Shrimp	43.40	33.48	15.6	30.20	32.40	79.8	45.80
	Shrimp alone	78.40	62.82	34.6	55.40	66.70	92.0	79.00
	Mangrove	74.30	61.36	40.5	52.30	65.40	97.4	74.30
	Fallow	71.10	62.38	47.5	60.60	62.70	93.5	70.00
Kadamakudy	Paddy - Shrimp	63.40	53.68	37.6	53.20	53.20	94.2	61.00
	Shrimp alone	60.20	52.46	33.2	52.00	53.70	92.6	63.20
	Mangrove	40.80	33.22	14.3	26.50	39.40	82.5	45.10
	Fallow	60.40	46.56	18.6	51.20	41.60	95.6	61.00
RRS, Vyttila	Paddy alone (a)	61.00	49.54	22.8	46.30	52.60	94.4	65.00
	Paddy alone (b)	65.90	51.46	26.4	32.50	65.10	85.3	67.40
	Paddy alone (c)	66.50	51.00	31.7	44.60	50.60	89.5	61.60
Mean		62.35	62.35	30.55	46.19	52.06	89.68	-
CD (0.05)		Months			3.052			
		Locations/Land use			4.826			
		interaction			11.820			

Table 31b. Spatial and temporal variation in exchangeable potassium (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	55.00	55.46	54.20	56.20	54.90	56.7	55.41
	Shrimp alone	56.42	57.60	55.41	56.35	55.71	56.3	56.30
	Mangrove	51.56	50.46	50.85	52.80	51.40	51.6	51.45
	Fallow	67.60	67.30	67.41	66.20	66.98	67.2	67.12
Kottuvally	Paddy - Shrimp	16.50	16.30	17.50	17.89	16.52	17.1	16.97
	Shrimp alone	55.20	54.20	54.39	55.12	56.90	56.5	55.39
	Mangrove	41.30	41.60	43.70	44.20	42.80	42.2	42.63
	Fallow	64.30	64.50	64.80	65.20	66.40	64.1	64.88
Kadamakudy	Paddy - Shrimp	52.30	54.60	51.60	52.60	51.70	51.6	52.40
	Shrimp alone	52.40	51.30	51.89	52.90	53.60	52.6	52.45
	Mangrove	72.10	73.50	73.60	74.90	73.95	72.7	73.46
	Fallow	59.60	58.40	58.60	57.41	58.60	58.9	58.59
RRS, Vyttila	Paddy alone (a)	45.20	46.50	46.80	47.52	46.90	47.1	46.67
	Paddy alone (b)	72.20	72.85	71.45	73.60	73.10	73.5	72.78
	Paddy alone (c)	54.23	53.60	52.10	51.40	53.20	54.1	53.11
Mean		54.39	54.54	54.29	54.95	54.84	54.81	-
CD (0.05)		Months			NS			
		Locations/Land use			7.328			
		interaction			NS			

Table 32a. Spatial and temporal variation in exchangeable calcium (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	296.00	302.00	454.6	388.30	291.20	150.6	312.44
	Shrimp alone	279.00	255.40	492.3	371.40	275.30	175.0	210.36
	Mangrove	201.00	230.00	237.0	187.00	201.40	199.0	243.70
	Fallow	275.00	311.00	519.0	465.20	248.30	269.1	253.88
Kottuvally	Paddy - Shrimp	230.00	222.50	324.0	212.30	155.20	125.3	170.90
	Shrimp alone	284.00	244.10	452.0	280.40	196.20	185.6	218.08
	Mangrove	325.31	230.10	583.4	443.50	280.60	245.3	224.72
	Fallow	343.20	344.00	457.6	319.60	254.10	221.9	216.40
Kadamakudy	Paddy - Shrimp	285.70	296.30	204.0	171.00	163.40	118.0	206.88
	Shrimp alone	191.40	220.40	124.0	142.00	123.40	114.0	158.24
	Mangrove	256.32	278.60	283.0	137.00	150.40	134.0	191.26
	Fallow	120.40	220.40	231.0	122.00	174.60	125.0	152.48
RRS, Vyttila	Paddy alone (a)	241.30	258.70	365.0	189.00	202.70	196.0	217.54
	Paddy alone (b)	252.40	251.60	466.8	378.40	231.80	187.0	220.16
	Paddy alone (c)	254.00	389.60	522.4	476.30	486.20	375.6	285.10
Mean		255.67	270.31	381.07	285.56	228.99	188.09	-
CD (0.05)		Months			1.817			
		Locations/Land use			2.872			
		interaction			7.036			

Table 32b. Spatial and temporal variation in exchangeable calcium (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	94.30	95.20	96.70	95.20	96.50	96.0	95.65
	Shrimp alone	73.50	74.90	75.40	75.60	74.60	75.0	74.83
	Mangrove	106.20	106.90	107.50	107.60	105.30	107.5	106.83
	Fallow	184.30	185.60	183.70	186.90	185.60	185.0	185.18
Kottuvally	Paddy - Shrimp	101.30	101.50	101.60	102.50	103.40	101.4	101.95
	Shrimp alone	112.50	113.60	112.80	114.70	113.50	113.6	113.45
	Mangrove	125.60	122.40	123.60	124.80	122.45	122.4	123.54
	Fallow	98.60	98.20	99.40	100.20	100.56	100.5	99.58
Kadamakudy	Paddy - Shrimp	105.30	106.40	106.80	104.30	105.40	105.3	105.58
	Shrimp alone	71.40	70.60	70.58	70.46	72.61	71.5	71.19
	Mangrove	104.20	104.90	103.60	103.85	104.56	105.21	104.39
	Fallow	98.32	97.34	98.67	98.40	99.10	99.5	98.56
RRS, Vyttila	Paddy alone (a)	96.50	97.60	98.40	97.30	97.42	96.4	97.27
	Paddy alone (b)	77.60	77.85	75.62	76.41	76.31	77.5	76.88
	Paddy alone (c)	95.12	94.32	94.20	96.47	96.84	96.0	95.49
Mean		102.98	103.15	103.24	103.65	103.61	103.52	-
CD (0.05)		Months			NS			
		Locations/Land use			3.585			
		interaction			NS			

Table 33a. Spatial and temporal variation in exchangeable magnesium (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	388.50	399.00	506	410.50	216.30	201.20	426.00
	Shrimp alone	170.20	288.60	898	595.60	345.10	141.23	488.10
	Mangrove	285.30	290.00	597	397.40	242.30	224.00	392.43
	Fallow	170.30	182.00	791	591.70	331.60	128.50	433.75
Kottuvally	Paddy - Shrimp	192.50	215.00	526	326.70	168.20	160.30	315.05
	Shrimp alone	256.30	24.00	848	548.60	294.10	190.40	419.23
	Mangrove	230.50	225.00	850	550.20	340.60	131.40	463.93
	Fallow	198.60	178.20	604	401.60	225.30	123.10	345.60
Kadamakudy	Paddy - Shrimp	221.30	232.00	340	201.60	178.33	170.50	248.73
	Shrimp alone	160.20	222.10	228	128.40	106.67	101.40	184.68
	Mangrove	210.40	225.60	750	550.60	370.40	165.30	434.15
	Fallow	201.40	215.80	317	117.90	150.83	145.30	213.03
RRS, Vyttila	Paddy alone (a)	225.30	236.10	351	151.90	175.83	172.30	241.08
	Paddy alone (b)	199.60	278.30	687	251.30	160.25	154.20	354.05
	Paddy alone (c)	189.30	201.00	506	362.10	255.40	250.00	314.60
Mean		258.00	267.00	586.60	372.41	237.41	163.94	-
CD (0.05)				Months	2.326			
				Locations/Land use	3.677			
				interaction	9.007			

Table 33b. Spatial and temporal variation in exchangeable magnesium (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	44.25	42.50	43.15	43.62	44.14	44.5	43.69
	Shrimp alone	51.64	52.30	53.60	51.40	52.78	51.5	52.20
	Mangrove	63.52	63.51	62.54	62.90	63.54	62.0	63.00
	Fallow	56.42	58.40	53.40	54.62	55.20	54.50	55.42
Kottuvally	Paddy - Shrimp	95.42	94.32	92.36	90.13	92.56	93.0	92.97
	Shrimp alone	97.30	98.21	96.20	95.31	96.74	96.5	96.71
	Mangrove	85.62	81.25	80.24	81.34	80.56	80.5	81.59
	Fallow	24.32	25.61	25.84	25.94	24.61	25.5	25.30
Kadamakudy	Paddy - Shrimp	40.13	40.56	41.62	41.32	42.58	40.0	41.04
	Shrimp alone	30.14	31.64	31.42	32.85	33.14	33.0	32.03
	Mangrove	44.12	40.61	42.61	41.32	43.52	4.0	42.70
	Fallow	60.12	60.32	63.12	63.52	63.47	61.5	62.01
RRS, Vyttila	Paddy alone (a)	16.52	17.65	15.95	15.46	15.32	16.5	16.23
	Paddy alone (b)	45.32	47.62	46.31	48.62	48.64	48.0	47.42
	Paddy alone (c)	47.56	47.62	48.56	48.21	49.38	47.0	48.06
Mean		53.49	53.47	53.13	53.10	53.75	53.20	-
CD (0.05)				Months	NS			
				Locations/Land use	3.906			
				interaction	9.569			

4.1.2.16.5. Exchangeable aluminium

Mean values of exchangeable aluminium in lowland soils (table 34a) was found to be decreasing significantly from June (85.08 mg kg^{-1}) to October (58.26 mg kg^{-1}) during low saline phase. Later, a significant increase was noticed from December (66.43 mg kg^{-1}) to April (98.34 mg kg^{-1}) during high saline phase. Among land uses, significant variation in exchangeable aluminium was observed and the highest mean value was noticed in paddy-shrimp in Kadamakudy (116.98 mg kg^{-1}) and the lowest was reported in shrimp alone in Kadamakudy (28.30 mg kg^{-1}).

Temporal variation in exchangeable aluminium in upland soils was reported as non-significant (table 34b). Exchangeable aluminium in land uses were reported as significantly varying and the mean values ranged from 6.10 (shrimp alone in Kottuvally) to 81.83 mg kg^{-1} (fallow land in Ezhikkara).

4.1.2.16.6. Exchangeable iron

Exchangeable iron in lowland soil (table 35a) was found to be significantly varying across the seasons and the mean values ranged (October) to 289.20 mg kg^{-1} (April). Spatial variation of exchangeable iron was also found to be significant. Shrimp alone in Ezhikkara (242.23 mg kg^{-1}) and shrimp alone in Kottuvally (202.09 mg kg^{-1}) showed the highest and lowest mean values of exchangeable iron respectively.

Upland soils showed a non-significant variation in exchangeable iron across the seasons (table 35b). Among land uses, the highest and lowest values of exchangeable iron was reported in fallow land in Ezhikkara, where it ranged from 118.47 to 120.56 mg kg^{-1} and in land use under mangrove at Kadamakudy, the content ranged from 61.47 to 63.54 mg kg^{-1}respectively.

Temporal variation in exchangeable zinc in upland soils was reported to be significant (table 36b) and the mean values ranged from 3.92 (June) to 4.46 mg kg^{-1} (Fabruary). Exchangeable zinc in land uses were also reported as significantly varying and the mean values ranged from 1.94 (paddy-shrimp in Kottuvally) to 9.16 mg kg^{-1} (shrimp alone in Ezhikkara).

4.1.2.16.7. Exchangeable manganese

Exchangeable magnesium in lowland soil (table 38a) was found to be significantly varying across the seasons and the mean values ranges from 2.00 (August) to 4.07 mg kg^{-1} (April). Spatial variation of exchangeable manganese was also found to be significant. Paddy-shrimp in Kadamakudy (7.57 mg kg^{-1}) and shrimp alone in Kotuvally (0.96 mg kg^{-1}) showed the highest and lowest mean values of exchangeable manganese respectively.

Upland soils showed a non-significant variation in exchangeable manganese across the seasons (table 38b). Among land uses, the highest (4.63 mg kg^{-1}) and lowest values (1.06 mg kg^{-1}) of exchangeable manganese was reported in paddy shrimp and fallow land respectively in Kadamakudy.

4.1.2.16.8. Exchangeable zinc

Mean values of exchangeable zinc in lowland soils (table 36a) was found to be decreasing significantly from June (22.77 mg kg^{-1}) to October (16.44 mg kg^{-1}) during low saline phase. Later, a significant increase was noticed from December (20.32 mg kg^{-1}) to April (46.76 mg kg^{-1}) during high saline phase. Among land uses, significant variation in exchangeable zinc was observed and the highest mean value was noticed in paddy shrimp in Kadamakudy (102.67 mg kg^{-1}) and the lowest was reported in paddy alone (c) in RRS-Vyttila (3.36 mg kg^{-1}).

4.1.2.16.9. Exchangeable copper

A significant decrease in exchangeable copper from June to October (0.62to 0.34 mg kg^{-1}) during low saline phase and an increase from December to April (0.82 to 1.65 mg kg^{-1}) during high saline phase was noticed in lowland soils (table 37a). Spatial variation of exchangeable copper was also found to be significant. Fallow land in Kadamakudy (1.51 mg kg^{-1}) and paddy shrimp in Ezhikkara (0.58 mg kg^{-1}) showed the highest and lowest mean values of exchangeable copper respectively.

Upland soils showed a significant variation in exchangeable copper throughout the seasons with values ranging from 0.17 (June) to 0.22 mg kg^{-1} (December) (table 37b). The highest mean value was recorded in mangrove in Kadamakudy (0.44 mg kg^{-1}) and the lowest value was noticed in paddy-shrimp in Kottuvally (0.05 mg kg^{-1}).

Table 34a. Spatial and temporal variation in exchangeable aluminium (mg kg^{-1}) of lowlands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	88.50	85.50	84.28	89.60	91.30	99.6	89.80
	Shrimp alone	86.40	72.40	55.02	59.60	83.50	92.6	74.92
	Mangrove	100.40	84.20	50.86	69.70	99.60	120.4	87.53
	Fallow	72.10	62.30	29.82	36.40	76.50	85.6	60.45
Kottuvally	Paddy - Shrimp	50.40	46.20	30.64	44.20	50.20	62.3	47.32
	Shrimp alone	98.40	82.63	76.5	85.60	90.20	105.4	89.79
	Mangrove	92.64	82.40	71.54	89.30	99.60	128.5	94.00
	Fallow	112.40	108.20	98.72	101.20	120.50	145.3	114.39
Kadamakudy	Paddy - Shrimp	121.30	114.50	98.06	100.52	132.50	135	116.98
	Shrimp alone	32.60	30.52	20.3	21.30	30.60	34.5	28.30
	Mangrove	74.60	60.62	49.6	56.30	70.50	82.4	65.67
	Fallow	52.10	42.20	13.4	20.40	42.10	56.4	37.77
RRS, Vyttila	Paddy alone (a)	101.30	99.90	93.6	101.40	111.30	122	104.92
	Paddy alone(b)	111.60	91.50	58	70.60	90.60	116.4	89.78
	Paddy alone(c)	81.40	73.60	43.6	50.40	62.40	88.7	66.68
Mean		85.08	75.78	58.26	66.43	83.43	98.34	-
CD (0.05)		Months			1.599			
		Locations/Land use			2.528			
		interaction			6.192			

Table 34b. Spatial and temporal variation in exchangeable aluminium (mg kg^{-1}) of uplands

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	11.25	11.63	10.25	9.62	10.42	10.92	10.68
	Shrimp alone	24.61	25.95	25.41	25.63	24.85	25.01	25.24
	Mangrove	65.34	64.52	66.51	65.21	64.28	64.48	65.06
	Fallow	81.42	80.52	81.35	82.64	82.57	82.45	81.83
Kottuvally	Paddy - Shrimp	60.36	65.31	63.24	63.15	62.45	63.2	62.95
	Shrimp alone	5.81	5.41	5.84	6.25	6.95	6.32	6.10
	Mangrove	58.64	58.63	57.31	57.43	59.34	59.0	58.39
	Fallow	34.61	34.28	36.54	35.91	32.47	35.27	34.85
Kadamakudy	Paddy - Shrimp	9.56	9.64	8.25	8.31	10.27	10.2	9.37
	Shrimp alone	13.62	13.75	14.35	14.85	14.92	14.2	14.28
	Mangrove	48.31	47.31	49.62	50.24	49.67	49.5	49.11
	Fallow	21.64	23.47	23.87	24.96	25.61	24.28	23.97
RRS, Vyttila	Paddy alone (a)	28.65	28.54	30.64	31.52	30.58	29.7	29.94
	Paddy alone (b)	50.62	47.54	48.62	48.31	49.67	48.14	48.82
	Paddy alone (c)	17.64	17.85	18.64	18.37	17.99	17.21	17.95
Mean		35.47	35.62	36.03	36.16	36.14	35.99	-
CD (0.05)		Months			NS			
		Locations/Land use			2.643			
		interaction			NS			

Table 35a. Spatial and temporal variation in exchangeable iron (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	236.00	215.30	112.6	202.50	311.00	315.0	232.07
	Shrimp alone	246.20	218.40	112.8	234.10	321.50	320.4	242.23
	Mangrove	253.10	220.60	119.2	204.00	245.30	259.8	217.00
	Fallow	296.40	185.30	162.3	207.00	274.60	283.4	234.83
Kottuvally	Paddy - Shrimp	264.10	156.40	128.5	206.30	312.40	325.40	232.18
	Shrimp alone	234.80	128.40	117.9	214.60	253.40	263.41	202.09
	Mangrove	246.50	128.40	111.2	217.60	251.70	266.7	203.68
	Fallow	283.50	234.50	115.16	226.30	263.40	278.4	233.54
Kadamakudy	Paddy - Shrimp	256.30	225.10	114.0	241.80	271.40	283.4	232.00
	Shrimp alone	243.60	142.20	112.4	244.40	274.60	287.1	217.38
	Mangrove	284.70	235.90	126.0	216.30	283.10	294.3	240.05
	Fallow	256.90	133.30	124.0	249.80	276.30	284.1	220.73
RRS, Vyttila	Paddy alone (a)	257.40	124.60	117.0	256.30	285.30	299.4	223.33
	Paddy alone(b)	275.60	228.60	116.0	254.70	263.10	278.4	236.07
	Paddy alone(c)	246.70	129.90	113.0	255.80	288.40	298.8	222.10
Mean		258.79	180.46	120.14	228.77	278.37	289.20	-
CD (0.05)		Months			1.526			
		Locations/Land use			2.413			
		interaction			5.911			

Table 35b. Spatial and temporal variation in exchangeable iron (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	82.32	81.11	82.56	83.25	83.41	83.97	82.77
	Shrimp alone	71.23	71.52	72.14	71.64	72.78	71.07	71.73
	Mangrove	101.74	101.76	101.62	101.54	101.77	101.75	101.70
	Fallow	120.18	120.11	119.53	118.47	119.74	120.56	119.77
Kottuvally	Paddy - Shrimp	96.32	96.41	95.26	95.87	96.14	96.19	96.03
	Shrimp alone	73.64	73.85	72.14	72.89	72.99	72.64	73.03
	Mangrove	83.62	83.24	83.58	84.21	84.63	84.45	83.96
	Fallow	75.24	75.62	75.74	76.34	76.89	76.63	76.08
Kadamakudy	Paddy - Shrimp	81.85	81.64	82.22	82.46	81.98	82.67	82.14
	Shrimp alone	54.56	54.52	55.23	55.84	55.55	55.87	55.26
	Mangrove	62.51	62.61	61.47	62.61	61.47	63.54	62.37
	Fallow	91.25	91.85	91.46	91.76	91.31	91.22	91.48
RRS, Vyttila	Paddy alone (a)	95.24	96.58	96.42	97.32	97.25	97.51	96.72
	Paddy alone (b)	82.54	82.68	83.61	83.41	84.43	83.95	83.44
	Paddy alone (c)	72.14	73.15	74.45	75.61	76.95	74.57	74.48
Mean		82.96	83.11	83.16	83.55	83.82	83.77	-
CD (0.05)		Months			NS			
		Locations/Land use			2.643			
		interaction			NS			

Table 36a. Spatial and temporal variation in exchangeable manganese (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1.85	1.51	1.42	1.65	2.41	2.46	1.88
	Shrimp alone	3.89	2.56	3.6	1.74	5.60	6	3.90
	Mangrove	1.65	1.20	1.3	1.46	1.98	2.18	1.63
	Fallow	1.63	1.46	1.34	1.53	1.56	1.76	1.55
Kottuvally	Paddy - Shrimp	3.61	2.53	3.46	2.62	5.50	5.9	3.94
	Shrimp alone	0.95	0.62	0.56	1.11	1.12	1.42	0.96
	Mangrove	1.89	1.52	1.22	1.56	2.61	3.12	1.99
	Fallow	3.84	2.61	3.6	2.68	6.34	6.25	4.22
Kadamakudy	Paddy - Shrimp	6.01	5.95	6.56	6.52	10.11	10.27	7.57
	Shrimp alone	0.19	0.14	0.85	1.64	2.41	2.65	1.31
	Mangrove	1.85	1.62	1.32	2.14	3.45	3.82	2.37
	Fallow	1.96	1.64	1.34	1.55	1.99	2.02	1.75
RRS, Vyttila	Paddy alone (a)	1.84	1.46	1.36	1.64	2.56	2.17	1.84
	Paddy alone (b)	4.66	2.58	5.31	0.60	7.51	7.02	4.61
	Paddy alone (c)	2.87	2.56	2.36	3.70	4.31	4.07	3.31
Mean		2.58	2.00	2.37	2.14	3.96	4.07	-
CD (0.05)		Months			0.402			
		Locations/Land use			0.636			
		interaction			1.559			

Table 36b. Spatial and temporal variation in exchangeable manganese (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1.52	1.43	1.65	1.70	1.55	1.69	1.59
	Shrimp alone	2.14	2.47	2.61	2.57	2.61	2.88	2.55
	Mangrove	1.42	1.62	1.74	1.63	1.47	1.55	1.57
	Fallow	1.22	1.48	1.89	2.11	2.43	1.27	1.73
Kottuvally	Paddy - Shrimp	1.45	1.62	1.74	1.11	1.13	1.1	1.36
	Shrimp alone	1.15	1.61	1.47	1.95	1.46	1.05	1.45
	Mangrove	2.41	2.61	2.74	2.96	2.48	2.4	2.60
	Fallow	2.05	2.47	2.61	2.74	1.95	2.01	2.31
Kadamakudy	Paddy - Shrimp	4.32	4.52	4.92	4.73	4.82	4.45	4.63
	Shrimp alone	1.22	1.23	1.45	1.74	1.69	1.35	1.45
	Mangrove	1.99	1.85	1.83	1.73	1.99	1.93	1.89
	Fallow	1.05	1.05	1.04	1.07	1.05	1.09	1.06
RRS, Vyttila	Paddy alone (a)	1.23	1.42	1.28	1.41	1.62	1.33	1.38
	Paddy alone (b)	2.44	2.14	2.64	1.89	1.99	2.57	2.28
	Paddy alone (c)	1.22	1.11	1.64	2.12	0.12	1.94	1.36
Mean		1.79	1.91	2.08	2.10	1.89	1.91	-
CD (0.05)		Months			NS			
		Locations/Land use			0.731			
		interaction			NS			

Table 37a. Spatial and temporal variation in exchangeable zinc (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	6.20	5.10	2.74	3.50	10.70	11.2	6.57
	Shrimp alone	5.23	3.20	2.58	2.96	10.00	10.23	5.70
	Mangrove	4.30	3.60	1.3	2.60	12.10	12.57	6.08
	Fallow	5.32	2.60	1.28	2.40	17.20	17.7	7.75
Kottuvally	Paddy - Shrimp	6.30	3.40	2.86	3.10	14.80	15.22	7.61
	Shrimp alone	3.20	2.10	1.84	0.50	11.50	11.17	5.05
	Mangrove	56.70	46.10	45.3	56.30	71.30	76.52	58.70
	Fallow	4.30	2.20	1.76	3.60	11.30	11.00	5.69
Kadamakudy	Paddy - Shrimp	99.60	96.30	95.4	100.40	111.50	112.83	102.67
	Shrimp alone	55.40	48.30	42.1	55.60	125.30	126.83	75.59
	Mangrove	45.30	36.40	35.36	54.30	142.30	146.66	76.72
	Fallow	32.50	28.60	10.52	11.62	124.30	125.13	55.45
RRS, Vyttila	Paddy alone (a)	5.60	2.10	1.06	2.50	12.30	13.62	6.20
	Paddy alone (b)	6.40	2.20	1.34	2.60	6.51	6.56	4.27
	Paddy alone (c)	5.20	2.50	1.16	2.80	4.30	4.20	3.36
Mean		22.77	18.98	16.44	20.32	45.69	46.76	-
CD (0.05)		Months			0.925			
		Locations/Land use			1.462			
		interaction			3.581			

Table 37b. Spatial and temporal variation in exchangeable zinc (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2.11	3.56	3.45	2.86	2.94	2.54	2.91
	Shrimp alone	8.62	8.46	9.16	9.52	10.12	9.05	9.16
	Mangrove	2.15	1.46	1.48	2.59	2.47	2.63	2.13
	Fallow	4.62	4.85	3.61	3.20	4.12	3.36	3.96
Kottuvally	Paddy - Shrimp	1.88	1.62	2.14	2.62	1.52	1.84	1.94
	Shrimp alone	5.26	5.41	5.34	6.21	6.34	6.07	5.77
	Mangrove	6.13	6.54	7.62	7.14	6.84	6.39	6.78
	Fallow	1.25	1.64	2.14	2.64	2.47	2.36	2.08
Kadamakudy	Paddy - Shrimp	5.16	5.24	4.96	4.82	4.13	5.06	4.90
	Shrimp alone	5.26	5.62	6.12	7.14	7.62	6.79	6.43
	Mangrove	3.15	3.69	2.31	2.84	2.95	3.25	3.03
	Fallow	7.54	7.85	8.42	8.12	8.61	8.34	8.15
RRS, Vyttila	Paddy alone (a)	2.14	2.16	1.58	1.64	2.46	2.12	2.02
	Paddy alone (b)	2.11	1.84	1.62	2.54	2.66	2.19	2.16
	Paddy alone (c)	1.46	1.62	2.43	2.15	1.64	2.49	1.97
Mean		3.92	4.10	4.16	4.40	4.46	4.30	-
CD (0.05)		Months			0.145			
		Locations/Land use			0.230			
		interaction			0.563			

Table 38a. Spatial and temporal variation in exchangeable copper (mg kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.05	0.09	0.08	0.75	1.21	1.32	0.58
	Shrimp alone	0.61	0.41	0.23	0.81	1.23	1.32	0.77
	Mangrove	0.32	0.25	0.17	0.55	1.30	1.32	0.65
	Fallow	0.38	0.26	0.3	0.62	1.60	1.8	0.83
Kottuvally	Paddy - Shrimp	0.40	0.27	0.10	0.95	1.80	1.92	0.91
	Shrimp alone	0.39	0.29	0.18	0.64	1.62	1.78	0.82
	Mangrove	0.34	0.24	0.13	0.74	1.36	1.44	0.71
	Fallow	0.47	0.33	0.23	0.61	1.21	1.28	0.69
Kadamakudy	Paddy - Shrimp	0.85	0.62	0.48	0.68	1.67	1.78	1.01
	Shrimp alone	0.86	0.71	0.67	0.82	1.83	1.9	1.13
	Mangrove	1.06	0.99	0.9	1.05	1.50	1.66	1.19
	Fallow	1.03	0.95	1.01	1.50	2.10	2.44	1.51
RRS, Vyttila	Paddy alone (a)	0.86	0.62	0.23	0.95	1.92	1.94	1.09
	Paddy alone (b)	0.92	0.67	0.23	0.82	1.20	1.64	0.91
	Paddy alone (c)	0.75	0.54	0.22	0.81	1.12	1.26	0.78
Mean		0.62	0.48	0.34	0.82	1.51	1.65	-
CD (0.05)		Months			0.007			
		Locations/Land use			0.011			
		interaction			0.028			

Table 38b. Spatial and temporal variation in exchangeable copper (mg kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.11	0.15	0.17	0.19	0.15	0.19	0.16
	Shrimp alone	0.11	0.13	0.14	0.18	0.14	0.17	0.15
	Mangrove	0.31	0.35	0.32	0.37	0.35	0.32	0.34
	Fallow	0.22	0.24	0.21	0.20	0.25	0.21	0.22
Kottuvally	Paddy - Shrimp	0.01	0.05	0.06	0.04	0.08	0.03	0.05
	Shrimp alone	0.25	0.24	0.26	0.28	0.24	0.21	0.25
	Mangrove	0.14	0.16	0.18	0.14	0.16	0.19	0.16
	Fallow	0.20	0.24	0.29	0.24	0.22	0.21	0.23
Kadamakudy	Paddy - Shrimp	0.14	0.16	0.15	0.18	0.14	0.15	0.15
	Shrimp alone	0.01	0.06	0.03	0.02	0.07	0.04	0.04
	Mangrove	0.41	0.46	0.44	0.42	0.47	0.44	0.44
	Fallow	0.11	0.19	0.17	0.16	0.14	0.12	0.15
RRS, Vyttila	Paddy alone (a)	0.05	0.04	0.01	0.07	0.05	0.06	0.05
	Paddy alone (b)	0.21	0.25	0.26	0.27	0.28	0.25	0.25
	Paddy alone (c)	0.28	0.21	0.22	0.60	0.25	0.26	0.30
Mean		0.17	0.20	0.19	0.22	0.20	0.19	-
CD (0.05)		Months			0.007			
		Locations/Land use			0.011			
		interaction			0.028			

4.1.2.17. Cation exchange capacity

Cation exchange capacity in lowland soil (table 39a) was found to be significantly varying across the seasons and the mean values ranged from 7.18 (Fabruary) to 9.57cmol p(+) kg^{-1} (October). Spatial variation of cation exchange capacity was also found to be significant. Paddy shrimp in Ezhikkara (9.70cmol p(+) kg^{-1}) and fallow land in Kadamakudy (6.62cmol p(+) kg^{-1}) showed the highest and lowest mean values of cation exchange capacity respectively.

Upland soils showed a non significant variation in cation exchange capacity across the seasons (table 39b) and land uses.

4.1.2.18. Anion exchange capacity

A non-significant decrease in anion exchange capacity from June to October (16.81 to 15.56 cmol e(-) kg^{-1}) during low saline phase and an increase from December to April (16.91 to 17.36 cmol e(-) kg^{-1}) during high saline phase was noticed in lowland soils (table 40a). Spatial variation of anion exchange capacity was found to be significant. Mangrove (22.23 cmol e(-) kg^{-1}) and shrimp alone (11.68 cmol e(-) kg^{-1}) in Kadamakudy showed the highest and lowest mean values of anion exchange capacity respectively.

Upland soils showed a non-significant variation in anion exchange capacity throughout the seasons (table 40b). Among land uses, the highest mean value was recorded in paddy-shrimp in Kadamakudy (9.17 cmol(-) kg^{-1}) and the lowest value was noticed in shrimp alone in Kadamakudy (cmol(-) kg^{-1}).

Table 39a. Spatial and temporal variations in cation exchange capacity (cmol p(+) kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	9.14	10.46	9.96	9.37	7.79	7.62	9.70
	Shrimp alone	7.42	7.82	12.98	10.49	8.76	7.36	8.97
	Mangrove	7.66	9.03	8.12	7.29	6.67	7.50	8.63
	Fallow	6.34	10.40	11.12	9.67	7.29	6.31	8.97
Kottuvally	Paddy - Shrimp	6.99	6.59	8.51	6.66	5.61	7.09	7.04
	Shrimp alone	8.71	9.40	12.87	10.39	8.25	8.15	9.38
	Mangrove	8.07	7.39	12.32	9.83	7.76	8.02	7.98
	Fallow	8.20	7.71	10.31	8.56	7.18	7.48	7.86
Kadamakudy	Paddy - Shrimp	8.81	9.58	7.90	7.29	7.66	8.01	9.62
	Shrimp alone	6.64	7.74	5.84	5.36	5.58	6.39	7.67
	Mangrove	7.49	9.22	10.37	8.49	7.87	6.86	9.62
	Fallow	5.71	5.92	4.88	4.02	5.31	5.83	6.62
RRS, Vyttila	Paddy alone (a)	7.84	8.37	8.31	6.54	7.17	7.95	8.76
	Paddy alone (b)	7.36	8.47	10.68	7.48	6.40	7.21	8.20
	Paddy alone (c)	7.27	7.66	9.37	8.72	8.44	8.79	8.44
Mean		7.58	8.38	9.57	8.01	7.18	7.37	-
CD (0.05)		Months			0.908			
		Locations/Land use			1.436			
		interaction			NS			

Table 39b. Spatial and temporal variations in cation exchange capacity (cmol p(+) kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2.11	2.10	2.11	2.10	2.12	2.13	2.11
	Shrimp alone	2.30	2.34	2.35	2.33	2.33	2.32	2.33
	Mangrove	3.03	3.02	3.04	3.04	3.02	3.03	3.03
	Fallow	3.72	3.73	3.69	3.72	3.73	3.71	3.72
Kottuvally	Paddy - Shrimp	3.69	3.74	3.71	3.69	3.71	3.72	3.71
	Shrimp alone	2.47	2.48	2.46	2.48	2.50	2.49	2.48
	Mangrove	3.02	2.97	2.96	2.98	2.98	2.97	2.98
	Fallow	1.96	1.96	2.00	2.00	1.95	1.99	1.98
Kadamakudy	Paddy - Shrimp	2.06	2.08	2.06	2.05	2.09	2.06	2.07
	Shrimp alone	1.68	1.69	1.69	1.72	1.74	1.72	1.71
	Mangrove	3.45	3.40	3.44	3.45	3.45	3.46	3.44
	Fallow	2.27	2.29	2.33	2.34	2.35	2.32	2.32
RRS, Vyttila	Paddy alone (a)	2.12	2.14	2.16	2.17	2.16	2.15	2.15
	Paddy alone (b)	2.40	2.38	2.37	2.39	2.42	2.40	2.39
	Paddy alone (c)	2.19	2.19	2.21	2.22	2.23	2.20	2.21
Mean		2.56	2.57	2.57	2.58	2.58	2.58	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		interaction			NS			

Table 40a. Spatial and temporal variations in anion exchange capacity (cmol e(-) kg^{-1}) of lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	16.42	15.49	14.61	15.32	16.41	17.11	15.89
	Shrimp alone	18.12	19.34	18.52	18.41	19.62	19.32	18.89
	Mangrove	16.50	17.61	16.8	16.34	16.21	17.61	16.85
	Fallow	14.85	14.56	13.24	14.84	15.63	15.21	14.72
Kottuvally	Paddy - Shrimp	16.23	16.24	15.32	16.42	16.37	17.99	16.43
	Shrimp alone	14.62	14.23	13.85	15.00	15.84	15.62	14.86
	Mangrove	18.62	19.84	18.26	17.20	18.64	19.21	18.63
	Fallow	16.66	15.21	14.42	16.84	17.11	17.32	16.26
Kadamakudy	Paddy - Shrimp	21.33	21.47	20.41	22.74	22.96	21.47	21.73
	Shrimp alone	11.42	11.25	10.36	12.47	12.95	11.62	11.68
	Mangrove	22.56	22.48	20.61	21.78	23.64	22.31	22.23
	Fallow	14.62	14.95	12.85	15.63	14.85	14.46	14.56
RRS, Vyttila	Paddy alone (a)	15.62	15.84	13.84	16.74	15.84	15.95	15.64
	Paddy alone (b)	16.34	15.28	13.94	16.34	15.47	16.52	15.65
	Paddy alone (c)	18.23	18.64	16.41	17.62	16.40	18.61	17.65
Mean		16.81	16.83	15.56	16.91	17.20	17.36	-
CD (0.05)		Months			NS			
		Locations/Land use			2.643			
		interaction			NS			

Table 40b. Spatial and temporal variations in anion exchange capacity (cmol e(-) kg^{-1}) of uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	7.42	7.55	8.12	8.61	8.44	8.89	8.17
	Shrimp alone	6.23	6.34	5.12	5.46	6.32	6.65	6.02
	Mangrove	3.12	3.54	3.84	4.52	4.61	3.61	3.87
	Fallow	9.95	9.52	8.12	8.61	7.45	9.31	8.83
Kottuvally	Paddy - Shrimp	4.56	5.12	4.63	5.13	4.44	4.96	4.81
	Shrimp alone	8.44	8.31	8.46	8.64	8.74	8.52	8.52
	Mangrove	7.66	7.61	5.41	6.12	6.96	7.64	6.90
	Fallow	8.12	8.56	8.55	7.46	7.80	8.56	8.18
Kadamakudy	Paddy - Shrimp	9.12	9.85	9.62	8.16	8.42	9.85	9.17
	Shrimp alone	1.32	1.95	1.88	2.16	2.45	2.33	2.02
	Mangrove	5.96	5.64	6.12	6.42	6.61	6.62	6.23
	Fallow	8.12	8.62	8.85	7.46	7.96	8.13	8.19
RRS, Vyttila	Paddy alone (a)	9.12	9.64	8.32	8.64	8.88	9.44	9.01
	Paddy alone (b)	7.14	7.77	6.14	6.58	7.51	7.43	7.10
	Paddy alone (c)	9.19	9.25	8.13	8.46	7.64	9.12	8.63
Mean		7.03	7.28	6.75	6.83	6.95	7.40	-
CD (0.05)		Months			NS			
		Locations/Land use			2.413			
		interaction			NS			

4.1.3. Biological properties

4.1.3.1. Population of nitrogen fixing bacteria (PNFB)

A significant decrease in population of nitrogen fixing bacteria in lowland soils (table 41a) was observed from low saline phase (June to October) to high saline phase (December to April). The mean values of population of nitrogen fixing bacteria ranges from 14.07x10^3cfu (April) to 23.27x10^3cfu (August). Spatial variation of nitrogen fixing bacterial population was also found to be significant. Paddy-shrimp in Kadamakudy (83.67x10^3cfu) and fallow land in Ezhikkara (3.00x10^3cfu) showed the highest and lowest mean values of population of nitrogen fixing bacteria respectively.

Significant decrease in mean values of nitrogen fixing bacterial counts in upland soils (table 41b) was noticed across the seasons. The bacterial count ranged from 2 x10^3 - 40 x10^3cfu in June and 2 x10^3-18 x10^3cfu in April. Population of nitrogen fixing bacteria in land uses were reported as significantly varying and the mean values ranged from 3.67x10^3cfu (paddy alone land use, a in RRS-Vyttila) to 30.83x10^3cfu (mangrove in Kottuvally).

4.1.3.2. Microbial biomass carbon (MBC)

Microbial biomass carbon of lowland soils detailed in table 42a showed a significant decrease from low saline phase (June to October) to high saline phase (December to April). Highest and lowest mean values of microbial biomass carbon was reported in June (175.08 µg g^{-1}) and April (117.82 µg g^{-1}) respectively. Significant variation in spatial distribution of microbial biomass carbon was identified and the mean values ranged from 246.61 µg g^{-1} to (mangrove in Kadamakudy) to 102.40 µg g^{-1} (fallow land in Kottuvally).

Upland soils showed a decrease in microbial biomass carbon which proved non significant variation with the advancement of seasons (table 42b) and among the land uses. The mean values of microbial biomass carbon varied from 62.42 (April) to 82.86 µg g^{-1} (June). Among land uses, the highest and lowest values of microbial biomass carbon was reported in paddy-shrimp in Kadamakudy ranging from 81.75 to 112.51 µg g^{-1} and mangrove in Ezhikkara ranging from 48.62 to 56.23 µg g^{-1} respectively.

4.1.3.3. Dehydrogenase enzyme activity (DEA)

Mean values of dehydrogenase enzyme activity in lowland soils (table 43a) was found to be increasing significantly from June (3163.67 µg TPFg^{-1} day^{-1}) to October (4892.13 µg TPFg^{-1} day^{-1}) during low saline phase. Later, a significant decrease was noticed from December (2952.87 µgTPFg^{-1}day^{-1}) to April (1673.41 µg TPFg^{-1} day^{-1}) during high saline phase. Among land uses, significant variation in dehydrogenase enzyme activity was observed and the highest mean value was noticed in mangrove in Kottuvally (4503.17 µg TPFg^{-1} day^{-1}) and the lowest was reported in mangrove in Kadamakudy (1887.67 µg TPFg^{-1} day^{-1}).

Significant decrease in dehydrogenase enzyme activity was observed with the advancement of seasons in upland soils (table 43b). The mean values of dehydrogenase enzyme activity ranged from 994.19 (June) to 245.41 µg TPFg^{-1} day^{-1} (April). Spatial variation in dehydrogenase enzyme activity was found to be significant. Among land uses, paddy-shrimp (2089.73µg TPFg^{-1} day^{-1}) in Kottuvally registered the highest dehydrogenase enzyme activity ranging from 951.10 to 2966.00 µg TPFg^{-1} day^{-1} whereas shrimp-alone in Ezhikkara recorded the lowest enzyme activity ranging from 84.60 to 145.30 µg TPFg^{-1} day^{-1}.

Table 41a. Spatial and temporal variations of population of NFB (x 10^{3} cfu) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	10	18	13	15	12	9	12.83
	Shrimp alone	18	13	18	15	12	10	14.33
	Mangrove	2	7	6	6	5	5	5.17
	Fallow	2	6	3	3	2	2	3.00
Kottuvally	Paddy - Shrimp	34	21	18	20	15	12	20.00
	Shrimp alone	28	46	40	37	32	29	35.33
	Mangrove	14	12	14	10	12	9	11.83
	Fallow	10	13	15	12	12	9	11.83
Kadamakudy	Paddy - Shrimp	90	101	95	81	72	63	83.67
	Shrimp alone	84	44	41	32	29	22	42.00
	Mangrove	6	8	7	7	6	5	6.50
	Fallow	8	4	9	8	6	7	7.00
RRS, Vyttila	Paddy alone (a)	7	10	13	12	11	9	10.33
	Paddy alone (b)	13	48	22	11	10	9	18.83
	Paddy alone (c)	12	9	35	28	24	11	19.83
Mean		22.53	24.00	23.27	19.80	17.33	14.07	-
CD (0.05)		Months			2.125 x 10^{3}			
		Locations/Land use			3.361 x 10^{3}			
		Interaction			8.232 x 10^{3}			

Table 41b. Spatial and temporal variations of population of NFB (x 10^3 cfu) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2	5	4	4	5	4	4.00
	Shrimp alone	3	6	3	5	6	5	4.67
	Mangrove	19	18	13	12	13	10	14.17
	Fallow	30	13	14	15	10	4	14.33
Kottuvally	Paddy - Shrimp	12	13	8	10	12	6	10.17
	Shrimp alone	14	12	25	10	12	10	13.83
	Mangrove	38	33	48	28	21	17	30.83
	Fallow	20	25	13	10	5	3	12.67
Kadamakudy	Paddy - Shrimp	40	15	12	18	15	10	18.33
	Shrimp alone	39	32	29	28	14	11	25.50
	Mangrove	25	20	19	14	10	8	16.00
	Fallow	25	23	26	20	15	18	21.17
RRS, Vyttila	Paddy alone (a)	4	1	5	5	4	3	3.67
	Paddy alone (b)	4	3	5	6	5	4	4.50
	Paddy alone (c)	2	4	9	5	4	2	4.33
Mean		18.47	14.87	15.53	12.67	10.07	7.67	-
CD (0.05)		Months			8.232 x10^3			
		Locations/Land use			1.149 x10^3			
		Interaction			2.815 x10^3			

Table 42a. Spatial and temporal variations of MBC (μg g^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	125.1	164.5	145.3	134.2	98.5	82.1	124.9
	Shrimp alone	165.1	152.1	174.2	160.5	153.2	120.4	154.2
	Mangrove	123.5	121.3	135.4	111.3	98.6	97.4	114.6
	Fallow	132.5	120.4	121.5	109.8	85.6	72.3	107.0
Kottuvally	Paddy - Shrimp	140.5	130.4	125.6	132.4	101.5	94.2	120.8
	Shrimp alone	132.6	135.6	145.2	120.5	95.6	94.1	120.6
	Mangrove	149.8	150.2	132.1	146.1	120.1	110.4	134.8
	Fallow	120.7	111.5	99.8	101.2	95.6	85.4	102.4
Kadamakudy	Paddy - Shrimp	254.2	241.3	218.9	185.6	145.2	130.2	195.9
	Shrimp alone	241.6	256.3	241.3	210.4	185.6	172.6	218.0
	Mangrove	275.1	264.5	271.4	241.6	214.6	212.3	246.6
	Fallow	213.5	214.7	212.5	110.8	95.4	84.2	155.2
RRS, Vyttila	Paddy alone (a)	192.1	199.3	201.4	205.6	180.2	174.6	192.2
	Paddy alone (b)	184.5	182.5	192.5	140.2	153.1	132.4	164.2
	Paddy alone (c)	174.8	150.2	142.6	121.6	98.6	104.2	132.0
Mean		175.0	173.0	170.7	148.8	128.1	117.8	-
CD (0.05)		Months			39.239			
		Locations/Land use			60.043			
		Interaction			NS			

Table 42b. Spatial and temporal variations of MBC (µg g^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	74.56	75.41	60.12	54.62	50.12	51.26	61.02
	Shrimp alone	64.15	61.42	63.54	58.62	59.14	57.41	60.71
	Mangrove	55.21	56.23	52.14	49.62	50.16	48.62	52.00
	Fallow	61.25	65.23	63.15	58.47	55.12	48.16	58.56
Kottuvally	Paddy - Shrimp	95.41	92.15	84.56	82.43	74.62	71.35	83.42
	Shrimp alone	84.56	82.15	74.56	70.41	69.31	54.87	72.64
	Mangrove	82.14	78.52	79.41	68.43	65.32	61.47	72.55
	Fallow	74.64	73.24	65.42	62.46	54.16	51.47	63.57
Kadamakudy	Paddy - Shrimp	112.51	110.25	98.54	99.62	86.51	81.75	98.20
	Shrimp alone	99.58	85.62	95.61	82.44	75.32	71.95	85.09
	Mangrove	86.54	84.53	78.41	81.26	76.34	69.14	79.37
	Fallow	75.41	74.25	71.62	68.24	62.17	58.64	68.39
RRS, Vyttila	Paddy alone (a)	95.12	91.52	92.56	85.64	82.15	83.14	88.36
	Paddy alone (b)	99.32	95.62	89.64	76.41	71.25	65.86	83.02
	Paddy alone (c)	82.54	70.56	74.82	72.41	65.46	61.24	71.17
Mean		82.86	79.78	76.27	71.41	66.48	62.42	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

Table 43a. Spatial and temporal variations of DEA (µg TPF g^{-1} day^{-1}) in lowlands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2329	3092	6022	2692	2379	1715	3038
	Shrimp alone	4979	4998	5805	4914	2189	1887	4128
	Mangrove	4221	4493	5855	4143	3485	3165	4227
	Fallow	2504	3882	4996	2416	1823	823	2740
Kottuvally	Paddy - Shrimp	2781	3259	3811	2961	2702	1112	2771
	Shrimp alone	1586	3709	5139	1650	1245	550	2313
	Mangrove	4167	5588	5684	4286	3816	3478	4503
	Fallow	4523	4108	5382	4555	3311	1785	3944
Kadamakudy	Paddy - Shrimp	2065	1966	3310	1840	1528	1020	1954
	Shrimp alone	2767	2649	3240	2531	1962	1594	2457
	Mangrove	1357	3168	3465	1385	1025	926	1887
	Fallow	3818	3387	4753	2014	1503	1397	2812
RRS, Vyttila	Paddy alone (a)	2716	3815	4057	2239	2045	1832	2784
	Paddy alone (b)	3030	4415	5824	2788	2214	1741	3335
	Paddy alone (c)	4612	5123	6039	3879	2652	2076	4063
Mean		3163.6	3843.4	4892.1	2952.8	2258.6	1673.4	-
CD (0.05)		Months			998.4			
		Locations/Land use			1,578.6			
		Interaction			NS			

Table 43b. Spatial and temporal variations of DEA (µg TPF g^{-1} day^{-1}) in uplands

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	215	434	205	288	211	100	242.2
	Shrimp alone	110	84	139	145	103	127	118.2
	Mangrove	1067	1004	778	845	608	598	816.9
	Fallow	633	504	302	183	122	134	313.3
Kottuvally	Paddy - Shrimp	2966	2309	2616	1930	1766	951	2089.7
	Shrimp alone	1073	1419	1374	842	220	320	875.1
	Mangrove	1290	837	654	417	367	306	645.5
	Fallow	1582	808	597	195	105	123	568.8
Kadamakudy	Paddy - Shrimp	1840	1475	632	547	531	180	867.7
	Shrimp alone	875	984	735	528	412	247	630.5
	Mangrove	809	712	794	396	193	119	504.2
	Fallow	1085	480	617	404	333	309	538.2
RRS, Vyttila	Paddy alone (a)	461	135	134	85	74	60	158.8
	Paddy alone (b)	381	96	137	119	113	80	154.9
	Paddy alone (c)	523	219	219	198	127	23	218.5
Mean		994.1	767.1	662.6	475.2	352.7	245.4	-
CD (0.05)		Months			70.077			
		Locations/Land use			112.383			
		Interaction			275.280			

4.2. Water analysis

4.2.1. Electro chemical properties

4.2.1.1. pH

Both field and source water showed the same trend in pH. An immediate and significant increase in pH was noticed in December and then got decreased later (tables 44a and 44b). The pH of water samples ranged from 7.18(October) to 8.11(December) and 7.33(August) to 6.84(December) in field and source water respectively. Among land uses, significant difference in pH was not detected and the pH values were in neutral pH in both field (7.30 to7.79) and source (6.97 to 7.63) water.

4.2.1.2. Electrical conductivity (EC) and Total soluble salts (TSS)

Electrical conductivity in both field and source water showed decrease in EC from June to October and then an increase from December to April (tables 45a and 45b). The least and highest values of EC ranged from 2.78(October) to 29.33 dS m^{-1}(February) and 2.04(October) to 26.69 dS m^{-1} (February) in field and source water respectively. Paddy alone land use (c) from RRS, Vyttila (4.71 dS m^{-1}in field water and 2.44 dS m^{-1} in source water) and shrimp alone land use from Ezhikkara (17.93 dSm^{-1} in field water and 17.75 dS m^{-1} source water) recorded least and highest EC values.

Total soluble salt also followed the same trend in electrical conductivity (tables 46a and 46b). The least and highest values of TSS ranged from 1778.4 (October) to 18773 mg L^{-1}(February) and 1305.5 (October) to 17079 mg L^{-1}(February) in field and source water respectively. Among land uses, shrimp alone land use in Ezhikkara (11473.1 mg L^{-1}in field water and 11362.1 mg L^{-1} in source water) and paddy alone land use (c) in RRS, Vyttila (3014.2 mg L^{-1} in field water and 1560.2 mg L^{-1} in source water) recorded highest and least values.

4.2.2. Concentration of cations

Water soluble calcium in field and source water ranged from 20.30 (October) to 222.91 mg L^{-1} (February) and 14.76 (October) to 219.57 mg L^{-1}(February) respectively (tables 47a and 47b). Among land uses, it varied from 44.78(paddy alone land use (c) in RRS, Vyttila) to 142.66 mg L^{-1} (shrimp alone land use in Ezhikkara) and 28.53 (paddy alone land use (c) in RRS, Vyttila) to 132.46 mg L^{-1} (shrimp alone land use in Ezhikkara) in field and source water respectively.

Water soluble magnesium was found to be least on October in both field and source water and the values were 49.0 and 33.7 mg L^{-1} respectively (tables 48a and 48b). Highest water soluble magnesium was detected during April (782.8 mg L^{-1}) in field water and on February (792.3 mg L^{-1}) in source water. Among land uses, the least value of water soluble magnesium was observed in paddy alone land use (c) in RRS, Vyttila in both field (101.1 mg L^{-1}) and source water (98.6 mg L^{-1}). Highest values were noticed in shrimp alone land use (470.7 mg L^{-1}) and fallow land (472.6 mg L^{-1}) in Ezhikkara in field and source water respectively.

Highest and least values of water soluble sodium was observed in Februaryand October respectively in field and source water (tables 49a and 49b). The values ranged from 525.0 to 7157.2 mg L^{-1} and 346.6 to 6513.5 mg L^{-1} in field and source water respectively. Considering the land uses, highest value of water soluble sodium was estimated in mangrove in Kadamakudy (4100.0 mg L^{-1}) in field water and paddy-shrimp in Ezhikkara (3948.7 mg L^{-1}) in source water. The least values were observed in paddy alone land use (c) in RRS, Vyttila and the values were 1024.4 mg L^{-1} in field water and 478.0 mg L^{-1} in source water.

While looking over water soluble potassium in field and source water, both followed the same trend in spatial and temporal variation (tables 50a and 50b). Water soluble potassium ranged from 20.97(October) to 279.47 mg L^{-1} (February) in field water and 15.45(October) to 261.45 mg L^{-1} (February) in source water. Among land uses, highest and least values were noticed in shrimp alone land use in Ezhikkara and paddy alone land use (c) in RRS, Vyttila respectively. The mean values ranged from 43.59 to 167.57 mg L^{-1} and 22.02 to 158.05 mg L^{-1} in field and source water respectively.

4.2.3. Concentration of anions

Bicarbonate content in field water ranged from 0.69(June) to 1.65 mEq L^{-1}(February). Paddy-shrimp in Ezhikkara (1.43 mEq L^{-1}) and paddy alone (a) in RRS,Vyttila recorded highest (0.83 mEq L^{-1}) and least values of bicarbonate content (table 51a). Spatial and temporal variation of bicarbonate in source water was non-significant (table 51b).

Negligible amount of nitrate was observed in water samples. It ranged from 0.01 (February and April) to 0.08 mg L^{-1} (October) in field and source water (tables 52a and 52b). Minimum value of nitrate was found in mangrove in Ezhikkara (0.01 mg L^{-1} in both field and source water) and maximum value was observed in paddy alone (c) in RRS, Vyttila (0.06 mg L^{-1} in field water and 0.08 mg L^{-1} in source water).

Temporal variation in phosphate was noticed over the period and it ranged from 0.211(August) to 0.469 mg L^{-1} (February) and 0.219 (October) to 0.669 mg L^{-1} (February) in field and source water respectively (tables 53a and 53b). Among land uses, fallow land in Kadamakudy recorded least values of phosphate in field (0.220 mg L^{-1}) and source water (0.200 mg L^{-1}).The highest value of phosphate in field and source water were 0.405 mg L^{-1} (fallow land in Kottuvally) and 0.759 mg L^{-1} (paddy alone (c) in RRS, Vyttila) respectively.

Temporal variation of borate showed a decrease in water soluble borate from June to October whereas an increase was noticed from December to April in both field and source water (tables 54a and 54b). In field water, it ranged from 0.35(October) to 2.28 mg L^{-1} (February) and it was 0.25(October) to 2.14 mg L^{-1} (February) for source water. Spatial variation of water soluble borate ranged from 0.53 (paddy alone land use, c in RRS,Vyttila) to 1.51 mg L^{-1} (shrimp alone in Ezhikkara) in field water and it was 0.32 (paddy alone land use (b) in RRS, Vyttila) to1.48 mg L^{-1} (mangrove in Ezhikkara) for source water.

Highest and least values of chloride in field and source water ranged from 1171(October) to 12878 mg L^{-1} (February) and from 1065 (October) to 12094 mg L^{-1} (April) respectively (tables 55a and 55b). Among land uses, shrimp alone in Ezhikkara recorded highest value for chloride in field (7962 mg L^{-1}) and source (8224 mg L^{-1}) water. The least values were reported in plot c (1953 mg L^{-1}) and plot b (1265 mg L^{-1}) respectively of paddy alone in RRS, Vyttila for field and source water.

Water soluble sulphate in field and source water ranged from 74.61(October) to 435.54 mg L^{-1} (April) and 71.70 (October) to 499.62 mg L^{-1} (April) respectively (tables 56a and 56b). Among land uses, shrimp alone in Ezhikkara (337.91 mg L^{-1} in field water and 334.14 mg L^{-1} in source water) and plot a (75.17 mg L^{-1} in field water and 87.46 mg L^{-1} in source water) of paddy alone in RRS, Vyttila reported highest and least values for sulphate content.

Table 44a. Spatial and temporal variations in pH of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	7.09	8.18	8.31	8.12	7.55	7.17	7.74
	Shrimp alone	7.22	7.95	6.96	8.09	7.56	7.31	7.52
	Mangrove	7.52	8.26	7.52	8.16	7.49	7.30	7.71
	Fallow	7.33	8.06	8.57	8.14	7.43	7.23	7.79
Kottuvally	Paddy - Shrimp	6.89	8.15	7.27	8.18	7.48	7.28	7.54
	Shrimp alone	7.06	7.97	7.25	8.29	7.47	6.99	7.51
	Mangrove	7.54	7.83	6.94	8.05	7.47	7.49	7.55
	Fallow	7.42	7.97	7.06	8.31	7.50	7.24	7.58
Kadamakudy	Paddy - Shrimp	7.71	7.41	6.70	7.97	7.41	7.30	7.42
	Shrimp alone	7.66	7.39	6.97	7.88	7.40	7.33	7.44
	Mangrove	7.39	7.65	6.80	8.05	7.47	7.36	7.45
	Fallow	7.42	7.33	6.43	7.77	7.49	7.36	7.30
RRS, Vyttila	Paddy alone (a)	7.84	7.25	6.96	8.02	7.59	6.60	7.38
	Paddy alone (b)	7.80	7.89	6.97	8.38	7.61	6.90	7.59
	Paddy alone (c)	7.12	7.74	6.96	8.27	7.66	7.15	7.48
Mean		7.40	7.80	7.18	8.11	7.51	7.20	-
CD (0.05)		Months			0.451			
		Locations/Land use			NS			
		Interaction			NS			

Table 44b. Spatial and temporal variations in pH of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	7.53	7.90	7.26	8.16	7.47	7.37	7.62
	Shrimp alone	7.12	7.91	7.25	8.12	7.48	7.30	7.53
	Mangrove	7.58	7.95	7.31	8.07	7.46	7.40	7.63
	Fallow	7.02	7.97	7.29	8.12	7.51	7.40	7.55
Kottuvally	Paddy - Shrimp	7.65	7.70	7.16	8.04	7.49	7.30	7.56
	Shrimp alone	7.08	7.68	7.09	8.07	7.47	7.23	7.44
	Mangrove	7.32	7.55	7.08	8.02	7.48	7.27	7.45
	Fallow	7.13	7.66	7.08	8.04	7.41	7.18	7.42
Kadamakudy	Paddy - Shrimp	7.44	7.09	6.73	7.95	7.44	7.27	7.32
	Shrimp alone	7.47	7.03	6.61	7.94	7.41	7.20	7.28
	Mangrove	7.05	7.30	6.86	8.06	7.44	7.21	7.32
	Fallow	7.54	7.05	6.64	7.92	7.49	7.15	7.30
RRS, Vyttila	Paddy alone (a)	7.30	7.00	6.06	7.71	6.67	7.10	6.97
	Paddy alone (b)	7.23	7.01	6.07	8.15	7.26	7.24	7.16
	Paddy alone (c)	7.44	7.03	6.12	7.90	7.31	7.04	7.14
Mean		7.40	7.33	7.46	6.84	8.02	7.39	7.24
CD (0.05)		Months			0.400			
		Locations/Land use			NS			
		Interaction			NS			

Table 45a. Spatial and temporal variations in electrical conductivity (dS m^{-1}) of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	11.35	8.01	4.93	16.16	34.80	29.70	17.49
	Shrimp alone	15.86	7.06	3.55	16.79	34.90	29.40	17.93
	Mangrove	5.15	7.30	3.48	17.34	34.70	30.10	16.35
	Fallow	13.20	8.49	4.58	13.76	33.60	30.30	17.32
Kottuvally	Paddy - Shrimp	5.40	6.58	3.28	12.20	31.60	33.30	15.39
	Shrimp alone	11.46	9.64	4.11	11.31	31.50	32.50	16.75
	Mangrove	7.32	3.37	2.45	13.39	30.20	31.40	14.69
	Fallow	8.65	3.62	2.11	10.92	31.40	34.20	15.15
Kadamakudy	Paddy - Shrimp	19.33	1.28	0.60	14.57	32.20	32.20	16.70
	Shrimp alone	5.28	1.87	1.35	11.97	32.00	31.60	14.01
	Mangrove	10.29	3.38	1.60	21.20	32.70	32.30	16.91
	Fallow	4.42	1.10	1.09	7.68	30.40	31.70	12.73
RRS, Vyttila	Paddy alone (a)	5.43	0.49	1.56	6.69	18.50	12.50	7.53
	Paddy alone (b)	3.86	1.50	2.82	4.46	18.80	7.20	6.44
	Paddy alone (c)	4.24	1.55	4.17	3.20	12.70	2.40	4.71
Mean		8.75	4.35	2.78	12.11	29.33	26.72	-
CD (0.05)		Months			0.446			
		Locations/Land use			0.704			
		Interaction			1.726			

Table 45b. Spatial and temporal variations in electrical conductivity (dS m^{-1}) of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	13.44	6.97	3.71	15.87	34.20	30.10	17.38
	Shrimp alone	15.19	6.98	3.42	17.23	34.60	29.10	17.75
	Mangrove	15.15	6.83	3.28	17.20	33.80	29.00	17.54
	Fallow	13.06	7.06	3.72	16.20	33.80	30.30	17.36
Kottuvally	Paddy - Shrimp	10.42	5.31	2.87	13.63	31.10	32.00	15.89
	Shrimp alone	10.65	5.29	2.84	14.80	30.50	32.10	16.03
	Mangrove	10.74	3.37	1.89	13.60	27.70	30.00	14.55
	Fallow	1.42	5.23	2.77	13.98	31.50	32.00	14.48
Kadamakudy	Paddy - Shrimp	4.38	0.65	0.98	12.59	30.40	32.00	13.50
	Shrimp alone	8.96	0.66	0.97	11.96	30.60	32.40	14.26
	Mangrove	4.24	1.83	2.60	16.13	30.50	32.80	14.68
	Fallow	4.24	0.67	0.96	12.02	30.30	32.10	13.38
RRS, Vyttila	Paddy alone (a)	0.38	0.21	0.19	4.74	7.00	2.30	2.47
	Paddy alone (b)	0.37	0.21	0.20	4.60	7.30	2.20	2.48
	Paddy alone (c)	0.23	0.21	0.20	4.69	7.00	2.30	2.44
Mean		7.52	3.43	2.04	12.62	26.69	25.38	-
CD (0.05)		Months			0.450			
		Locations/Land use			0.711			
		Interaction			1.741			

Table 46a. Spatial and temporal variations in total soluble salt (TSS) (mg L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	7264.0	5126.4	3155.2	10342.4	22272	19008	11194.7
	Shrimp alone	10150.4	4518.4	2272	10745.6	22336	18816	11473.1
	Mangrove	3296.0	4672.0	2227.2	11097.6	22208	19264	10460.8
	Fallow	8448.0	5433.6	2931.2	8806.4	21504	19392	11085.8
Kottuvally	Paddy - Shrimp	3456.0	4211.2	2099.2	7808.0	20224	21312	9851.7
	Shrimp alone	7334.4	6169.6	2630.4	7238.4	20160	20800	10722.1
	Mangrove	4684.8	2156.8	1568.0	8569.6	19328	20096	9400.5
	Fallow	5536.0	2316.8	1350.4	6988.8	20096	21888	9696.0
Kadamakudy	Paddy - Shrimp	12371.2	817.9	385.3	9324.8	20608	20608	10685.8
	Shrimp alone	3379.2	1198.1	862.1	7660.8	20480	20224	8967.3
	Mangrove	6585.6	2163.2	1022.1	13568	20928	20672	10823.1
	Fallow	2828.8	705.9	700.1	4915.2	19456	20288	8149.0
RRS, Vyttila	Paddy alone (a)	3475.2	312.9	1000.3	4281.6	11840	8000	4818.3
	Paddy alone (b)	2470.4	956.8	1804.8	2854.4	12032	4608	4121.0
	Paddy alone (c)	2713.6	990.7	2668.8	2048.0	8128	1536	3014.2
Mean		5599.5	2783.4	1778.4	7749.9	18773	17100	
CD (0.05)		Months			320.134			
		Locations/Land use			506.176			
		Interaction			1,239.874			

Table 46b. Spatial and temporal variations in total soluble salt (TSS) (mg L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	8601.6	4460.8	2374.4	10156.8	21888	19264	11124.2
	Shrimp alone	9721.6	4467.2	2188.8	11027.2	22144	18624	11362.1
	Mangrove	9696.0	4371.2	2099.2	11008.0	21632	18560	11227.7
	Fallow	8358.4	4518.4	2380.8	10368.0	21632	19392	11108.2
Kottuvally	Paddy - Shrimp	6668.8	3398.4	1836.8	8723.2	19904	20480	10168.5
	Shrimp alone	6816.0	3385.6	1817.6	9472.0	19520	20544	10259.2
	Mangrove	6873.6	2156.8	1212.1	8704.0	17728	19200	9312.4
	Fallow	907.52	3347.2	1772.8	8947.2	20160	20480	9269.1
Kadamakudy	Paddy - Shrimp	2803.2	413.4	627.8	8057.6	19456	20480	8639.6
	Shrimp alone	5734.4	419.8	618.2	7654.4	19584	20736	9124.4
	Mangrove	2713.6	1173.7	1664	10323.2	19520	20992	9397.7
	Fallow	2713.6	428.1	613.7	7692.8	19392	20544	8564.0
RRS, Vyttila	Paddy alone (a)	243.8	133.1	124.1	3033.6	4480	1472	1581.1
	Paddy alone (b)	238.0	132.4	126.0	2944.0	4672	1408	1586.7
	Paddy alone (c)	149.1	131.8	126.5	3001.6	4480	1472	1560.2
Mean		4815.9	2195.8	1305.5	8074.0	17079	16243	
CD (0.05)		Months			384.159			
		Locations/Land use			607.408			
		Interaction			1,487.840			

Table 47a. Spatial and temporal variations in water soluble calcium (mg L^{-1}) of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	99.20	70.40	24.70	105.10	272.30	214.20	130.98
	Shrimp alone	114.10	55.90	20.00	109.00	315.50	241.45	142.66
	Mangrove	32.20	53.85	20.45	107.20	273.05	251.15	122.98
	Fallow	91.90	61.80	25.95	94.70	291.70	257.30	137.23
Kottuvally	Paddy - Shrimp	43.05	56.75	23.00	76.25	214.80	266.55	113.40
	Shrimp alone	71.40	75.05	24.35	75.75	217.95	282.70	124.53
	Mangrove	45.45	38.50	21.55	98.25	247.65	264.20	119.27
	Fallow	65.25	62.40	17.20	90.20	247.65	316.60	133.22
Kadamakudy	Paddy - Shrimp	137.70	20.95	15.50	101.10	251.25	244.00	128.42
	Shrimp alone	32.50	25.85	10.15	82.35	255.75	260.60	111.20
	Mangrove	66.95	20.80	10.65	140.60	138.15	260.95	106.35
	Fallow	29.30	32.60	9.25	52.30	240.35	232.20	99.33
RRS, Vyttila	Paddy alone (a)	42.90	23.50	17.75	53.55	136.85	139.05	68.93
	Paddy alone (b)	46.35	54.95	32.15	35.55	142.10	80.65	65.29
	Paddy alone (c)	38.80	43.95	31.90	33.35	98.55	22.10	44.78
Mean		63.80	46.48	20.30	83.68	222.91	222.25	-
CD (0.05)		Months			10.838			
		Locations/Land use			17.137			
		Interaction			41.976			

Table 47b. Spatial and temporal variations in water soluble calcium (mg L^{-1}) of source water

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	84.90	60.05	20.15	112.00	274.05	242.87	132.34
	Shrimp alone	113.90	56.00	16.85	127.20	270.70	210.10	132.46
	Mangrove	108.55	56.80	20.80	125.20	273.85	208.95	132.36
	Fallow	89.80	53.55	22.15	109.05	272.05	239.45	131.01
Kottuvally	Paddy - Shrimp	71.50	48.30	17.65	92.80	280.65	280.65	131.93
	Shrimp alone	67.90	47.00	20.55	96.45	280.70	274.25	131.14
	Mangrove	65.00	34.35	18.45	97.25	214.70	250.85	113.43
	Fallow	66.00	47.25	17.70	91.75	246.25	247.75	119.45
Kadamakudy	Paddy - Shrimp	17.50	16.75	14.00	84.45	237.65	270.55	106.82
	Shrimp alone	28.70	14.60	8.10	75.40	275.50	259.00	110.22
	Mangrove	65.95	20.20	8.20	110.00	262.05	257.50	120.65
	Fallow	26.50	13.65	8.20	90.70	248.05	246.15	105.54
RRS, Vyttila	Paddy alone (a)	20.25	15.95	8.60	52.40	55.50	27.50	30.03
	Paddy alone (b)	18.95	18.95	8.80	48.80	55.35	20.30	28.53
	Paddy alone (c)	55.05	22.90	11.20	54.25	46.55	19.95	34.98
Mean		60.03	35.09	14.76	91.18	219.57	203.72	-
CD (0.05)		Months			8.528			
		Locations/Land use			13.479			
		Interaction			33.018			

Table 48a. Spatial and temporal variations in water soluble magnesium (mg L^{-1}) of field water

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	279.0	186.3	82.3	408.9	997.5	812	461.0
	Shrimp alone	345.3	156.0	60.1	389.5	987.5	886	470.7
	Mangrove	88.2	143.2	59.5	445.8	845.25	865	407.8
	Fallow	293.9	173.9	79.5	311.6	963	924	457.6
Kottuvally	Paddy - Shrimp	190.4	131.9	53.7	227.2	723.5	974.5	383.5
	Shrimp alone	245.2	197.3	71.0	234.05	830.75	981.25	426.6
	Mangrove	149.1	68.0	44.9	296.6	661	806	337.6
	Fallow	202.4	71.2	28.5	250	683.5	903.5	356.5
Kadamakudy	Paddy - Shrimp	450.9	22.6	10.1	315.3	931	1017.7	457.9
	Shrimp alone	110.1	35.9	23.0	256.85	670	981	346.1
	Mangrove	229.0	28.8	24.1	460.1	941.5	1024	451.2
	Fallow	88.1	57.0	19.5	154.05	782.5	957.25	343.1
RRS, Vyttila	Paddy alone (a)	107.2	49.6	46.3	133.35	453.75	338	188.0
	Paddy alone (b)	89.1	78.2	76.0	79.75	445.75	213.25	163.7
	Paddy alone (c)	90.8	66.1	57.5	60.7	274	57.75	101.1
Mean		197.2	97.7	49.0	268.3	746.0	782.8	-
CD (0.05)		Months			13.021			
		Locations/Land use			20.589			
		Interaction			50.431			

Table 48b. Spatial and temporal variations in water soluble magnesium (mg L^{-1}) of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	220.9	162.9	55.7	348.5	1036.7	805.2	438.3
	Shrimp alone	347.8	149.6	55.3	406.8	940.0	818.7	453.0
	Mangrove	335.8	149.1	56.7	390.7	995.5	811.2	456.5
	Fallow	299.5	138.9	61.5	339	1049.2	947.5	472.6
Kottuvally	Paddy - Shrimp	239.7	109.7	45.1	291	982.7	975.2	440.6
	Shrimp alone	223.9	106.2	52.9	308.8	853.5	931.5	412.8
	Mangrove	310.0	60.6	32.6	298.55	745.2	1000.0	407.8
	Fallow	231.0	115.9	44.6	301.65	744.2	1081.2	419.8
Kadamakudy	Paddy - Shrimp	31.0	13.7	16.8	266.2	973.7	976.2	379.6
	Shrimp alone	90.8	11.5	17.0	237.4	835.2	1028.0	370.0
	Mangrove	218.6	32.0	42.3	390.9	872.2	952.5	418.1
	Fallow	74.4	11.5	17.0	274.4	775.0	906.2	343.1
RRS, Vyttila	Paddy alone (a)	10.5	3.3	3.0	95.85	381.7	146.4	106.8
	Paddy alone (b)	9.9	3.3	2.7	84.15	377.0	114.4	98.6
	Paddy alone (c)	48.8	3.5	3.1	96.9	322.3	119.4	99.0
Mean		179.5	71.4	33.7	275.4	792.3	774.3	-
CD (0.05)		Months			14.907			
		Locations/Land use			23.569			
		Interaction			57.733			

Table 49a. Spatial and temporal variations in water soluble sodium (mg L^{-1}) of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2215.0	1531.0	954.3	3326.5	8908	6772	3951.1
	Shrimp alone	2718.0	1391.0	697.3	3368.5	8807	7195	4029.5
	Mangrove	1981.3	1493.8	661.8	3229.5	8600	7592	3926.4
	Fallow	2543.5	1547.0	917.0	2732	8861	7964	4094.1
Kottuvally	Paddy - Shrimp	1054.8	1211.5	635.8	2040.5	7685	7877	3417.4
	Shrimp alone	1235.0	1904.3	805.5	2167.5	7649	7898	3609.9
	Mangrove	1325.3	622.5	393.5	2566	7214	7921	3340.4
	Fallow	1707.3	641.0	367.8	2261.5	7459	8892	3554.8
Kadamakudy	Paddy - Shrimp	1637.0	241.8	96.8	2772	8198	8602	3591.3
	Shrimp alone	988.8	372.0	226.8	2271.5	8095	8082	3339.3
	Mangrove	2022.5	814.8	353.8	4118.5	8409	8882	4100.1
	Fallow	771.3	254.8	186.8	1318.5	7369	7693	2932.2
RRS, Vyttila	Paddy alone (a)	983.5	157.8	348.8	1103	3307	2565	1410.8
	Paddy alone (b)	634.8	309.3	551.5	669.5	4332	1343	1306.7
	Paddy alone (c)	640.5	311.5	678.3	733	2465	1426	1042.4
Mean		1497.2	853.6	525.0	2311.9	7157.2	6713.6	-
CD (0.05)		Months			322.511			
		Locations/Land use			509.934			
		Interaction			1,249.079			

Table 49b. Spatial and temporal variations in water soluble sodium (mg L^{-1}) of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	2447.3	1357.3	687.8	3407	8670	7123	3948.7
	Shrimp alone	2690.8	1315.0	606.3	3823	8095	7000	3921.7
	Mangrove	2048.3	1213.8	568.8	3558.5	8371	6952	3785.4
	Fallow	2378.3	1381.5	674.8	3030.5	8334	7761	3926.7
Kottuvally	Paddy - Shrimp	2057.5	1016.8	523.5	2669	7705	7981	3658.8
	Shrimp alone	2010.8	1013.8	488.8	2716.5	7354	8156	3623.3
	Mangrove	2025.0	546.8	326.5	2688.5	6432	7631	3275.0
	Fallow	2057.8	1066.8	481.8	2797	7625	7908	3656.0
Kadamakudy	Paddy - Shrimp	256.5	127.5	156.8	2430	7668	7793	3072.0
	Shrimp alone	738.3	175.0	153.5	2132	7666	8230	3182.5
	Mangrove	1669.3	373.0	449.5	3152	7533	8508	3614.1
	Fallow	721.3	99.0	20.1	2458.5	7766	8014	3179.8
RRS, Vyttila	Paddy alone (a)	70.5	20.3	20.8	786.5	1565.5	609.5	512.2
	Paddy alone (b)	106.0	20.6	20.1	697.5	1568.5	455	478.0
	Paddy alone (c)	351.8	20.9	20.6	818.5	1350	475.5	506.2
Mean		1441.9	649.9	346.6	2477.7	6513.5	6306.5	-
CD (0.05)		Months			249.648			
		Locations/Land use			394.728			
		Interaction			966.882			

Table 50a. Spatial and temporal variations in water soluble potassium (mg L^{-1}) of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	77.29	60.37	36.90	88.00	324.50	281.00	144.68
	Shrimp alone	120.70	53.13	26.11	130.50	360.50	314.50	167.57
	Mangrove	62.65	56.13	25.80	123.00	323.00	330.00	153.43
	Fallow	85.92	64.32	34.33	79.59	346.00	325.50	155.94
Kottuvally	Paddy - Shrimp	56.81	49.53	25.32	75.18	251.50	327.00	130.89
	Shrimp alone	80.12	74.75	30.91	68.08	271.00	331.00	142.64
	Mangrove	50.73	24.66	16.97	78.32	293.50	324.50	131.45
	Fallow	65.31	27.12	13.19	67.87	281.00	372.00	137.75
Kadamakudy	Paddy - Shrimp	145.05	10.61	5.61	83.34	303.00	310.50	143.02
	Shrimp alone	41.24	15.64	11.08	71.33	324.50	325.50	131.55
	Mangrove	75.12	27.56	13.18	154.00	307.50	332.50	151.64
	Fallow	32.89	9.23	7.37	47.77	289.50	289.00	112.63
RRS, Vyttila	Paddy alone (a)	38.54	4.99	13.43	43.45	190.00	118.00	68.07
	Paddy alone (b)	27.96	10.41	23.66	36.24	193.00	60.00	58.55
	Paddy alone (c)	28.75	10.80	30.68	33.28	133.50	24.50	43.59
Mean		65.94	33.28	20.97	78.66	279.47	271.03	
CD (0.05)		Months			10.402			
		Locations/Land use			16.448			
		Interaction			40.288			

Table 50b. Spatial and temporal variations in water soluble potassium (mg L^{-1}) of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	86.94	53.76	27.77	89.32	328.00	311.00	149.47
	Shrimp alone	113.55	52.93	24.30	142.50	335.00	280.00	158.05
	Mangrove	116.45	52.52	23.37	134.50	331.00	279.00	156.14
	Fallow	86.07	53.20	27.24	113.00	327.50	303.50	151.75
Kottuvally	Paddy - Shrimp	76.95	41.39	21.22	82.03	320.00	336.50	146.35
	Shrimp alone	76.75	41.64	20.91	85.68	319.00	327.00	145.16
	Mangrove	75.20	24.18	14.12	80.75	269.50	303.50	127.88
	Fallow	76.84	41.34	20.55	81.90	299.00	298.00	136.27
Kadamakudy	Paddy - Shrimp	12.03	5.61	8.26	75.40	288.50	324.50	119.05
	Shrimp alone	32.22	5.42	8.24	74.98	328.00	322.50	128.56
	Mangrove	67.02	14.68	17.43	75.26	311.50	319.50	134.23
	Fallow	32.45	5.46	8.47	74.74	306.50	310.00	122.94
RRS, Vyttila	Paddy alone (a)	25.41	3.20	3.32	32.60	52.43	24.63	23.60
	Paddy alone (b)	25.57	3.15	3.28	32.51	53.12	21.03	23.11
	Paddy alone (c)	20.77	3.17	3.30	31.38	52.76	20.75	22.02
Mean		61.61	26.78	15.45	80.44	261.45	252.09	-
CD (0.05)		Months			6.454			
		Locations/Land use			10.205			
		Interaction			24.996			

Table 51a. Spatial and temporal variations in bicarbonate (mEq L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.80	1.00	1.40	1.60	2.00	1.80	1.43
	Shrimp alone	0.60	1.00	1.40	1.00	2.00	1.60	1.27
	Mangrove	0.80	1.20	1.20	1.20	2.00	1.20	1.27
	Fallow	0.80	1.20	1.20	0.80	1.60	1.40	1.17
Kottuvally	Paddy - Shrimp	1.00	1.40	1.40	1.40	2.00	1.40	1.43
	Shrimp alone	0.80	1.00	1.20	1.60	1.80	1.80	1.37
	Mangrove	1.00	1.00	0.60	0.80	0.60	1.20	0.87
	Fallow	0.80	1.80	1.20	1.00	1.00	1.20	1.17
Kadamakudy	Paddy - Shrimp	0.80	0.60	0.40	0.80	1.60	1.60	0.97
	Shrimp alone	0.80	0.80	0.40	1.00	1.40	1.20	0.93
	Mangrove	0.80	0.60	0.80	1.20	1.40	1.40	1.03
	Fallow	0.80	0.60	0.60	0.80	1.60	1.60	1.00
RRS, Vyttila	Paddy alone (a)	0.20	0.80	1.20	1.00	1.20	0.60	0.83
	Paddy alone (b)	0.20	1.40	1.20	2.40	2.20	0.40	1.30
	Paddy alone (c)	0.10	1.00	1.40	1.40	2.40	1.00	1.22
Mean		0.69	1.03	1.04	1.20	1.65	1.29	-
CD (0.05)		Months			0.145			
		Locations/Land use			0.229			
		Interaction			0.560			

Table 51b. Spatial and temporal variations in bicarbonate (mEq L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1.00	1.00	1.40	1.00	1.60	1.60	1.27
	Shrimp alone	1.20	1.00	1.20	1.20	1.60	1.60	1.30
	Mangrove	1.20	1.00	1.20	1.00	1.40	1.40	1.20
	Fallow	0.80	1.20	1.40	1.00	1.40	1.40	1.20
Kottuvally	Paddy - Shrimp	1.20	1.20	1.20	1.00	1.60	1.40	1.27
	Shrimp alone	1.00	1.20	0.40	1.20	1.60	1.20	1.10
	Mangrove	1.20	0.80	1.40	0.80	1.40	1.20	1.13
	Fallow	1.20	1.00	1.40	0.60	1.60	1.40	1.20
Kadamakudy	Paddy - Shrimp	0.80	0.60	0.80	1.20	1.20	1.20	0.97
	Shrimp alone	1.00	0.80	0.80	1.00	1.20	1.40	1.03
	Mangrove	0.80	0.60	1.40	1.40	1.60	1.40	1.20
	Fallow	0.80	0.60	0.80	1.00	1.20	1.20	0.93
RRS, Vyttila	Paddy alone (a)	0.60	2.00	0.80	1.20	1.00	1.60	1.20
	Paddy alone (b)	0.60	1.80	0.80	1.40	0.80	1.40	1.13
	Paddy alone (c)	0.80	1.40	1.00	1.40	1.00	1.20	1.13
Mean		0.69	0.95	1.08	1.07	1.09	1.35	1.37
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

Table 52a. Spatial and temporal variations in nitrate (mg L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.05	0.01	0.03	0.00	0.00	0.00	0.02
	Shrimp alone	0.05	0.01	0.03	0.00	0.00	0.00	0.02
	Mangrove	0.02	0.02	0.03	0.00	0.00	0.00	0.01
	Fallow	0.09	0.00	0.06	0.06	0.01	0.00	0.04
Kottuvally	Paddy - Shrimp	0.05	0.10	0.06	0.09	0.01	0.00	0.05
	Shrimp alone	0.02	0.00	0.13	0.13	0.00	0.00	0.05
	Mangrove	0.02	0.02	0.06	0.03	0.00	0.01	0.03
	Fallow	0.02	0.01	0.07	0.09	0.01	0.00	0.03
Kadamakudy	Paddy - Shrimp	0.07	0.05	0.06	0.00	0.01	0.00	0.03
	Shrimp alone	0.05	0.04	0.06	0.03	0.00	0.00	0.03
	Mangrove	0.05	0.00	0.11	0.00	0.00	0.00	0.03
	Fallow	0.02	0.02	0.13	0.00	0.00	0.00	0.03
RRS, Vyttila	Paddy alone (a)	0.03	0.01	0.11	0.15	0.01	0.03	0.06
	Paddy alone (b)	0.05	0.03	0.09	0.00	0.01	0.02	0.04
	Paddy alone (c)	0.02	0.02	0.13	0.13	0.03	0.01	0.06
Mean		0.04	0.02	0.08	0.05	0.01	0.01	-
CD (0.05)		Months			0.001			
		Locations/Land use			0.002			
		Interaction			0.005			

Table 52b. Spatial and temporal variations in nitrate (mg L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.00	0.02	0.06	0.03	0.00	0.00	0.02
	Shrimp alone	0.00	0.02	0.06	0.03	0.00	0.01	0.02
	Mangrove	0.02	0.02	0.03	0.00	0.00	0.00	0.01
	Fallow	0.04	0.01	0.03	0.06	0.00	0.00	0.02
Kottuvally	Paddy - Shrimp	0.01	0.02	0.09	0.13	0.00	0.00	0.04
	Shrimp alone	0.01	0.02	0.06	0.09	0.00	0.00	0.03
	Mangrove	0.00	0.02	0.09	0.09	0.00	0.00	0.04
	Fallow	0.02	0.03	0.09	0.00	0.00	0.00	0.03
Kadamakudy	Paddy - Shrimp	0.04	0.03	0.06	0.00	0.01	0.01	0.03
	Shrimp alone	0.01	0.03	0.06	0.00	0.01	0.01	0.02
	Mangrove	0.02	0.04	0.09	0.06	0.01	0.01	0.04
	Fallow	0.02	0.03	0.09	0.00	0.01	0.01	0.03
RRS, Vyttila	Paddy alone (a)	0.02	0.06	0.13	0.09	0.02	0.03	0.06
	Paddy alone (b)	0.00	0.04	0.09	0.06	0.02	0.03	0.04
	Paddy alone (c)	0.13	0.08	0.14	0.06	0.02	0.02	0.08
Mean		0.02	0.03	0.08	0.05	0.01	0.01	-
CD (0.05)		Months			0.001			
		Locations/Land use			0.002			
		Interaction			0.005			

Table 53a. Spatial and temporal variations in phosphate (mg L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.278	0.193	0.467	0.235	0.377	0.336	0.314
	Shrimp alone	0.290	0.183	0.234	0.229	0.240	0.281	0.243
	Mangrove	0.326	0.318	0.234	0.230	0.307	0.247	0.277
	Fallow	0.216	0.404	0.408	0.249	0.337	0.331	0.324
Kottuvally	Paddy - Shrimp	0.245	0.424	0.679	0.361	0.321	0.241	0.379
	Shrimp alone	0.258	0.280	0.383	0.486	0.247	0.658	0.385
	Mangrove	0.276	0.103	0.146	0.222	0.359	0.698	0.301
	Fallow	0.221	0.110	0.707	0.583	0.433	0.378	0.405
Kadamakudy	Paddy - Shrimp	0.547	0.126	0.140	0.240	0.295	0.273	0.270
	Shrimp alone	0.358	0.154	0.117	0.212	0.238	0.262	0.224
	Mangrove	0.410	0.273	0.155	0.232	0.299	0.298	0.278
	Fallow	0.321	0.106	0.155	0.211	0.248	0.276	0.220
RRS, Vyttila	Paddy alone (a)	0.183	0.190	0.148	0.300	1.163	0.237	0.370
	Paddy alone (b)	0.172	0.182	0.146	0.291	1.211	0.341	0.391
	Paddy alone (c)	0.197	0.122	0.164	0.153	0.956	0.663	0.376
Mean		0.287	0.211	0.286	0.282	0.469	0.368	-
CD (0.05)		Months			0.073			
		Locations/Land use			0.115			
		Interaction			0.281			

Table 53b. Spatial and temporal variations in phosphate (mg L^{-1}) content of source water

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.319	0.343	0.310	0.245	0.285	0.315	0.303
	Shrimp alone	0.322	0.311	0.229	0.258	0.326	0.290	0.289
	Mangrove	0.301	0.308	0.243	0.243	0.297	0.292	0.281
	Fallow	0.310	0.312	0.311	0.212	0.303	0.312	0.293
Kottuvally	Paddy - Shrimp	0.216	0.245	0.219	0.222	0.230	0.244	0.229
	Shrimp alone	0.210	0.211	0.222	0.232	0.304	0.211	0.232
	Mangrove	0.211	0.251	0.253	0.261	0.284	0.210	0.245
	Fallow	0.232	0.232	0.231	0.242	0.250	0.232	0.237
Kadamakudy	Paddy - Shrimp	0.292	0.191	0.101	0.222	0.324	0.238	0.228
	Shrimp alone	0.225	0.111	0.111	0.212	0.333	0.212	0.201
	Mangrove	0.210	0.124	0.232	0.242	0.315	0.232	0.226
	Fallow	0.211	0.120	0.120	0.220	0.314	0.213	0.200
RRS, Vyttila	Paddy alone (a)	0.180	0.646	0.255	0.255	2.008	0.330	0.612
	Paddy alone (b)	0.199	0.666	0.237	0.779	2.245	0.312	0.740
	Paddy alone (c)	0.302	0.671	0.215	0.804	2.216	0.345	0.759
Mean		0.249	0.316	0.219	0.310	0.669	0.266	-
CD (0.05)		Months			0.079			
		Locations/Land use			0.126			
		Interaction			0.308			

Table 54a. Spatial and temporal variations in borate (mg L^{-1}) content of field water

Locations	**Land Use**	**Months**						**Mean**
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1.02	0.77	0.65	1.39	2.56	2.34	1.45
	Shrimp alone	1.35	0.70	0.44	1.42	2.72	2.42	1.51
	Mangrove	0.66	0.74	0.42	1.48	2.75	2.47	1.42
	Fallow	1.17	0.70	0.53	1.23	2.31	2.11	1.34
Kottuvally	Paddy - Shrimp	0.66	0.74	0.44	1.14	2.44	2.55	1.33
	Shrimp alone	1.01	0.95	0.46	1.12	2.42	2.52	1.41
	Mangrove	0.72	0.41	0.32	1.18	2.40	2.50	1.26
	Fallow	0.82	0.38	0.27	1.00	2.39	2.40	1.21
Kadamakudy	Paddy - Shrimp	1.63	0.22	0.14	1.26	2.58	2.68	1.42
	Shrimp alone	0.65	0.24	0.21	1.21	2.51	2.64	1.24
	Mangrove	0.95	0.41	0.15	1.65	2.64	2.75	1.42
	Fallow	0.50	0.19	0.20	1.31	2.13	2.42	1.12
RRS, Vyttila	Paddy alone (a)	0.53	0.12	0.29	0.65	1.66	1.26	0.75
	Paddy alone (b)	0.50	0.15	0.35	0.51	1.51	0.66	0.62
	Paddy alone (c)	0.46	0.19	0.43	0.38	1.16	0.58	0.53
Mean		0.84	0.46	0.35	1.13	2.28	2.15	-
CD (0.05)		Months			0.214			
		Locations/Land use			0.338			
		Interaction			NS			

Table 54b. Spatial and temporal variations in borate (mg L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	1.11	0.70	0.43	1.38	2.58	2.33	1.42
	Shrimp alone	1.34	0.69	0.41	1.42	2.43	2.31	1.43
	Mangrove	1.37	0.69	0.38	1.58	2.54	2.32	1.48
	Fallow	1.01	0.73	0.41	1.31	2.40	2.36	1.37
Kottuvally	Paddy - Shrimp	0.96	0.59	0.34	1.22	2.51	2.39	1.34
	Shrimp alone	0.91	0.52	0.32	1.21	2.51	2.31	1.30
	Mangrove	0.91	0.39	0.24	1.35	2.62	2.32	1.31
	Fallow	0.94	0.56	0.31	1.21	2.51	2.30	1.30
Kadamakudy	Paddy - Shrimp	0.24	0.15	0.15	1.15	2.47	2.58	1.12
	Shrimp alone	0.33	0.13	0.15	1.21	2.52	2.61	1.16
	Mangrove	0.82	0.23	0.31	2.06	2.47	2.48	1.39
	Fallow	0.42	0.15	0.15	1.36	2.17	2.41	1.11
RRS, Vyttila	Paddy alone (a)	0.15	0.08	0.07	0.54	0.81	0.46	0.35
	Paddy alone (b)	0.16	0.07	0.07	0.54	0.80	0.30	0.32
	Paddy alone (c)	0.27	0.08	0.07	0.58	0.81	0.32	0.36
Mean		0.73	0.38	0.25	1.21	2.14	1.99	-
CD (0.05)		Months			0.213			
		Locations/Land use			0.337			
		Interaction			NS			

Table 55a. Spatial and temporal variations in chloride (mg L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	4615	3195	1775	6035	14129	14910	7443
	Shrimp alone	7455	2840	1775	6390	17242	12070	7962
	Mangrove	4130	3195	1065	6390	15265	13135	7197
	Fallow	5325	3905	2130	4260	14935	12780	7222
Kottuvally	Paddy - Shrimp	4260	2485	1420	4260	14733	14555	6952
	Shrimp alone	4840	3550	1775	4970	11609	14910	6942
	Mangrove	2840	1420	888	5325	12425	14555	6242
	Fallow	3550	1775	1065	4970	15798	14555	6952
Kadamakudy	Paddy - Shrimp	4970	1065	710	5325	13135	16330	6923
	Shrimp alone	2130	1065	1065	3905	15088	15265	6420
	Mangrove	4615	1775	710	6745	13668	14200	6952
	Fallow	2130	710	702	3195	13845	15265	5974
RRS, Vyttila	Paddy alone (a)	2130	710	710	2485	8520	4615	3195
	Paddy alone (b)	1775	1065	1065	1953	7455	3195	2751
	Paddy alone (c)	1775	710	710	1420	5325	1775	1953
Mean		3769	1964	1171	4509	12878	12141	-
CD (0.05)		Months			81.472			
		Locations/Land use			128.819			
		Interaction			315.540			

Table 55b. Spatial and temporal variations in chloride (mg L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	4970	2840	1420	6035	12040	13490	6799
	Shrimp alone	6745	2485	1775	7810	15975	14555	8224
	Mangrove	6390	2840	1420	6745	15975	14200	7928
	Fallow	5680	2840	1775	6390	16685	15265	8106
Kottuvally	Paddy - Shrimp	4615	2130	1065	4970	20235	15265	8047
	Shrimp alone	3905	2485	1420	5325	13845	14910	6982
	Mangrove	4970	4260	888	5325	11005	14200	6775
	Fallow	4615	2485	1420	4615	12425	14555	6686
Kadamakudy	Paddy - Shrimp	1065	710	710	4615	13490	16330	6153
	Shrimp alone	1775	710	710	8165	13490	14200	6508
	Mangrove	3550	1065	1065	5325	12425	15975	6568
	Fallow	2130	710	710	4615	11715	13845	5621
RRS, Vyttila	Paddy alone (a)	710	355	355	1775	3195	1775	1361
	Paddy alone (b)	533	310	710	1065	3550	1420	1265
	Paddy alone (c)	1065	355	533	1775	3195	1420	1390
Mean		3515	1772	1065	4970	11950	12094	
CD (0.05)				Months	74.476			
				Locations/Land use	117.758			
				Interaction	288.446			

Table 56a. Spatial and temporal variations in sulphate (mg L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	145.80	103.50	78.60	206.21	599.00	573.50	284.44
	Shrimp alone	341.90	235.21	70.20	256.13	590.50	533.50	337.91
	Mangrove	111.70	98.56	68.30	164.23	428.40	403.00	212.37
	Fallow	178.45	163.23	83.85	213.54	540.50	489.50	278.18
Kottuvally	Paddy - Shrimp	98.85	75.41	60.15	123.45	396.10	773.50	254.58
	Shrimp alone	151.30	130.56	116.10	202.84	411.35	603.00	269.19
	Mangrove	105.75	98.65	87.10	286.45	527.00	596.50	283.58
	Fallow	131.40	96.52	54.90	214.23	436.85	445.75	229.94
Kadamakudy	Paddy - Shrimp	230.80	162.51	91.05	198.45	454.80	465.00	267.10
	Shrimp alone	87.10	75.45	54.45	246.52	509.50	523.50	249.42
	Mangrove	76.05	70.12	77.15	135.59	495.10	456.50	218.42
	Fallow	68.40	65.33	61.65	212.45	319.90	311.50	173.21
RRS, Vyttila	Paddy alone (a)	89.00	75.12	66.85	68.52	70.60	80.95	75.17
	Paddy alone (b)	112.80	96.52	70.70	102.32	219.85	141.25	123.91
	Paddy alone (c)	190.60	90.62	78.10	98.65	135.35	136.10	121.57
Mean		141.33	109.15	74.61	181.97	408.99	435.54	-
CD (0.05)				Months	12.237			
				Locations/Land use	19.348			
				Interaction	47.393			

Table 56b. Spatial and temporal variations in sulphate (mg L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	255.35	156.45	96.65	268.12	767.00	502.50	341.01
	Shrimp alone	248.85	178.42	124.55	296.45	591.50	565.00	334.13
	Mangrove	230.25	144.63	106.90	213.54	537.00	423.95	276.05
	Fallow	197.25	163.21	60.35	312.51	597.00	521.50	308.64
Kottuvally	Paddy - Shrimp	175.95	156.52	40.05	356.32	519.50	639.00	314.56
	Shrimp alone	144.10	120.31	111.20	254.12	527.00	553.50	285.04
	Mangrove	150.55	99.85	71.00	298.46	571.00	579.50	295.06
	Fallow	150.60	100.23	50.95	212.32	577.00	580.00	278.52
Kadamakudy	Paddy - Shrimp	72.70	55.62	48.00	231.23	455.35	581.50	240.73
	Shrimp alone	69.55	55.21	34.85	365.23	727.00	753.00	334.14
	Mangrove	124.00	103.21	77.30	213.15	529.50	700.50	291.28
	Fallow	73.20	72.12	71.90	89.56	407.50	663.50	229.63
RRS, Vyttila	Paddy alone (a)	62.05	54.32	34.35	99.65	128.75	145.65	87.46
	Paddy alone (b)	53.20	55.42	70.15	98.23	176.55	156.65	101.70
	Paddy alone (c)	90.60	88.26	77.25	99.25	186.70	128.55	111.77
Mean		139.88	106.92	71.70	227.21	486.56	499.62	-
CD (0.05)		Months			18.493			
		Locations/Land use			29.241			
		Interaction			71.625			

4.2.4. Heavy metals

Water soluble nickel, chromium, lead, arsenic and mercury in field and source water were below detectable level (<0.001 mg L^{-1}). But water soluble cadmium was detected from 0.001(October) to 0.006 mg L^{-1} (April) in field water and 0.001 mg L^{-1} (high saline phase) in source water (tables 57a and 57b). Among land uses, it ranges from 0.001(fallow land in Kotuvally, paddy-shrimp and fallow land in Kadamakudy) to 0.011 mg L^{-1} (mangrove in Kadamakudy). Water soluble cadmium was absent in fallow land in Ezhikkara. In source water, fifty percentage of the land uses were free from water soluble cadmium unlike most of the land uses which were found to contain cadmium from 0.001 to 0.002 mg L^{-1}

Table 57a. Spatial and temporal variations in cadmium (mg L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.000	0.000	0.000	0.000	0.000	0.010	0.002
	Shrimp alone	0.000	0.000	0.000	0.000	0.000	0.010	0.002
	Mangrove	0.001	0.000	0.000	0.000	0.010	0.010	0.004
	Fallow	0.000	0.000	0.000	0.000	0.000	0.00	0.000
Kottuvally	Paddy - Shrimp	0.001	0.00	0.001	0.010	0.000	0.002	0.003
	Shrimp alone	0.002	0.002	0.002	0.00	0.001	0.001	0.002
	Mangrove	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fallow	0.001	0.002	0.001	0.002	0.001	0.001	0.001
Kadamakudy	Paddy - Shrimp	0.000	0.001	0.001	0.000	0.000	0.001	0.001
	Shrimp alone	0.010	0.010	0.00	0.00	0.011	0.00	0.010
	Mangrove	0.010	0.010	0.012	0.011	0.011	0.010	0.011
	Fallow	0.001	0.002	0.000	0.000	0.001	0.001	0.001
RRS, Vyttila	Paddy alone (a)	0.000	0.000	0.000	0.000	0.000	0.010	0.002
	Paddy alone (b)	0.000	0.000	0.000	0.000	0.000	0.010	0.002
	Paddy alone (c)	0.000	0.000	0.000	0.000	0.000	0.010	0.002
Mean		0.002	0.002	0.001	0.002	0.002	0.006	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

Table 57b. Spatial and temporal variations in cadmium (mg L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.001	0.000	0.000	0.001	0.000	0.000	0.000
	Shrimp alone	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mangrove	0.000	0.001	0.001	0.002	0.000	0.001	0.001
	Fallow	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kottuvally	Paddy - Shrimp	0.002	0.001	0.000	0.001	0.002	0.004	0.002
	Shrimp alone	0.001	0.000	0.000	0.000	0.002	0.001	0.001
	Mangrove	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fallow	0.002	0.000	0.000	0.001	0.002	0.002	0.001
Kadamakudy	Paddy - Shrimp	0.001	0.000	0.000	0.001	0.002	0.001	0.001
	Shrimp alone	0.001	0.000	0.000	0.002	0.002	0.001	0.001
	Mangrove	0.002	0.002	0.000	0.001	0.001	0.002	0.001
	Fallow	0.001	0.002	0.001	0.001	0.002	0.001	0.001
RRS, Vyttila	Paddy alone (a)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Paddy alone (b)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Paddy alone (c)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mean		0.001	0.000	0.000	0.001	0.001	0.001	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

Table 58a. Spatial and temporal variations in cobalt (mg L^{-1}) content of field water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.001	0.000	0.000	0.000	0.001	0.001	0.001
	Shrimp alone	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mangrove	0.000	0.000	0.001	0.000	0.001	0.002	0.001
	Fallow	0.001	0.001	0.001	0.001	0.001	0.002	0.001
Kottuvally	Paddy - Shrimp	0.001	0.000	0.000	0.001	0.002	0.002	0.001
	Shrimp alone	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mangrove	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fallow	0.001	0.000	0.000	0.000	0.002	0.002	0.001
Kadamakudy	Paddy - Shrimp	0.001	0.002	0.000	0.000	0.001	0.002	0.001
	Shrimp alone	0.001	0.000	0.000	0.001	0.001	0.001	0.001
	Mangrove	0.001	0.001	0.002	0.002	0.001	0.001	0.001
	Fallow	0.001	0.002	BDL	0.002	0.001	0.001	0.001
RRS, Vyttila	Paddy alone (a)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Paddy alone (b)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Paddy alone (c)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mean		0.001	0.000	0.000	0.000	0.001	0.001	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

Table 58b. Spatial and temporal variations in cobalt (mg L^{-1}) content of source water

Locations	Land Use	Months						Mean
		Jun	Aug	Oct	Dec	Feb	Apr	
Ezhikkara	Paddy - Shrimp	0.001	0.000	0.000	0.002	0.001	0.001	0.001
	Shrimp alone	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mangrove	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fallow	0.002	0.002	0.001	0.002	0.002	0.001	0.002
Kottuvally	Paddy - Shrimp	0.001	0.002	0.001	0.002	0.001	0.001	0.001
	Shrimp alone	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mangrove	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fallow	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kadamakudy	Paddy - Shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Shrimp alone	0.002	0.000	0.000	0.000	0.001	0.001	0.001
	Mangrove	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Fallow	0.001	0.002	0.002	0.002	0.002	0.003	0.002
RRS, Vyttila	Paddy alone (a)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Paddy alone (b)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Paddy alone (c)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mean		0.001	0.000	0.000	0.001	0.001	0.001	-
CD (0.05)		Months			NS			
		Locations/Land use			NS			
		Interaction			NS			

4.3. Weather parameters

4.3.1. Average rainfall

In Ezhikkara and Kottuvally, highest average rainfall (9.76 mm day^{-1}) was received in August and the lowest in December (0.01 mm day^{-1}). In Kadamakudy and Vyttila region the highest rainfall of 12.23 mm day^{-1} was received during October and the lowest in December (0.07 mm day^{-1})(table 59).

4.3.2. Relative humidity

The highest relative humidity was observed in June (89.96 to 91.15 %) and the lowest in February (55.26 to 73.79 %) in all the locations. Irrespective of the locations, relative humidity over the experimental period followed the order June > August≥ October> April> December> February irrespective of the locations (table 60)

4.4. Correlation study

4.4.1. Correlations between electro chemical properties and nutrient status in lowlands

Correlation between electrochemical properties and nutrient status in lowland soil are given in table 61. Soil pH was significantly and negatively correlated to redox potential(-0.538**), electrical conductivity (-0.432**), available potassium (-0.315**), available zinc (-0.346**), available copper (-0.584**), available iron (-0.385**), available manganese (-0.496**) and negatively correlated to available sulphur (-0.219*). Electrical conductivity was significantly and positively correlated to available potassium (0.625**), available calcium (0.591**), available magnesium (0.505**), available sulphur (0.408**), available zinc (0.462**), available copper (0.506**), available iron (0.487**), available manganese (0.632**), available boron (0.507**) and significantly and negatively correlated to available phosphorus (-0.526**).

Available phosphorus was significantly and negatively correlated to available zinc (-0.378**), available copper (-0.332**), available iron (-0.465**), available manganese (-0.452**) and negatively correlated to available calcium (-0.231*) and available magnesium (-0.218*). Available potassium was significantly and positively correlated to available calcium (0.451**), available magnesium (0.479**), available sulphur (0.328**), available copper (0.391**),available iron (0.300**), available manganese (0.399**) and available boron (0.586**).

Table 59. Average rainfall (mm day^{-1}) of land uses in different locations

Locations	Land Use	Months					
		Jun	Aug	Oct	Dec	Feb	Apr
Ezhikkara	Paddy - Shrimp	4.85	9.76	3.21	0.04	0.12	1.94
	Shrimp alone	4.85	9.76	3.21	0.01	0.12	1.94
	Mangrove	4.85	9.76	3.21	0.01	0.12	1.94
	Fallow	4.85	9.76	3.21	0.04	0.12	1.94
Kottuvally	Paddy - Shrimp	4.48	9.76	3.21	0.01	0.12	1.94
	Shrimp alone	4.48	9.76	3.21	0.01	0.12	1.94
	Mangrove	4.48	9.76	3.21	0.01	0.12	1.94
	Fallow	4.48	9.76	3.21	0.01	0.12	1.94
Kadamakudy	Paddy - Shrimp	2.51	5.36	12.23	0.07	2.36	2.16
	Shrimp alone	2.51	5.36	12.23	0.07	2.36	2.16
	Mangrove	2.51	5.36	12.23	0.07	2.36	2.16
	Fallow	2.51	5.36	12.23	0.07	2.36	2.16
RRS, Vyttila	Paddy alone (a)	2.51	5.36	12.23	0.07	2.36	2.16
	Paddy alone (b)	2.51	5.36	12.23	0.07	2.36	2.16
	Paddy alone (c)	2.51	5.36	12.23	0.07	2.36	2.16

Table 60. Relative humidity (%) of land uses in different locations

Locations	Land Use	Months					
		Jun	Aug	Oct	Dec	Feb	Apr
Ezhikkara	Paddy - Shrimp	89.96	87.61	88.53	70.86	55.26	81.9
	Shrimp alone	89.96	87.61	88.53	70.86	55.26	81.9
	Mangrove	89.96	87.61	88.53	72.47	55.26	81.9
	Fallow	89.96	87.61	88.53	70.86	55.26	81.9
Kottuvally	Paddy - Shrimp	89.96	87.61	88.53	72.47	55.26	81.9
	Shrimp alone	89.96	87.61	88.53	72.47	55.26	81.9
	Mangrove	89.96	87.61	88.53	72.47	55.26	81.9
	Fallow	89.96	87.61	88.53	72.47	55.26	81.9
Kadamakudy	Paddy - Shrimp	90.52	87.94	87	73.64	68.44	77.36
	Shrimp alone	90.52	87.94	87	73.64	68.44	77.36
	Mangrove	90.52	87.94	87	73.64	68.44	77.36
	Fallow	90.52	87.94	87	73.64	68.44	77.36
RRS, Vyttila	Paddy alone (a)	90.52	87.94	87	73.64	68.44	77.36
	Paddy alone (b)	90.52	87.94	87	73.64	68.44	77.36
	Paddy alone (c)	90.52	87.94	87	73.64	68.44	77.36

Available calcium was positively and significantly correlated to available magnesium (0.687**), available sulphur (0.358**), available zinc (0.431**), available iron (0.425**), available manganese (0.361**) and available boron (0.584**). Available magnesium in lowland soil was significantly and positively correlated to available sulphur (0.314**), available zinc (0.362**), available copper (0.302**), available iron (0.473**), available manganese (0.417**) and available boron (0.607**). Available sulphur was significantly and positively correlated to available zinc (0.566**), available copper (0.313**), available iron (0.454**), available manganese (0.499**).

Available zinc in lowland soil was significantly and positively correlated to available copper (0.354**), available iron (0.669**), available manganese (0.629**). Available copper in lowland soil was significantly and positively correlated to available iron (0.345**), available manganese (0.542**). Available iron in lowland soil was significantly and positively correlated to available manganese (0.709**) and positively correlated to available boron (0.236*).

4.4.2. Correlation of AEC and exchangeable cations with electro chemical properties and nutrient status in lowlands

Table 62 explains the relationship of exchangeable cations and AEC with electro chemical properties and nutrient status in lowland soil. Anion exchange capacity was significantly and positively correlated to redox potential (0.464**), electrical conductivity (0.544**), available potassium (0.536**), available magnesium (0.599**), available sulphur (0.467**), available copper (0.656**), available iron (0.777**), available manganese (0.732**) and positively correlated to available zinc (0.420*), available boron (0.386*) and significantly and negatively correlated to pH (-0.783**) and available phosphorus (-0.456*).

Exchangeable sodium was significantly and positively correlated to electrical conductivity (0.553**), available potassium (0.502**), available magnesium (0.477**), available boron (0.468**) and positively correlated to available calcium (0.418*), available iron (0.419*), available manganese (0.374*).Exchangeable calcium of lowland soil was positively correlated to pH (0.450*), available phosphorus (0.416*) and significantly and negatively correlated to available potassium (-0.502**), available copper (-0.513**), available magnesium (-0.470**) and negatively correlated to electrical conductivity (-0.423*), available calcium (-0.378*), available zinc (-0.405*), available iron (-0.451*).

Exchangeable magnesium of lowland soil was significantly and positively correlated to pH (0.535**) and significantly and negatively correlated to electrical conductivity (-0.605**), available potassium (-0.547**), available copper (-0.573**), available manganese (-0.577**) and negatively correlated to available sulphur (-0.398*), available zinc (-0.400*), available iron (-0.418*).Exchangeable potassium was significantly and positively correlated to pH (0.697**), available phosphorus (0.425*) and significantly and negatively correlated to redox potential (-0.562**), available sulphur (-0.581**), available zinc (-0.617**), available copper (-0.603**) available iron (-0.700**), available manganese (-0.740**), electrical conductivity (-0.399*), available potassium (-0.387*), available magnesium (-0.369*).

Exchangeable aluminium was significantly and positively correlated to electrical conductivity (0.537**), available zinc (0.577**), available copper (0.588**) available iron (0.610**), available manganese (0.645**) and positively correlated to available sulphur (0.391*) and significantly and negatively correlated to pH (-0.536**), available phosphorus (-0.503**).Exchangeable iron was significantly and positively correlated to available magnesium (0.463**), available zinc (0.515**), available iron (0.640**), available potassium (0.392*), available sulphur (0.379*), available manganese (0.432*).Exchangeable copper of lowland soil was positively correlated to pH (0.445*) and significantly and negatively correlated to available boron (-0.519**).

4.4.3. Correlation of weather parameters and biological properties with chemical properties and nutrient status of lowlands

The influence of weather parameters and biological properties with chemical properties and nutrient status of lowland soil are detailed in table 63. Soil temperature of lowland soil was significantly and negatively correlated to available calcium (-0.377**), available boron (-0.312**) and negatively correlated to electrical conductivity (-0.212*), available magnesium (-0.257*). Relative humidity of lowland soil was significantly and positively correlated to pH (0.322**), MBC (0.368**), DEA (0.419**) and significantly and negatively correlated to electrical conductivity (-0.374**), available calcium (-0.359**), available magnesium (-0.477**), available boron (-0.391**), available potassium (-0.249*), and available manganese (-0.233*). Rainfall of lowland soil was significantly and positively correlated to pH (0.398**), MBC (0.334**), DEA (0.253**) and significantly and negatively correlated to electrical conductivity (-0.321**), available boron (-0.285**), available potassium (-0.246*), available calcium (-0.234**) and available magnesium (-0.216*).

Nitrogen fixing bacteria was significantly and positively correlated to available zinc (0.477**), available iron (0.328**), available manganese (0.218*). Microbial biomass carbon was significantly and positively correlated to available zinc (0.329**), NFB (0.342**) and available iron (0.266*) and, significantly and negatively correlated to available boron (-0.546**). Dehydrogenase enzyme activity was significantly and positively correlated to pH (0.355**) and significantly and negatively correlated to electrical conductivity (-0.497**), available potassium (-0.344**), available calcium (-0.535**), available magnesium (-0.577**), available zinc (-0.317**), available boron (-0.382**) and negatively correlated to available copper (-0.211*).

4.4.4. Correlation between electro chemical properties and nutrient status of uplands

Table 64 reveals the correlation between electro chemical properties and nutrient status of upland soil. Soil pH of upland soil was significantly and positively correlated to available potassium (0.287**), available calcium (0.375**), available magnesium (0.429**), available zinc (0.533**), available copper (0.240*) and significantly and negatively correlated to available iron (-0.555**) and available boron (-0.232*). Electrical conductivity was significantly and positively correlated to available magnesium (0.331**), available sulphur (0.396**), available boron (0.359**), available potassium (0.231*), available copper (0.255*). Organic carbon was significantly and positively correlated to total nitrogen (0.300**), available magnesium (0.227*) and significantly and negatively correlated to available calcium (-0.297**).

Total nitrogen was significantly and positively correlated to available potassium (0.430**), available magnesium (0.442**). Available phosphorus was significantly and positively correlated to available iron (0.768**) and significantly and negatively correlated to available magnesium (-0.377**), available zinc (-0.413**). Available potassium was significantly and positively correlated to available magnesium (-0.715**), available zinc (0.443**), available boron (0.281**).

Available calcium was significantly and positively correlated to available zinc (0.372**), available copper (0.292**), available manganese (0.349**) and, significantly and negatively correlated to available iron (-0.366**). Available magnesium was significantly and positively correlated to available zinc (0.537**), available boron (0.228**) and, significantly and negatively correlated to available iron (-0.416**). Available sulphur was significantly and positively correlated to available copper (0.273**), available boron (0.565**) and positively correlated to available manganese (0.242*).

Available zinc was significantly and positively correlated to available copper (0.468**), available manganese (0.279**) and significantly and negatively correlated to available iron (-0.474**). Available iron was positively correlated to available boron (0.213*).

4.4.5. Correlation of electro chemical properties and nutrient status with textural attributes and exchangeable cations in uplands

Relationship of textural attributes and exchangeable cations with electro chemical properties of upland soil was given in the table 65. Soil pH was significantly and positively correlated to exchangeable calcium (0.469**), exchangeable magnesium (0.466**) and significantly and negatively correlated to anion exchange capacity (-0.412**), exchangeable aluminium (-0.646**), exchangeable iron (-0.488**), exchangeable copper (-0.315**). Organic carbon of upland soil was significantly and positively correlated to clay (0.386**), exchangeable manganese (0.372**) and significantly and negatively correlated to anion exchange capacity (-0.409**).

Total nitrogen was significantly and positively correlated to clay (0.325**), exchangeable magnesium (0.446**), exchangeable manganese (0.376**) positively correlated to cation exchange capacity (0.224*), exchangeable sodium (0.208*) and significantly and negatively correlated to anion exchange capacity (-0.400**). Available phosphorus was significantly and positively correlated to exchangeable aluminium (0.573**), exchangeable iron (0.520**), exchangeable copper (0.281**) and significantly and negatively correlated to exchangeable magnesium (-0.408**), exchangeable zinc (-0.355**) and negatively correlated to anion exchange capacity (-0.270*). Available potassium was significantly and positively correlated to clay

(0.476**), cation exchange capacity (0.508**), exchangeable sodium (0.759**), exchangeable magnesium (0.783**), exchangeable potassium (0.686**), exchangeable manganese (0.210*) and, significantly and negatively correlated to anion exchange capacity (-0.389**), exchangeable zinc (-0.404**).

Available calcium was significantly and positively correlated to exchangeable calcium (0.524**), exchangeable zinc (0.332**) and significantly and negatively correlated to clay (-0.422**), exchangeable aluminium (-0.509**), exchangeable iron (-0.290**). Available magnesium was significantly and positively correlated to cation exchange capacity (0.362**), exchangeable sodium (0.516**), exchangeable magnesium (0.847**), exchangeable potassium (0.420**), exchangeable manganese (0.285**) and clay (0.231*) and, significantly and negatively correlated to anion exchange capacity (-0.317**), exchangeable aluminium (-0.346**), exchangeable iron (-0.340**) and exchangeable copper (-0.300**).

Available zinc was significantly and positively correlated to exchangeable sodium (0.556**), exchangeable magnesium (0.603**), cation exchange capacity (0.243*), exchangeable calcium (0.234*)and significantly and negatively correlated to exchangeable aluminium (-0.515**), exchangeable iron (-0.390**). Available iron was significantly and positively correlated to clay (0.436**), exchangeable aluminium (0.794**), exchangeable iron (0.679**), exchangeable copper (0.405**) and significantly and negatively correlated to exchangeable magnesium (-0.459**), exchangeable zinc (-0.295**) and negatively correlated to exchangeable calcium (-0.223*). Available manganese was significantly and positively correlated to exchangeable calcium (0.301**), exchangeable manganese (0.604**), exchangeable zinc (0.457**)and significantly and negatively correlated to exchangeable aluminium (-0.271**). Available boron was significantly and positively correlated to cation exchange capacity (0.384**), exchangeable sodium (0.438**), exchangeable magnesium (0.302**), exchangeable aluminium (0.360**) and positively correlated to clay (0.261*) and exchangeable iron (0.269*).

4.4.6. Correlation between weather parameters and biological properties with chemical properties of uplands

Table 66 depicts the correlation between weather parameters and biological properties with chemical properties of upland soil. Temperature of upland soil was positively correlated with electrical conductivity (0.213*), Relative humidity was significantly and positively correlated to DEA (0.301**), MBC (0.403**), NFB (0.241*) and significantly and negatively correlated to electrical conductivity (-0.399**), available sulphur (-0.424**), available copper (-0.365**), available boron (0.271**). Rainfall was significantly and positively correlated to MBC (0.327**) and significantly and negatively correlated to electrical conductivity (-0.347**), available sulphur (-0.304**), available copper (-0.304**).

Nitrogen fixing bacteria was significantly and positively correlated to pH (0.482**), available calcium (0.473**), available manganese (0.281**) and positively correlated to available zinc (0.261*) and significantly and negatively correlated to electrical conductivity (-0.254**), available phosphorus (-0.498**), available iron (-0.517**), available boron (0.308**). Microbial biomass carbon was positively correlated to pH (0.216*), available phosphorus (0.256*), NFB (0.264*) and significantly and negatively correlated to electrical conductivity (-0.420**), available sulphur (-0.526**). Dehydrogenase enzyme activity of upland soil was significantly and positively correlated to pH (0.661**), available potassium (0.376**), available magnesium (0.500**), available zinc (0.395**), NFB (0.396**), MBC (0.393**) and significantly and negatively correlated to available phosphorus (-0.277**), available sulphur (-0.460**), available iron (0.374**) and negatively correlated to electrical conductivity (-0.219*), available boron (-0.234*).

Table 61. Correlation between electro chemical properties and nutrient status in lowlands

	pH	**EC**	**Av.P**	**Av.K**	**Av.Ca**	**Av.Mg**	**Av.S**	**Av.Zn**	**Av.Cu**	**Av.Fe**
RP	-0.538**									
EC	-0.432**									
Av. P		-0.526**								
Av.K	-0.315**	0.625**								
Av.Ca		0.591**	-0.231*	0.451**						
Av.Mg		0.505**	-0.218*	0.479**	0.687**					
Av.S	-0.219*	0.408**		0.328**	0.358**	0.314**				
Av.Zn	-0.346**	0.462**	-0.378**		0.431**	0.362**	0.566**			
Av.Cu	-0.584**	0.506**	-0.332**	0.391**		0.302**	0.313**	0.354**		
Av.Fe	-0.385**	0.487**	-0.465**	0.300**	0.425**	0.473**	0.454**	0.669**	0.345**	
Av.Mn	-0.496**	0.632**	-0.452**	0.399**	0.361**	0.417**	0.499**	0.629**	0.542**	0.709**
Av.B		0.507**		0.586**	0.584**	0.607**				0.236*

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

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

Table 62. Correlation of exchangeable cations and AEC with electro chemical properties and nutrient status in lowlands

	AEC	Ex Na	Ex Ca	Ex Mg	Ex K	Ex Al	Ex Fe	Ex Cu
pH	-0.783^{**}		0.450^{*}	0.535^{**}	0.697^{**}	-0.536^{**}		0.445^{*}
RP	0.464^{**}				-0.562^{**}			
EC	0.544^{**}	0.553^{**}	-0.423^{*}	-0.605^{**}	-0.399^{*}	0.537^{**}		
Av.P	-0.456^{*}		0.416^{*}		0.425^{*}	-0.503^{**}		
Av.K	0.536^{**}	0.502^{**}	-0.502^{**}	-0.547^{**}	-0.387^{*}		0.392^{*}	
Av.Ca		0.418^{*}	-0.378^{*}					
Av.Mg	0.599^{**}	0.477^{**}			-0.369^{*}		0.463^{**}	
Av.S	0.467^{**}			-0.398^{*}	-0.581^{**}	0.391^{*}	0.379^{*}	
Av.Zn	0.420^{*}		-0.405^{*}	-0.400^{*}	$-0.6\ 17^{**}$	0.577^{**}	0.515^{**}	
Av.Cu	0.656^{**}		-0.513^{**}	-0.573^{**}	-0.603^{**}	0.588^{**}		
Av.Fe	0.777^{**}	0.419^{*}	-0.451^{*}	-0.418^{*}	-0.700^{**}	0.610^{**}	0.640^{**}	
Av.Mn	0.732^{**}	0.374^{*}	-0.470^{**}	-0.577^{**}	-0.740^{**}	0.645^{**}	0.432^{*}	
Av.B	0.386^{*}	0.468^{**}						-0.519^{**}

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

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

Table 63. Correlation of weather parameters and biological properties with chemical properties and nutrient status of lowlands

Lowland	Soil Temperature	RH	Rain fall	NFB	MBC	DEA
PH		0.322^{**}	0.398^{**}			0.355^{**}
EC	-0.212^{*}	-0.374^{**}	-0.321^{**}			-0.497^{**}
Av. K		-0.249^{*}	-0.246^{*}			-0.344^{**}
Av. Ca	-0.377^{**}	-0.359^{**}	-0.234^{*}			-0.535^{**}
Av. Mg	-0.257^{*}	-0.477^{**}	-0.216^{*}			-0.577^{**}
Av. Zn				0.477^{**}	0.329^{**}	-0.317^{**}
Av. Cu						-0.211^{*}
Av. Fe				0.328^{**}	0.266^{*}	
Av. Mn		-0.233^{*}		0.218^{*}		
Av. B	-0.312^{**}	-0.391^{**}	-0.285^{**}		-0.546^{**}	-0.382^{**}
NFB					0.342^{**}	
MBC		0.368^{**}	0.334^{**}			
DEA		0.419^{**}	0.253^{*}			

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

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

Table 64. Correlation between electro chemical properties and nutrient status of uplands

	PH	EC	OC	TN	Av. P	Av. K	Av. Ca	Av. Mg	Av. S	Av. Zn	Av. Fe
TN			0.300^{**}								
Av. K	0.287^{**}	0.231^{*}		0.430^{**}							
Av. Ca	0.375^{**}		-0.297^{**}								
Av.Mg	0.429^{**}	0.331^{**}	0.227^{*}	0.442^{**}	-0.377^{**}	0.715^{**}					
Av.S		0.396^{**}									
Av. Zn	0.533^{**}				-0.413^{**}	0.443^{**}	0.372^{**}	0.537^{**}			
Av.Cu	0.240^{*}	0.255^{*}					0.292^{**}		0.273^{**}	0.468^{**}	
Av.Fe	-0.555^{**}				0.768^{**}		-0.366^{**}	-0.416^{**}		-0.474^{**}	
Av.Mn							0.349^{**}		0.242^{*}	0.279^{**}	
Av. B	-0.232^{*}	0.359^{**}				0.281^{**}		0.228^{*}	0.565^{**}		0.213^{*}

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

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

Table 65. Correlation of textural attributes exchangeable cations with electro chemical properties of uplands

	PH	**OC**	**TN**	**Av. P**	**Av. K**	**Av. Ca**	**Av. Mg**	**Av. Zn**	**Av. Fe**	**Av. Mn**	**Av. B**
clay		0.386^{**}	0.325^{**}		0.476^{**}	-0.422^{**}	0.231^{*}		0.436^{**}		0.261^{*}
CEC			0.224^{*}		0.508^{**}		0.362^{**}	0.243^{*}			0.384^{**}
AEC	-0.412^{**}	-0.409^{**}	-0.400^{**}	-0.270^{*}	-0.389^{**}		-0.317^{**}				
Ex Na			0.208^{*}		0.759^{**}		0.516^{**}	0.556^{**}			0.438^{**}
Ex Ca	0.469^{**}					0.524^{**}		0.258^{*}	-0.223^{*}	0.301^{**}	
Ex Mg	0.466^{**}		0.446^{**}	-0.408^{**}	0.783^{**}		0.847^{**}	0.603^{**}	-0.459^{**}		0.302^{**}
Ex K					0.686^{**}		0.420^{**}	0.234^{*}			
Ex Al	-0.646^{**}			0.573^{**}		-0.509^{**}	-0.346^{**}	-0.515^{**}	0.794^{**}	-0.271^{**}	0.360^{**}
Ex Fe	-0.488^{**}			0.520^{**}		-0.290^{**}	-0.340^{**}	-0.390^{**}	0.679^{**}		0.269^{*}
Ex Cu	-0.315^{**}			0.281^{**}			-0.300^{**}		0.405^{**}		
Ex Mn		0.372^{**}	0.376^{**}		0.210^{*}		0.285^{**}			0.604^{**}	
Ex Zn				-0.355^{**}	-0.404^{**}	0.332^{**}			-0.295^{**}	0.457^{**}	

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

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

Table 66. Correlation between weather parameters and biological properties with chemical properties of uplands

	Temp	RH	Rain fall	NFB	MBC	DEA
PH				0.482**	0.216*	0.661**
EC	0.213*	-0.399**	-0.347**	-0.254*	-0.420**	-0.219*
Av. P				-0.498**	0.256*	-0.277**
Av. K						0.376**
Av. Ca				0.473**		
Av. Mg						0.500**
Av. S		-0.424**	-0.372**		-0.526**	-0.460**
Av. Zn				0.261*		0.395**
Av. Cu		-0.365**	-0.304**			
Av. Fe				-0.517**		-0.374**
Av. Mn				0.281**		
Av. B		-0.271**		-0.308**		-0.234*
DEA		0.301**				
NFB		0.241*			0.264*	0.396**
MBC		0.403**	0.327**			0.393**

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

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

4.4.7. Correlation between chemical properties of field water

Table 67 describes correlation between chemical properties of field water. pH of field water was significantly and positively correlated to bicarbonate ions (0.418**). Electrical conductivity of field water had a positive and highly significant correlation with calcium ions (0.976**), magnesium ions (0.984**), sodium ions (0.985**), potassium ions (0.984**), borate ions (0.991**), chloride ions (0.985**), sulphate ions (0.916**) and was positively and significantly correlated to water soluble cobalt (0.396**) and negatively and significantly correlated to nitrate ions (-0.520**). Total soluble salt of field water maintained a positive and highly significant correlation with calcium ions (0.976**), magnesium ions (0.984**), sodium ions (0.985**), potassium ions (0.984**), borate ions (0.991**), chloride ions (0.985**), sulphate ions (0.916**) and positively and significantly correlated to water soluble cobalt (0.396**) and positively correlated to bicarbonate ions (0.262*) and negatively and significantly correlated to nitrate ions (-0.520**).

Calcium ions of field water had positive and highly significant correlation with magnesium ions (0.970**), sodium ions (0.972**), potassium ions (0.982**), borate ions (0.960**), chloride ions (0.971**), sulphate ions (0.915**) and positively and significantly correlated to water soluble cobalt (0.396**) and was positively correlated to bicarbonate ions (0.262*) and negatively and significantly correlated to nitrate ions (-0.520**). Magnesium ions of field water showed positive and highly significant correlation with sodium ions (0.983**), potassium ions (0.983**), borate ions (0.975**), chloride ions (0.976**), sulphate ions (0.920**), positively and significantly correlated to water soluble cobalt (0.395**) and positively correlated to bicarbonate ions (0.257*) and negatively and significantly correlated to nitrate ions (-0.522**). Sodium ions of field water revealed positive and highly significant correlation with potassium ions (0.988**), borate ions (0.974**), chloride ions (0.986**), sulphate ions (0.923**), positively and significantly correlated to water soluble cobalt (0.402**) and positively correlated to bicarbonate ions (0.246*) and negatively and significantly correlated to nitrate ions (-0.528**). Potassium ions of field water sustained positive and highly significant correlation with borate ions (0.972**), chloride ions (0.983**), sulphate ions (0.921**), positively and significantly correlated to water soluble cobalt (0.388**), positively correlated to bicarbonate ions (0.229*), phosphate ions (0.213*) and negatively and significantly correlated to nitrate ions (-0.524**).

Bicarbonate ions of field water was positively and significantly correlated to borate ions (0.280**) and positively correlated to phosphate ions (0.251*), chloride ions (0.229*). Nitrate ions of field water was negatively and significantly correlated to borate ions (-0.525**), chloride ions (-0.527**), sulphate ions (-0.487**) and negatively correlated to water soluble cobalt (-0.220*). Phosphate ions of field water was positively correlated to borate ions (0.211*). Borate ions of field water showed positive and highly significant correlation with chloride ions (0.977**), sulphate ions (0.908**) and was positively and significantly correlated to water soluble cobalt (0.388**). Chloride ions of field water retained positive and highly significant correlation with sulphate ions (0.920**) and positively and significantly correlated to water soluble cobalt (0.401**). Sulphate ions of field water was positively and significantly correlated to water soluble cobalt (0.351**). Water soluble cadmium of field water was positively correlated to water soluble cobalt (0.259*).

4.4.8. Correlation between chemical properties of source water

Relationship between chemical properties of source water is given in the table 68. pH of source water was significantly and positively correlated to borate ions

(0.289**) and positively correlated to electrical conductivity (0.242*), total soluble salt (0.242*) and significantly and negatively correlated to nitrate (-0.289**). Electrical conductivity of source water followed positive and highly significant correlation with total soluble salt (1.000**), calcium ions (0.986**), magnesium ions (0.978**), sodium ions (0.990**), potassium ions (0.982**), borate ions (0.983**), chloride ions (0.974**), sulphate ions (0.959**) and positively and significantly correlated to bicarbonate (0.467**), water soluble cadmium (0.373**) and positively correlated to water soluble cobalt (0.208*) and negatively and significantly correlated to nitrate ions (-0.553**). Total soluble salt had a positive and highly significant correlation with calcium ions (0.986**), magnesium ions (0.978**), sodium ions (0.990**), potassium ions (0.982**), borate ions (0.983**), chloride ions (0.974**), sulphate ions (0.959**) and positively and significantly correlated to bicarbonate (0.467**), water soluble cadmium (0.373**) and positively correlated to water soluble cobalt (0.208*) and negatively and significantly correlated to nitrate ions (-0.553**).

Calcium ions had positive and highly significant correlation with magnesium ions (0.983**), sodium ions (0.993**), potassium ions (0.993**), borate ions (0.976**), chloride ions (0.978**), sulphate ions (0.961**) and positively and significantly correlated to bicarbonate (0.478**), water soluble cadmium (0.396**) and negatively and significantly correlated to nitrate ions (-0.534**). Magnesium ions had positive and highly significant correlation with sodium ions (0.989**), potassium ions (0.984**), borate ions (0.968**), chloride ions (0.977**), sulphate ions (0.958**) and was positively and significantly correlated to bicarbonate (0.471**), water soluble cadmium (0.363**) and negatively and significantly correlated to nitrate ions (-0.555**). Sodium ions of source water had positive and highly significant correlation with potassium ions (0.994**), borate ions (0.977**), chloride ions (0.979**), sulphate ions (0.966**) and positively and significantly correlated to bicarbonate (0.475**), water soluble cadmium (0.392**) and negatively and significantly correlated to nitrate ions (-0.542**). Potassium ions had positive and highly significant correlation with borate ions (0.964**), chloride ions (0.979**), sulphate ions (0.962**) and was positively and significantly correlated to bicarbonate (0.484**), water soluble cadmium (0.383**) and negatively and significantly correlated to nitrate ions (-0.549**).

Bicarbonate ions were positively and significantly correlated to borate ions (0.468**), chloride ions (0.463**), sulphate ions (0.464**). Nitrate ions of source water was negatively and significantly correlated to borate ions (-0.556**), chloride ions (-0.557**), sulphate ions (-0.464**), water soluble cadmium (-0.358**). Borate ions maintained positive and highly significant correlation with chloride ions (0.963**), sulphate ions (0.948**) and was positively and significantly correlated to water soluble cadmium (0.358**). Chloride ions of source water had positive and highly significant correlation with sulphate ions (0.946**) and was positively and significantly correlated to water soluble cadmium (0.393**). Sulphate ions was positively and significantly correlated to water soluble cadmium (0.367**). Water soluble cadmium of source water was positively and significantly correlated to water soluble cobalt (0.286**).

4.4.9. Correlation between chemical properties of field and source water

Table 69 reveals correlation between chemical properties of field and source water. Field water pH was significantly and positively correlated to source water pH (0.724**). Electrical conductivity of field had positive and highly significant correlation with electrical conductivity (0.960**), total soluble salt (0.960**), calcium ions (0.960**), magnesium ions (0.970**), sodium ions (0.966**), potassium ions (0.958**), borate ions (0.954**), chloride ions (0.946**), sulphate ions (0.938**), bicarbonate (0.447**), water soluble cadmium (0.373**) of source water and negatively and significantly correlated to nitrate ions (-0.554**) of source water Total soluble salt of . field water had positive and highly significant correlation with electrical conductivity (0.960**), total soluble salt (0.960**), calcium ions (0.960**), magnesium ions (0.970**), sodium ions (0.966**), potassium ions (0.958**), borate ions (0.954**), chloride ions (0.946**), sulphate ions (0.938**), bicarbonate (0.447**), water soluble cadmium (0.373**) of source water and negatively and significantly correlated to nitrate ions (-0.554**).

Calcium ions in the field water revealed positive and highly significant correlation with source water electrical conductivity (0.935**), total soluble salt (0.935**), calcium ions (0.938**), magnesium ions (0.956**), sodium ions (0.949**), potassium ions (0.942**), borate ions (0.919**), chloride ions (0.929**), sulphate ions

(0.927**), bicarbonate (0.456**), water soluble cadmium (0.334**) and was negatively and significantly correlated to nitrate ions (-0.552**).

Magnesium ions in the field water had positive and highly significant correlation with electrical conductivity (0.952**), total soluble salt (0.952**), calcium ions (0.954**), magnesium ions (0.971**), sodium ions (0.966**), potassium ions (0.959**), borate ions (0.936**), chloride ions (0.944**), sulphate ions (0.936**), bicarbonate (0.461**), water soluble cadmium (0.361**) of source water and was negatively and significantly correlated to nitrate ions (-0.547**).

Sodium ions in the field water had positive and highly significant correlation with source water electrical conductivity (0.967**), total soluble salt (0.967**), calcium ions (0.975**), magnesium ions (0.987**), sodium ions (0.982**), potassium ions (0.978**), borate ions (0.956**), chloride ions (0.962**), sulphate ions (0.955**), bicarbonate (0.473**), water soluble cadmium (0.356**) and was negatively and significantly correlated to nitrate ions (-0.546**).

Potassium ions in the field water had positive and highly significant correlation with electrical conductivity (0.945**), total soluble salt (0.945**), calcium ions (0.950**), magnesium ions (0.972**), sodium ions (0.960**), potassium ions (0.960**), borate ions (0.930**), chloride ions (0.939**), sulphate ions (0.932**), bicarbonate (0.463**), water soluble cadmium (0.336**) of source water and negatively and significantly correlated to nitrate ions (-0.551**).

Bicarbonate ions in the field water had positive and significant correlation with pH (0.383**), electrical conductivity (0.294**), total soluble salt (0.294**), bicarbonate (0.292**), borate ions (0.311**), calcium ions (0.267*), magnesium ions (0.268*), sodium ions (0.270*), potassium ions (0.238*), phosphate (0.267*), chloride ions (0.265*), sulphate ions (0.268*) of source water. Nitrate in field water was positively and significantly correlated to source water nitrate (0.645**) and showed negative and significant correlation with source water pH (-0.283**), electrical conductivity (-0.498**), total soluble salt (-0.498**), calcium ions (-0.511**), magnesium ions (-0.521**), sodium ions (-0.512**), potassium ions (-0.512**), bicarbonate (-0.354**), borate ions (-0.522**), chloride ions (-0.507**), sulphate ions (-0.481**) of source water and was negatively correlated to water soluble cadmium (-

0.252*). Phosphate ions in field water was positively and significantly correlated to source water phosphate (0.675**).

Borate in field water had positive and highly significant correlation with source water electrical conductivity (0.955**), total soluble salt (0.955**), calcium ions (0.950**), magnesium ions (0.961**), sodium ions (0.956**), potassium ions (0.947**), borate ions (0.956**), chloride ions (0.940**), sulphate ions (0.931**) and was positively and significantly correlated to bicarbonate (0.433**), water soluble cadmium (0.379**) and negatively and significantly correlated to nitrate ions (-0.569**) of source water.

Chloride in field water had positive and highly significant correlation with source water electrical conductivity (0.966**), total soluble salt (0.966**), calcium ions (0.971**), magnesium ions (0.97861**), sodium ions (0.975**), potassium ions (0.974**), borate ions (0.953**), chloride ions (0.958**), sulphate ions (0.946**) and was positively and significantly correlated to bicarbonate (0.456**), water soluble cadmium (0.363**) and negatively and significantly correlated to nitrate ions (-0.571**) of source water.

Sulphate in field water had a positive and highly significant correlation with source water electrical conductivity (0.917**), total soluble salt (0.917**), calcium ions (0.929**), magnesium ions (0.923**), sodium ions (0.926**), potassium ions (0.932**), borate ions (0.896**), chloride ions (0.910**), sulphate ions (0.924**) and was positively and significantly correlated to bicarbonate (0.432**), water soluble cadmium (0.307**) and negatively and significantly correlated to nitrate ions (-0.514**) of source water.

Water soluble cobalt in field water had positive and significant correlation with source water electrical conductivity (0.413**), total soluble salt (0.413**), calcium ions (0.405**), magnesium ions (0.411**), sodium ions (0.423**), potassium ions (0.408**), borate ions (0.424**), chloride ions (0.434**), sulphate ions (0.377**), water soluble cadmium (0.525**), water soluble cobalt (0.447**) and was negatively and significantly correlated to nitrate ions (-0.277**) of source water.

4.4.10. Correlation between chemical properties of field water and lowlands

Table 70 contains values of correlation coefficients between chemical properties of field water and lowland soils. Soil pH in lowland had positive and significant correlation with nitrate (0.414**) and negatively and significantly correlated to electrical conductivity (-0.485**), total soluble salt (-0.485**), calcium ions (-0.504**), magnesium ions (-0.529**), sodium ions (-0.507**), potassium ions (-0.513**), borate ions (-0.510**), chloride ions (-0.495**), sulphate ions (-0.440**) and water soluble cobalt (-0.209**) of field water.

Electrical conductivity of lowland soil revealed positive and significant correlation with electrical conductivity (0.789**), total soluble salt (0.789**), calcium ions (0.778**), magnesium ions (0.810**), sodium ions (0.794**), potassium ions (0.811**), borate ions (0.782**), chloride ions (0.788**), sulphate ions (0.736**), water soluble cadmium (0.408**),water soluble cobalt (0.430**) and was negatively and significantly correlated to pH (-0.284**), nitrate (-0.428**) of field water.

Available phosphorus showed positive and significant correlation with field water nitrate (0.340**) and negatively and significantly correlated to field water electrical conductivity (-0.405**), total soluble salt (-0.405**), calcium ions (-0.366**), magnesium ions (-0.398**), sodium ions (-0.391**), potassium ions (-0.390**), borate ions (-0.411**), chloride ions (-0.391**), sulphate ions (-0.347**) and water soluble cobalt (-0.318**) of field water.

Available potassium had positive and significant correlation with field water electrical conductivity (0.518**), total soluble salt (0.518**), calcium ions (0.512**), magnesium ions (0.533**), sodium ions (0.529**), potassium ions (0.528**), borate ions (0.514**), chloride ions (0.532**), sulphate ions (0.514**), water soluble cadmium (0.292**), water soluble cobalt (0.383**) and was negatively correlated to nitrate (-0.268*) of field water.

Available calcium had positive and significant correlation with field water electrical conductivity (0.555**), total soluble salt (0.555**), calcium ions (0.494**), magnesium ions (0.534**), sodium ions (0.543**), potassium ions (0.515**), borate ions (0.548**), chloride ions (0.517**), sulphate ions (0.520**), water soluble cobalt

(0.439**) and was positively correlated to field water soluble cadmium (0.222*) and negatively correlated to nitrate (-0.218*) of field water.

Available magnesium depicted a positive and significant correlation with field water electrical conductivity (0.552**), total soluble salt (0.552**), calcium ions (0.513**), magnesium ions (0.526**), sodium ions (0.563**), potassium ions (0.537**), borate ions (0.553**), chloride ions (0.512**), sulphate ions (0.511**), water soluble cadmium (0.346**),water soluble cobalt (0.312**), positively correlated to field water bicarbonate (0.265*) and negatively correlated to nitrate (-0.232*) of field water.

Available sulphur had positive and significant correlation with field water electrical conductivity (0.324**), total soluble salt (0.324**), calcium ions (0.303**), magnesium ions (0.338**), sodium ions (0.333**), potassium ions (0.317**), borate ions (0.336**), chloride ions (0.329**), sulphate ions (0.309**) and water soluble cobalt (0.361**) of field water.

Available zinc showed positive and significant correlation with field water electrical conductivity (0.322**), total soluble salt (0.322**), calcium ions (0.282**), magnesium ions (0.347**), sodium ions (0.324**), potassium ions (0.316**), borate ions (0.350**), chloride ions (0.323**), sulphate ions (0.291**) and water soluble cobalt (0.333**) of field water.

Available copper had positive and significant correlation with field water potassium ions (0.281**), water soluble cadmium (0.295**) and positively correlated to electrical conductivity (0.220*), total soluble salt (0.220*), calcium ions (0.266*), magnesium ions (0.252*), sodium ions (0.242*), borate ions (0.229*), chloride ions (0.236*),and negatively and significantly correlated to nitrate (-0.282**) and negatively correlated with pH (-0.219*) of field water.

Available iron had positive correlation with field water borate ions (0.218*) of field water. Available manganese revealed a positive and significant correlation with field water electrical conductivity (0.376**), total soluble salt (0.376**), calcium ions (0.322**), magnesium ions (0.353**), sodium ions (0.372**), potassium ions (0.386**), borate ions (0.400**), chloride ions (0.381**), sulphate ions (0.292**) and was positively correlated with water soluble cadmium (0.225*), water soluble cobalt (0.236*) and significantly and negatively correlated to pH (-0.359**) and negatively correlated to bicarbonate (-0.238*) of field water.

Available boron had positive and significant correlation with field water electrical conductivity (0.579**), total soluble salt (0.579**), calcium ions (0.566**), magnesium ions (0.569**), sodium ions (0.590**), potassium ions (0.575**), borate ions (0.551**), chloride ions (0.568**), sulphate ions (0.537**), water soluble cobalt (0.331**) and was negatively correlated to nitrate (-0.272**) of field water.

Microbial biomass carbon maintained positive and significant correlation with field water soluble cadmium(0.283**) and was negatively and significantly correlated to field water pH (-0.414**), electrical conductivity (-0.414**), total soluble salt (-0.435**), calcium ions (-0.402**), magnesium ions (-0.424**), sodium ions (-0.408**), potassium ions (-0.405**), borate ions (-0.408**), chloride ions (-0.429**), sulphate ions (-0.417**) and negatively correlated to nitrate (-0.240*) of field water.

Dehydrogenase enzyme activity was negatively and significantly correlated to field water pH (-0.496**), electrical conductivity (-0.496**), total soluble salt (-0.481**), calcium ions (-0.532**), magnesium ions (-0.517**), sodium ions (-0.513**), potassium ions (-0.304**), borate ions (-0.498**), chloride ions (-0.484**), sulphate ions (-0.444**), water soluble cadmium (0.323**) and water soluble cobalt (0.355**) of field water.

Table 67. Correlation between chemical properties of field water

	pH	**EC**	**TSS**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**HCO_3^-**	**NO_3^-**	**PO_4^{3-}**	**BO_3^{3-}**	**Cl^-**	**SO_4^{2-}**	**WSCd**
Ca2+		0.976^{**}	0.976^{**}											
Mg2+		0.984^{**}	0.984^{**}	0.970^{**}										
Na+		0.985^{**}	0.985^{**}	0.972^{**}	0.983^{**}									
K+		0.984^{**}	0.984^{**}	0.982^{**}	0.983^{**}	0.988^{**}								
HCO_3^-	0.418^{**}	0.262^{*}	0.262^{*}	0.215^{*}	0.257^{*}	0.246^{*}	0.229^{*}							
NO_3^-		-0.520^{**}	-0.520^{**}	-0.519^{**}	-0.522^{**}	-0.528^{**}	-0.524^{**}							
PO_4^{3-}							0.213^{*}	0.251^{*}						
BO_3^{3-}		0.991^{**}	0.991^{**}	0.960^{**}	0.975^{**}	0.974^{**}	0.972^{**}	0.280^{**}	-0.525^{**}	0.211^{*}				
Cl-		0.985^{**}	0.985^{**}	0.971^{**}	0.976^{**}	0.986^{**}	0.983^{**}	0.229^{*}	-0.527^{**}		0.977^{**}			
SO_4		0.916^{**}	0.916^{**}	0.915^{**}	0.920^{**}	0.923^{**}	0.921^{**}		-0.487^{**}		0.908^{**}	0.920^{**}		
WSCo		0.396^{**}	0.396^{**}	0.374^{**}	0.395^{**}	0.402^{**}	0.388^{**}		-0.220^{*}		0.388^{**}	0.401^{**}	0.351^{**}	0.259^{*}

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

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

Table 68. Correlation between chemical properties of source water

	pH	**EC**	**TSS**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**HCO_3^{-}**	**NO_3^{-}**	**BO_3^{3-}**	**Cl^{-}**	**SO_4^{2-}**	**WSCd**
EC	0.242^{*}												
TSS	0.242^{*}	1.000^{**}											
Ca^{2+}		0.986^{**}	0.986^{**}										
Mg^{2+}		0.978^{**}	0.978^{**}	0.983^{**}									
Na^{+}		0.990^{**}	0.990^{**}	0.993^{**}	0.989^{**}								
K		0.982^{**}	0.982^{**}	0.993^{**}	0.984^{**}	0.994^{**}							
HCO_3^{-}		0.467^{**}	0.467^{**}	0.478^{**}	0.471^{**}	0.475^{**}	0.484^{**}						
NO_3^{-}	-0.289^{**}	-0.553^{**}	-0.553^{**}	-0.534^{**}	-0.555^{**}	-0.542^{**}	-0.549^{**}						
BO_3^{3-}	0.289^{**}	0.983^{**}	0.983^{**}	0.976^{**}	0.968^{**}	0.977^{**}	0.964^{**}	0.468^{**}	-0.556^{**}				
Cl^{-}		0.974^{**}	0.974^{**}	0.978^{**}	0.977^{**}	0.979^{**}	0.979^{**}	0.463^{**}	-0.557^{**}	0.963^{**}			
SO_4^{2-}		0.959^{**}	0.959^{**}	0.961^{**}	0.958^{**}	0.966^{**}	0.962^{**}	0.464^{**}	-0.500^{**}	0.948^{**}	0.946^{**}		
WSCd		0.373^{**}	0.373^{**}	0.396^{**}	0.363^{**}	0.392^{**}	0.383^{**}		-0.358^{**}	0.396^{**}	0.393^{**}	0.367^{**}	
WSCo		0.208^{*}	0.208^{*}										0.286^{**}

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

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

Table 69. Correlation between chemical properties of field and source water

		Chemical properties of field water													
		pH	EC	TSS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	NO_3^-	PO_4^{3-}	BO_3^{3-}	Cl^-	SO_4^-	WSCo
Chemical properties of source water	pH	0.724**							0.383**	-0.283**					
	EC		0.960**	0.960**	0.935**	0.952**	0.967**	0.945**	0.294**	-0.498**		0.955**	0.966**	0.917**	0.413**
	TSS		0.960**	0.960**	0.935**	0.952**	0.967**	0.945**	0.294**	-0.498**		0.955**	0.966**	0.917**	0.413**
	Ca^{2+}		0.960**	0.960**	0.938**	0.954**	0.975**	0.950**	0.267*	-0.511**		0.950**	0.971**	0.929**	0.405**
	Mg^{2+}		0.970**	0.970**	0.956**	0.971**	0.987**	0.972**	0.268*	-0.521**		0.961**	0.978**	0.923**	0.411**
	Na^{+}		0.966**	0.966**	0.949**	0.966**	0.982**	0.960**	0.270*	-0.512**		0.956**	0.975**	0.926**	0.423**
	K^{+}		0.958**	0.958**	0.942**	0.959**	0.978**	0.960**	0.238*	-0.512**		0.947**	0.974**	0.932**	0.408**
	HCO_3^-		0.447**	0.447**	0.456**	0.461**	0.473**	0.463**	0.292**	-0.354**		0.433**	0.456**	0.432**	
	NO_3^-		-0.554**	-0.554**	-0.552**	-0.547**	-0.546**	-0.551**		0.645**		-0.569**	-0.571**	-0.514**	-0.277**
	PO_4^{3-}								0.267*		0.675**				
	BO_3^{3-}		0.954**	0.954**	0.919**	0.936**	0.956**	0.930**	0.311**	-0.522**		0.956**	0.953**	0.896**	0.424**
	Cl^-		0.946**	0.946**	0.929**	0.944**	0.962**	0.939**	0.265*	-0.507**		0.940**	0.958**	0.910**	0.434**
	SO_4^{2-}		0.938**	0.938**	0.927**	0.936**	0.955**	0.932**	0.268*	-0.481**		0.931**	0.946**	0.924**	0.377**
	WSCd		0.373**	0.373**	0.334**	0.361**	0.356**	0.336**		-0.252*		0.379**	0.363**	0.307**	0.525**
	WSCo														0.447**

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

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

Table 70. Correlation between chemical properties of field water and lowlands

		Chemical properties of lowland soil													
		pH	**EC**	**av P**	**av K**	**av Ca**	**av Mg**	**av S**	**av Zn**	**av Cu**	**av Fe**	**av Mn**	**av B**	**MBC**	**DEA**
Chemical properties of field water	**pH**		-0.284**							-0.219*		-0.359**		-0.414**	-0.496**
	EC	-0.485**	0.789**	-0.405**	0.518**	0.555**	0.552**	0.324**	0.322**	0.220*		0.376**	0.579**	-0.414**	-0.496**
	TSS	-0.485**	0.789**	-0.405**	0.518**	0.555**	0.552**	0.324**	0.322**	0.220*		0.376**	0.579**	-0.435**	-0.481**
	Ca^{2+}	-0.504**	0.778**	-0.366**	0.512**	0.494**	0.513**	0.303**	0.282**	0.266*		0.322**	0.566**	-0.402**	-0.532**
	Mg^{2+}	-0.529**	0.810**	-0.398**	0.533**	0.534**	0.526**	0.338**	0.347**	0.252*		0.353**	0.569**	-0.424**	-0.517**
	Na^{+}	-0.507**	0.794**	-0.391**	0.529**	0.543**	0.563**	0.333**	0.324**	0.242*		0.372**	0.590**	-0.408**	-0.513**
	K^{+}	-0.513**	0.811**	-0.390**	0.528**	0.515**	0.537**	0.317**	0.316**	0.281**		0.386**	0.575**	-0.405**	-0.304**
	HCO_3^-						0.265*					-0.238*	0.251*		
	$NO3^-$	0.414**	-0.428**	0.340**	-0.268*	-0.218*	-0.232*			-0.282**			-0.272**	-0.240*	
	BO_3^{3-}	-0.510**	0.782**	-0.411**	0.514**	0.548**	0.553**	0.336**	0.350**	0.229*	0.218*	0.400**	0.551**	-0.408**	-0.498**
	Cl-	-0.495**	0.788**	-0.391**	0.532**	0.517**	0.512**	0.329**	0.323**	0.236*		0.381**	0.568**	-0.429**	-0.484**
	$SO4^{2-}$	-0.440**	0.736**	-0.347**	0.514**	0.520**	0.511**	0.309**	0.291**			0.292**	0.537**	-0.417**	-0.444**
	WSCd		0.408**	-0.318**	0.292**	0.222*	0.346**			0.295**		0.225*		0.283**	-0.323**
	WSCo	-0.209*	0.430**		0.383**	0.439**	0.312**	0.361**	0.333**			0.236*	0.331**		-0.355**

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

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

Experiment 2

4.5. Fractionation of phosphorus and copper in *Pokkali* soil

A total of fifteen soil samples collected from different land uses in October and April months were subjected to fractionation study for understanding the nutrient transformation with varying salinity and soil pH levels across the seasons.

4.5.1. Fractionation of phosphorus

The data on various fractions of phosphorus are given in thetables 71a and 761b.Water soluble phosphorus ranged from 14.98 (shrimp alone in Kotuvally) to 28.82 mgkg^{-1}(plot c of paddy alone in RRS, Vytilla) in October and 0.70 (mangrove in Kadamakudy) to 5.99 mg kg^{-1}(paddy-shrimp in Kadamakudy) in April. The highest value of aluminium bound P noticed in shrimp alone in Kottuvally (94.80 mg kg^{-1}) and paddy-shrimp in Ezhikkara (327.66 mg kg^{-1}) during October and April respectively. Whereas, the least value of aluminium bound P detected in plot c of paddy alone land use in RRS, Vyttila (51.49 mg kg^{-1}) and paddy-shrimp in Kadamakudy (104.99 mg kg^{-1}) in October and April consequently. The highest value of iron bound P (875.77 mg kg^{-1}) was found in shrimp alone in Kadamakudy and the highest value of occluded P (307.52 mg kg^{-1}) was observed in shrimp alone in Kottuvally during October. Whereas, the highest value of iron bound (973.60 mg kg^{-1}) and occluded P (528.39 mg kg^{-1}) during April was registered in mangrove in Kadamakudy. The least value of iron bound P (115.20 mg kg^{-1}) and occluded P (50.21 mg kg^{-1}) noticed in plot c of paddy alone land use in RRS, Vyttila in October and the least values of iron bound P (306.76 mg kg^{-1}) and occluded P (147.26 mg kg^{-1}) was reported in paddy-shrimp in Kadamakudy during April. Paddy-shrimp in Ezhikkara (626.97 mg kg^{-1}) and shrimp alone in Kottuvally (389.02 mg kg^{-1}) reported the highest values of Ca-P in October and April respectively. The least calcium bound P was registered in paddy-shrimp in Kadamakudy (74.99 mg kg^{-1}) and plot c of paddy alone land use in RRS, Vyttila (45.18 mg kg^{-1}) in October and April correspondingly. Shrimp alone in Kotuvally (389.02 mg kg^{-1}) and paddy-shrimp in Ezhikkara (626.97 mg kg^{-1}) showed the highest organic matter bound P in October and April respectively. Plot c of paddy alone in RRS, Vyttila (45.18 mg kg^{-1}) and paddy-shrimp in Kadamakudy (74.09 mg kg^{-1}) recorded least values of organic matter bound P in October and April consequently. Residual P (5296.92 mg kg^{-1} in October and 4823.87 mg kg^{-1} in April) and total P (6669.72 mg kg^{-1} in October and 6665.31 mg

kg^{-1} in April) were recorded the highest values in paddy-shrimp in Ezhikkara for both the months and that of least values of residual P (630.80 mg kg^{-1}) and total P (1692.45 mg kg^{-1}) reported in shrimp alone in Ezhikkara during October. In April, the least value of residual P observed in mangroves in Kadamakudy (152.77 mg kg^{-1}) and the least value of total P recorded in shrimp alone in Ezhikkara (1691.54 mg kg^{-1}).

Table 71a. Fractions of phosphorus in land uses under different locations in October (mg kg^{-1})

Location	Land uses	Ws- P	Al-P	Fe-P	Occl-P	Ca-P	Org-P	Res-P	Tot-P
Ezhikkara	Paddy-shrimp	21.29	78.24	305.19	176.04	626.97	165.07	5296.92	6669.72
	Shrimp alone	20.63	80.55	316.00	187.01	281.22	176.25	630.80	1692.45
	Mangrove	18.82	91.84	712.96	252.02	403.56	302.62	1171.87	2953.70
	Fallow	23.92	61.42	142.60	133.51	225.22	109.16	1459.51	2155.34
Kottuvally	Paddy-shrimp	24.41	59.97	138.38	131.80	262.23	108.30	2159.00	2884.09
	Shrimp alone	14.98	94.80	858.00	307.52	434.28	389.02	756.05	2854.64
	Mangrove	21.36	78.24	212.30	175.52	290.10	148.06	1830.53	2756.11
	Fallow	22.11	70.54	172.18	169.72	90.58	125.67	2159.54	2810.34
Kadamakudy	Paddy-shrimp	24.41	59.97	138.38	131.80	74.99	108.30	2304.71	2842.56
	Shrimp alone	18.79	92.88	875.77	265.79	315.79	316.81	985.67	2871.50
	Mangrove	20.30	89.05	354.19	211.38	496.19	283.60	1305.63	2760.33
	Fallow	21.64	72.22	185.87	172.54	351.29	134.90	1432.05	2370.50
RRS Vyttila	Paddy alone (plot a)	20.58	89.03	342.50	193.39	181.62	205.82	2090.97	3123.92
	Paddy alone (plot b)	22.54	68.26	150.40	137.98	158.79	116.79	1179.28	1834.04
	Paddy alone (plot c)	28.82	51.49	115.20	50.21	135.80	45.18	2346.63	2773.33
Mean		21.83	75.9	334.6613	179.7487	179.75	288.58	182.37	1807.28
Range		14.98-28.82	51.49-94.80	115.20-875.77	50.21-307.52	74.99-626.97	45.18-389.02	630.80-5296.92	1692.45-6669.72

Table 71b . Fractions of phosphorus in land uses under different locations in April (mg kg^{-1})

Location	Land uses	Ws- P	Al-P	Fe-P	Occl-P	Ca-P	Org-P	Res-P	Tot-P
Ezhikkara	Paddy-shrimp	1.36	327.66	336.50	383.88	165.07	626.97	4823.87	6665.31
	Shrimp alone	1.34	182.37	522.60	321.05	176.25	281.22	206.71	1691.54
	Mangrove	0.80	235.16	735.40	337.02	302.62	403.56	937.07	2951.63
	Fallow	1.46	173.83	463.28	290.77	109.16	225.22	892.38	2156.10
Kottuvally	Paddy-shrimp	1.40	179.13	467.20	294.94	108.30	262.23	1569.81	2883.01
	Shrimp alone	0.75	251.90	895.60	382.80	389.02	434.28	501.95	2856.30
	Mangrove	1.32	183.09	528.65	332.49	148.06	290.10	1273.89	2757.60
	Fallow	4.23	105.09	345.20	190.13	125.67	90.58	1950.69	2811.60
Kadamakudy	Paddy-shrimp	5.99	104.99	306.76	147.26	108.30	74.99	2095.31	2843.60
	Shrimp alone	1.07	213.48	562.40	335.64	316.81	315.79	1125.01	2870.20
	Mangrove	0.70	327.15	973.60	528.39	283.60	496.19	152.77	2762.40
	Fallow	1.03	215.62	566.40	335.91	134.90	251.30	868.25	2373.40
RRS Vyttila	Paddy alone (plot a)	1.48	153.87	439.48	260.03	205.82	181.62	1881.56	3123.88
	Paddy alone (plot b)	1.64	116.14	385.10	206.43	116.79	158.79	845.71	1830.60
	Paddy alone (plot c)	1.74	106.05	352.10	192.79	45.18	135.80	1937.94	2771.60
Mean		1.75	191.70	525.35	302.64	182.37	281.91	1404.19	2889.92
Range		0.7-5.99	105.0-327.66	306.8-973.6	147.3-528.39	45.2-389.02	75.0-626.97	152.8-4823.87	1691.5-6665.31

4.5.1.1. Correlation between P fractions and soil properties

Correlation between P fractions and soil properties are detailed in the table 72. Water soluble P significantly and positively correlated with soil pH (0.555**) where it negatively correlated to available Mg (-0.368*), Zn (-0.527**), Cu (-0.527**) and Mn (-0.422*). Aluminium bound P positively and significantly correlated with EC (0.663**), available P (0.506**), Mg (0.493**), Zn (0.688**), Cu (0.664**) and Mn (0.456*) and, negatively correlated with pH (-0.807**), dehydrogenase enzyme activity (-0.528**) and microbial biomass carbon (-0.578**). Occluded P significantly and negatively correlated with pH (-0.684**) and TN (-0.503**) and positively correlated with EC (0.537**), available P (0.443*), K (0.435*), Ca (0.538**), Zn (0.668**), Cu (0.577**), Mn (0.532**) and Fe (0.422*). Calcium bound P positively and significantly correlated with EC (0.513**), P (0.431*), Ca (0.373*), Cu (0.533**) and Mn (0.530**) whereas, it negatively correlated with TN (-0.484**). Organic P positively and significantly correlated with EC (0.394*), available P (0.362*), K (0.641**), Ca (0.460*), Mg (0.481**), S (0.510**), Cu (0.409*) and Mn (0.433*). Residual P positively correlated with pH (0.702**), TN (0.372*), and microbial biomass carbon (0.693**) and negatively correlated with available P (-0.417*), Mg (-0.388*), Zn (-0.600**), Cu (-0.611**) and Mn (-0.468**). Iron oxide bound P had positive correlation with available P (0.311*).

4.5.1.2. Correlation between P fractions, exchangeable cations and AEC

Table 73 shows the relationship between the phosphorus fractions, exchangeable cations and AEC. Water soluble P had positive correlation with residual P (0.693**) and ex K (0.392*) and negative correlation with Al-P (-0.578**), ex Al (0.445*), ex Mn (0.386*) and AEC (-0.386*). Aluminium P significantly and positively correlated to Fe-P (0.395*), occluded P (0.484*), ex Al (0.440*), ex Mn (0.528**), and AEC (0.466**) and, negatively correlated to res-P (.645**), ex-Mg (-0.549**) and ex Cu (-0.582**). Iron oxide bound P significantly and negatively correlated to org-P (0.385*) and res-P (-0.523**). Occluded P registered positive correlation with ex Na (0.478**), ex Al (0.500**) and AEC (0.722**) and, negatively correlated with residual P (-0.537**), ex K (-0.434*), ex. Ca (-0.436*) and ex Mg (-0.743**). Calcium bound P positively and significantly correlated with ex Na (0.362*), ex Al (0.362*), ex Fe (0.407) and AEC

(0.406*) whereas, it negatively correlated with ex K (-0.390*) and ex-Mg (-0.464**). Org P positively correlated with ex Al (0.383*). Residual P positively and significantly correlated with ex K (0.532**), ex Ca (0.555**) and ex Mg (0.382*). Residual P negatively correlated with ex Al (-0.534**), ex Mn (-.0362*) and AEC (-0.619**).

4.5.1.3 Contribution of different fractions of phosphorus to available pool

The path analysis of different fractions of phosphorus to available phosphorus in October and April is presented in table 74a and 74b correspondingly which indicates the direct and indirect effects of different fractions on available phosphorus which was found to be significantly correlated to water soluble P, aluminium P, iron P, occluded P and organic P.

4.5.1.3.1. Contribution of different fractions of phosphorus to available pool in October

The direct effect of water soluble P to available pool was negative and very high (-0.764). The indirect effect of water soluble P through aluminium bound P (0.994), occluded P (1.112) was positive and very high and, the indirect effect of water soluble P through iron bound P (0.167) was positive and negligible. Whereas, the indirect effect of water soluble P through organic P (-0.616) was very high and negative.

The direct effect of aluminium bound P fraction to available pool was very high and negative (-1.061). The indirect effect of aluminium bound P through water soluble P (0.715) and organic P (0.623) was positive and very high. And indirect effect of aluminium bound P through occluded P (-1.071) was negative and very high. Indirect effect of aluminium bound P through iron bound P was negative and low (-0.170).

The direct effect of iron bound P to available pool was negative and moderate (-0.208). The indirect effect of iron bound P through water soluble P (0.613) and organic P (0.624) was positive and very high and through aluminium bound P, occluded P was negative and very high and the values were -0.866 and -1.004 correspondingly .

The direct effect of occluded P fraction to available P was negative and very high (-1.134). The indirect effect of occluded P through water soluble P (0.749) and organic P (0.646) was positive and very high wheweas through aluminium bound P (-

1.002) was negative and very high and through iron bound P (-0.184) was negative and low.

The direct effect of organic P fraction to available P was positive and very high (0.672). The indirect effect of organic P through, water soluble P was positive and very high (0.700). The indirect effect of organic P through aluminium bound P (-0.984) and occluded P (-1.089) was very high and negative and through iron bound P was negative and low (-0.193).

4.5.1.3.2. Contribution of different fractions of phosphorus to available pool in April

The direct effect of water soluble P to available pool was positive and low (0.190). And the indirect effect of water soluble P through iron bound P (0.338) was positive and high and through occluded P and organic P was positive and moderate and the values were 0.215 and 0.245 respectively. Indirect effect of water soluble P through aluminium bound P (-0.285) was moderate and negative.

The direct effect of aluminium bound P to available pool was very high and positive (0.475). The indirect effect of aluminium bound P through water iron bound P (-0.385) and organic P (-0.377) was negative and high and through occluded P (-0.285) was negative and moderate and the indirect effect of aluminium bound P through water soluble P was negative and low (-0.114).

The direct effect of iron bound P to available pool was negative and high (-0.589). The indirect effect of iron bound P through aluminium bound P (0.311) was positive and high. Indirect effect of iron bound P through occluded P (-0.246) and organic P (-0.223) was negative and moderate and through water soluble P (-0.109) was negative and low.

The direct effect of occluded P fraction to available P was negative and high (-0.305). The indirect effect of occluded P through aluminium bound P (0.444) was high and positive. Indirect effect of occluded P through iron bound P was negative and high (-0.474) and through organic P (-0.338) was negative and high and, the indirect effect of occluded P through water soluble P (-0.133) was negative and low.

The direct effect of organic P fraction to available P was negative and high (-0.385). The indirect effect of organic P through aluminium bound P was positive and very high (0.465). The indirect effect of organic P through iron bound P (-0.340) was negative and high and through occluded P (-0.268) was moderate and negative and through water soluble P was negative and low (-0.121).

Table 72. Correlation between P fractions and soil properties

	pH	EC	TN	P	K	Ca	Mg	S	Zn	Cu	Mn	Fe	DEA	MBC
Ws- P	0.555**			0.892**			-0.368*		-0.527**	-0.527**	-0.422*			
Fe- P				-0.841**										
Al-P	-0.807**	0.663**		-0.963**			0.493**		0.688**	0.664**	0.456*		-0.528**	-0.578**
Occlu-P	-0.684**	0.537**	-0.503**	-0.925**	0.435*	0.538**			0.668**	0.577**	0.532**	0.422*		
Ca-P		0.513**	-0.484**	0.431*		0.373*				0.533**	0.530**			
Org-P		0.394*		-0.894**	0.641**	0.460*	0.481**	0.510**		0.409*	0.433*			
Res-P	0.702**		0.372*	-0.417*			-0.388*		-0.600**	-0.611**	-0.468**			0.693**

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

*Correlation significant at 0.05 level (2-tailed)

Table 73. Correlation between P fractions, exchangeable cations and AEC

	Ex Na	Ex K	Ex Ca	Ex Mg	Ex Al	Ex Fe	Ex Mn	Ex Cu	AEC	Al-P	Fe-P	Occlu-P	Org-P	Res-P	Tot-P
Ws- P		0.392*			-0.445*		-0.368*		-0.386*	-0.578**				0.693**	
Al-P		-0.535**		-0.549**	0.440*		0.528**	-0.582**	0.466**		0.395*	0.484**		-0.645**	
Fe-P													-0.385*	-0.523**	0.802**
Occlu-P	0.478**	-0.434*	-0.436*	-0.473**	0.500**				0.722**					-0.537**	
Ca-P	0.362*	-0.390*		-0.464**	0.362*	0.407*			0.406*						
Org-P						0.383*									
Res-P		0.532**	0.555**	0.382*	-0.534**		-0.362*		-0.619**						

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

*Correlation significant at 0.05 level (2-tailed)

Table 74a. Path coefficients of different fractions of phosphorus to available phosphorus during October

	Ws- P	Al-P	Fe-P	Occlu-P	Org-P	Correlation coefficient
Ws- P	**-0.764**	0.994	0.167	1.112	-0.616	0.893
Al-P	0.715	**-1.061**	-0.170	-1.071	0.623	-0.963
Fe-P	0.613	-0.866	**-0.208**	-1.004	0.624	-0.841
Occlu-P	0.749	-1.002	-0.184	**-1.134**	0.646	-0.925
Org-P	0.700	-0.984	-0.193	-1.089	**0.672**	-0.894

(Values on diagonal are direct effects and values on horizontal lines are indirect effects)

Table 74b. Path coefficients of different fractions of phosphorus to available phosphorus during April

	Ws- P	Al-P	Fe-P	Occlu-P	Org-P	Correlation coefficient
Ws- P	**0.190**	-0.285	0.338	0.215	0.245	0.702
Al-P	-0.114	**0.475**	-0.385	-0.285	-0.377	-0.686
Fe-P	-0.109	0.311	**-0.589**	-0.246	-0.223	-0.855
Occlu-P	-0.133	0.444	-0.474	**-0.305**	-0.338	-0.807
Org-P	-0.121	0.465	-0.340	-0.268	**-0.385**	-0.650

(Values on diagonal are direct effects and values on horizontal lines are indirect effects)

4.5.2. Fractions of copper

Tables 75a and 75b shows distribution of different fractions of copper in soil during October and April. The water soluble copper ranged from 0.19 (mangrove in Ezhikkara) to 1.94 mg kg^{-1} (paddy-shrimp in Kadamakudy) in October and 1.29 (plot18 of paddy alone in RRS, Vyttila) to 6.84 mg kg^{-1} (mangrove in Kadamakudy) in April.

Highest exchangeable Cu observed in paddy-shrimp in Kadamakudy (0.10 mg kg^{-1}) in October and, mangrove in Kadamakudy (1.82 mg kg^{-1}) in April. Specifically adsorbed Pb displaceable Cu was highest in mangrove in Ezhikkara (2.53 mg kg^{-1}) in October and in plot b of paddy alone land use in RRS Vyttila (0.49 mg kg^{-1}) in April. Mangroves in Ezhikkara recorded with the highest values of acid soluble (3.56 mg kg^{-1})

and manganese oxide occluded Cu (6.36 mg kg^{-1}) during October and plot b of paddy alone in RRS Vyttila observed with 1.09 mg kg^{-1} and 0.36 mg kg^{-1} respectively during April. Organic matter occluded Cu ranged from 4.29 (mangrove in Ezhikkara) to 10.93 mg kg^{-1} (paddy-shrimp in Kadamakudy) in October and 1.15 (plot b of paddy alone in RRS Vyttila) to 6.42 mg kg^{-1} (mangrove in Kadamakudy) in April. Amorphous and crystalline iron oxide occluded Cu were higher during October and the values ranged from 1.66 (paddy-shrimp in Kadamakudy) to 4.36 mg kg^{-1} (mangrove in Ezhikkara) and 1.44 (paddy-shrimp in Kadamakudy) to 4.04mg kg^{-1}(mangrove in Ezhikkara) respectively. In April, these values ranged from 0.14 (mangrove in Kadamakudy) to 0.44 mg kg^{-1} (plot b of paddy alone in RRS Vyttila) and 0.14 (mangrove in Kadamakudy) to 0.56 mg kg^{-1} (plot b of paddy alone in RRS Vyttila). Highest residual Cu reported as 6.63 and 23.31 mg kg^{-1} respectivelyduring October and Aprilin plot b of paddy alone in RRS Vyttila. Total Cu ranged from 20.49 (paddy-shrimp in Kadamakudy) to 29.20 mg kg^{-1} (plot b of paddy alone in RRS Vyttila) in October and 19.06 (paddy-shrimp in Kottuvally) to 29.24 mg kg^{-1} (plot b of paddy alone in RRS Vyttila) in April sequentially.

4.5.2.1. Correlation between copper fractions

Correlations between copper fractions were detailed in table 76. Water soluble copper was positively and highly correlated to exchangeable copper (0.921**) and positively and significantly correlated with organically occluded (0.871**) and residual copper (0.458*) and, had significant and negative correlation with specifically adsorbed lead displaceable copper (-0.830**), acid soluble copper (-0.670**), manganese oxide occluded copper (-0.761**), amorphous iron oxide bound copper (-0.823**) and crystalline iron oxide bound copper (-0.828**).

Table 75a. Fractions of copper across the locations under different land uses in October (mg kg^{-1})

Location	Land uses	Ws.Cu	Ex.Cu	Sp.ad.Pd .dis.Cu	Ac.So. Cu	MnOx. Cu	Org.Occl. Cu	Am.FeOx. Cu	Cry.FeOx. Cu	Re.Cu.	To.Cu
Ezhikkara	Paddy-shrimp	0.31	0.03	2.39	2.81	6.23	5.00	4.28	3.82	0.76	25.62
	Shrimp alone	0.40	0.04	2.10	2.06	5.62	5.99	4.01	3.36	2.68	26.24
	Mangrove	0.19	0.02	2.53	3.56	6.36	4.29	4.36	4.04	2.44	27.80
	Fallow	0.37	0.03	2.14	2.63	6.11	5.47	4.02	3.43	1.01	25.21
Kottuvally	Paddy-shrimp	1.26	0.08	1.25	1.13	2.04	10.89	1.90	1.66	0.72	20.95
	Shrimp alone	0.50	0.04	1.87	1.84	3.74	8.34	3.64	3.00	2.15	25.12
	Mangrove	0.82	0.08	1.32	1.23	2.16	9.88	1.91	2.01	1.23	20.64
	Fallow	0.71	0.04	1.81	1.76	3.52	9.26	3.30	2.85	1.38	24.62
Kadamakudy	Paddy-shrimp	1.94	0.10	1.04	0.94	1.66	10.93	1.66	1.44	0.77	20.49
	Shrimp alone	0.76	0.05	1.78	1.61	3.49	9.32	2.82	2.47	0.15	22.45
	Mangrove	0.77	0.05	1.54	1.60	2.54	9.41	2.78	2.39	0.44	21.52
	Fallow	0.41	0.04	1.98	2.02	5.56	6.43	3.92	3.16	2.47	25.99
Vyttila	Paddy alone (a)	0.46	0.04	1.94	1.95	4.20	7.11	3.80	3.10	5.50	28.09
	Paddy alone (b)	0.48	0.04	1.90	1.94	3.86	7.68	3.65	3.04	6.63	29.20
	Paddy alone (c)	0.79	0.06	1.49	1.53	2.39	9.62	2.63	2.12	4.55	25.17
Mean		0.68	0.05	1.81	1.91	3.97	7.97	3.25	2.79	2.19	24.61
Range		0.19-1.94	0.02-0.10	1.04-2.53	0.94-3.56	1.66-6.36	4.29-10.93	1.66-4.36	1.44-4.04	0.15-6.63	20.49-29.20

Table 75b. Fractions of copper across the locations under different land uses in April (mg kg^{-1})

Location	Land uses	Ws.Cu	Ex.Cu	Sp.ad.Pd.dis.Cu	Ac.So.Cu	MnOx.Cu	Org.Occl.Cu	Am.FeOx.Cu	Cry.FeOx.Cu	Re.Cu.	To.Cu
Ezhikkara	Paddy-shrimp	2.01	0.83	0.33	0.82	0.25	1.48	0.33	0.39	18.18	24.62
	Shrimp alone	2.47	0.77	0.41	0.93	0.33	1.27	0.37	0.48	18.31	25.35
	Mangrove	3.54	1.20	0.27	0.64	0.19	2.21	0.26	0.27	18.67	27.25
	Fallow	3.41	1.18	0.28	0.77	0.23	1.88	0.31	0.31	15.69	24.05
Kottuvally	Paddy-shrimp	5.94	1.40	0.16	0.46	0.14	3.13	0.18	0.24	7.41	19.06
	Shrimp alone	3.05	0.91	0.32	0.80	0.24	1.54	0.32	0.36	16.57	24.12
	Mangrove	3.45	1.19	0.27	0.70	0.21	1.97	0.28	0.28	11.23	19.57
	Fallow	2.90	0.80	0.39	0.91	0.28	1.43	0.36	0.41	16.15	23.64
Kadamakudy	Paddy-shrimp	3.24	1.00	0.29	0.78	0.24	1.73	0.31	0.33	12.91	20.83
	Shrimp alone	5.83	1.39	0.19	0.50	0.15	2.96	0.20	0.25	10.61	22.08
	Mangrove	6.84	1.82	0.13	0.36	0.11	6.42	0.14	0.14	4.60	20.56
	Fallow	3.34	1.24	0.21	0.59	0.18	2.56	0.24	0.27	17.28	25.90
Vyttila	Paddy alone (a)	6.69	1.64	0.15	0.42	0.12	4.53	0.17	0.17	14.27	28.15
	Paddy alone (b)	1.29	0.54	0.49	1.09	0.36	1.15	0.44	0.56	23.31	29.24
	Paddy alone (c)	4.65	1.28	0.21	0.54	0.16	2.77	0.21	0.26	15.67	25.74
Mean		3.91	1.15	0.27	0.69	0.21	2.47	0.27	0.31	14.72	24.01
Range		1.29-6.84	0.54-1.82	0.13-0.49	0.36-1.09	0.11-0.36	1.15-6.42	0.14-0.44	0.14-0.56	4.60-23.31	19.06-29.24

Exchangeable copper made positive and high correlation with organically occluded copper (0.917**) and it significantly and negatively correlated to specifically adsorbed lead displaceable copper (-0.827**), acid soluble copper (-0.654**), manganese oxide occluded copper (-0.777**), amorphous iron oxide bound copper (-0.832**) and crystalline iron oxide bound copper (-0.828**).

Specifically adsorbed lead displaceable copper had high positive correlation with manganese oxide occluded copper (0.920**) and acid soluble copper (0.875**). It had significant and negative correlation with amorphous iron oxide bound copper (-0.979**), crystalline iron oxide bound copper (-0.978**) and organically occluded copper (-0.692**).

Acid soluble copper recorded positive and high correlation with manganese oxide occluded copper (0.920**), amorphous iron oxide bound copper (0.876**), crystalline iron oxide bound copper (0.853**) and had negative and significant correlation with organically occluded copper (-0.526**).

Manganese oxide occluded copper was positively and highly correlated to amorphous iron oxide bound copper (0.925**) and crystalline iron oxide bound copper (0.878**) and draw up significant and negative correlation with organically occluded copper (-0.665**).

Organically occluded copper was positively correlated to crystalline iron oxide bound copper (0.432*) and constitute significant and negative correlation with amorphous iron oxide bound copper (-0.683**) and crystalline iron oxide bound copper (-0.688**).

Amorphous iron oxide bound copper was positively and highly correlated to crystalline iron oxide bound copper (0.972**). Residual copper established significant and positive correlation with total copper (0.669**).

4.5.2.2. Correlation of copper fractions with soil properties

Correlation of copper fractions with soil properties are given in table 77.Water soluble copper was significantly and positively correlated to electrical conductivity (0.788**), available potassium (0.654**), magnesium (0.546**), sulphur (0.583**), copper (0.845**), iron (0.764**), boron (0.485**) and calcium (0.442*) and was significant and negatively correlated with pH (-0.866**) and phosphorus (-0.566**). Water soluble copper was significant and positively correlated to anion exchange capacity (0.752**), manganese (0.869**), exchangeable sodium (0.493**), exchangeable aluminium (0.562**) and had negative and significant correlation with exchangeable potassium (-0.631**), exchangeable calcium (-0.472**), exchangeable magnesium (-0.587**), exchangeable copper (-0.463**), dehydrogenase enzyme activity (-0.851**) and microbial biomass carbon (-0.404*).

Exchangeable copper was significant and positively correlated with electrical conductivity (0.809**), available potassium (0.671**), magnesium (0.521**), sulphur (0.515**), copper (0.804**), iron (0.627**), boron (0.542**) and calcium (0.462*) and had negative and significant correlation with pH (-0.866**) and phosphorus (-0.534**). Exchangeable copper established positive and significant correlation with anion exchange capacity (0.613**), manganese (0.799**), exchangeable sodium (0.432**), exchangeable aluminium (0.463**) and had a negative and significant correlation with exchangeable potassium (-0.497**), exchangeable magnesium (-0.500**), exchangeable copper (-0.531**), dehydrogenase enzyme activity (-0.795**) and microbial biomass carbon (-0.485**).

Specifically adsorbed lead displaceable copper was significantly and positively correlated to soil pH (0.883**) and available phosphorus (0.484**) and was significant and negatively correlated with electrical conductivity (-0.694**), potassium (-0.656**), sulphur (-0.506**), copper (-0.779**), iron (-0.599**) and boron (-0.418*). Specifically adsorbed lead displaceable copper was significantly and positively correlated to exchangeable potassium (0.614**), exchangeable magnesium (0.569**), dehydrogenase enzyme activity (0.788**), microbial biomass carbon (0.488**), cation exchange capacity (0.391*) and exchangeable calcium (0.378*). However a negative and significant correlation existed between specifically adsorbed lead displaceable copper and anion exchange capacity (-0.631**), manganese (-0.800**), exchangeable aluminium (-0.562**) and exchangeable manganese (-0.393**).

Acid soluble copper was significantly and positively correlated with soil pH (0.751**) and had significant and negative correlation with electrical conductivity (-0.568**), potassium (-0.599**), sulphur (-0.402**), copper (-0.632**) and iron (-

0.477**). Acid soluble copper had positive and significant correlation with exchangeable potassium (0.520**), exchangeable magnesium (0.565**), dehydrogenase enzyme activity (0.682**), cation exchange capacity (0.374*) and exchangeable calcium (0.369*) and recorded negative and significant correlation with anion exchange capacity (-0.545**), manganese (-0.672** and exchangeable aluminium (0.483**).

Manganese oxide occluded copper possessed significant and positive correlation with soil pH (0.788**), phosphorus (0.514**) and had significant and negative correlation with electrical conductivity (-0.669**), potassium (-0.655**), sulphur (-0.464**), copper (-0.671**), iron (-0.496**) and boron (-0.437**). Manganese oxide occluded copper was significantly and positively correlated to exchangeable potassium (0.523**), exchangeable magnesium (0.515**), dehydrogenase enzyme activity (0.739**), cation exchange capacity (0.388*), exchangeable calcium (0.420*), population of nitrogen fixing bacteria (0.392*) and microbial biomass carbon (0.403*) and had negative and significant correlation with anion exchange capacity (-0.598**), manganese (-0.713**), exchangeable aluminium (-0.449*) and exchangeable manganese (-0.376*).

Organically occluded copper was significantly and positively correlated to electrical conductivity (0.805**), available potassium (0.616**), calcium (0.533**), magnesium (0.592**), sulphur (0.577**), copper (0.694**), iron (0.671**), boron (0.659**) and had significant and negative correlation with soil pH (-0.704**) and phosphorus (-0.506**). Organically occluded copper made positive and significant correlation with anion exchange capacity (0.599**), manganese (0.745**), exchangeable sodium (0.479**) and exchangeable aluminium (0.397*) and, a negative and significant correlation with exchangeable potassium (-0.465**), exchangeable magnesium (-0.456**), exchangeable copper (-0.591**), dehydrogenase enzyme activity (-0.695**) and microbial biomass carbon (-0.517**).

Amorphous iron oxide bound copper established significant and positive correlation with soil pH (0.878**) and phosphorus (0.483**) and a significant and negative correlation was found with electrical conductivity (-0.705**), available potassium (-0.626**), sulphur (-0.474**), copper (-0.755**), iron (-0.563**) and boron (-0.375*). Amorphous iron oxide bound copper was significantly and positively correlated to exchangeable potassium (0.596**), exchangeable magnesium (0.560**), dehydrogenase enzyme activity (0.787**), exchangeable calcium (0.366*) and microbial biomass carbon (0.406*) and this fraction of copper revealed anegative and significant correlation with anion exchange capacity (-0.630**), manganese (-0.780**), exchangeable aluminium (-0.519**) and exchangeable manganese (-0.403*).

Crystalline iron oxide bound copper was significantly and positively correlated to pH (0.890**) and available phosphorus (0.435*). Negative correlation of crystalline iron oxide bound copper with electrical conductivity (-0.679**), available potassium (-0.619**), sulphur (-0.464**), copper (-0.768**), iron (-0.582**) and boron (-0.387*) could also be noticed. Crystalline iron oxide bound copper made positive and significant correlation with exchangeable potassium (0.594**), exchangeable magnesium (0.563**), dehydrogenase enzyme activity (0.753**), microbial biomass carbon (0.501**) and exchangeable copper (0.389*) and had negative and significant correlation with anion exchange capacity (-0.631**), manganese (-0.776**), exchangeable aluminium (0.490**) and exchangeable manganese (-0.367*).

Residual copper had positive correlation with available calcium (0.399*), magnesium (0.446*) and iron (0.384*) and a negative correlation with phosphorus (-0.411*).

4.5.2.3. Contribution of different fractions of copper to available pool

The path analysis of different fractions of copper to available copper in October and April is presented in table 78a and 78b correspondingly which indicates the direct and indirect effects of different fractions on available copper. Available copper was not found to be significantly correlated to residual and total copper.

4.5.2.3.1. Contribution of different fractions of copper to available pool in October

The direct effect of water soluble copper to available copper was negative and moderate (-0.296). Indirect effect of water soluble Cu through exchangeable Cu (1.702), manganese oxide bound copper (0.498) and crystalline iron oxide copper (1.453) was very high and positive and through organic matter occluded copper (0.159) was positive and low. Indirect effect of water soluble copper through specifically adsorbed lead displaceable copper, acid soluble copper, and amorphous iron oxide occluded copper was negative and very high and the values were -1.413, -0.400 and -0.791 respectively.

Direct effect of exchangeable copper to available pool was very high and positive (1.809) and indirect effect of exchangeable copper through manganese oxide bound copper (0.539) and crystalline iron oxide copper (1.549) was also very high and positive. Indirect effect of exchangeable copper through organic matter occluded copper (0.172) was positive and low and through specifically adsorbed lead displaceable copper (0.769), acid soluble copper (-0.432), and amorphous iron oxide occluded copper (-0.863) was negative and very high. Indirect effect of exchangeable copper through water soluble copper was also negative but moderate (-0.278).

The direct effect of specifically adsorbed lead displaceable copper on available copper was positive and very high (1.590). The indirect effect of specifically adsorbed lead displaceable copper through acid soluble copper (0.479) and amorphous iron oxide occluded copper (0.861) was very high and positive and through water soluble copper was positive and moderate (0.263). The indirect effect of specifically adsorbed lead displaceable copper through exchangeable copper, manganese oxide occluded copper and crystalline iron oxide was negative and very high and the values were -1.730, -0.588 and -1.608 respectively and through organic matter occluded copper (-0.209) was negative and moderate.

The direct effect of acid soluble copper on available copper was positive and very high (0.506). Indirect effect of acid soluble copper through specifically adsorbed lead displaceable copper (1.590), amorphous iron oxide occluded copper (0.780) and through water soluble copper (0.234) was positive and moderate. The indirect effect of acid soluble copper through exchangeable copper, manganese oxide occluded copper and crystalline iron oxide was negative and very high and the values were -1.546, -0.559 and -1.517 respectively and through organic matter occluded copper (-0.230) was negative and moderate.

The direct effect of manganese oxide occluded copper to available copper was negative and very high (-0.618). Indirect effect of manganese oxide occluded copper through specifically adsorbed lead displaceable copper (1.504), acid soluble copper (0.458) and amorphous iron oxide occluded copper (0.780) was very high and positive.

The indirect effect of manganese oxide occluded copper through water soluble copper (0.234) was moderate and positive. The indirect effect of manganese oxide occluded copper through exchangeable copper, crystalline iron oxide was negative and very high and the values were -1.578 and -1.540 respectively and through organic matter occluded copper (-0.204) was moderate and negative.

The direct effect of organic matter occluded copper on available pool was negative and moderate (-0.240). The indirect effect of organic matter occluded through specifically adsorbed lead displaceable copper (1.512), acid soluble copper (0.485) and amorphous iron oxide occluded copper (0.688) was very high and positive. And, the indirect effect of organic matter occluded copper through water soluble copper (0.196) was positive and low. The indirect effect of organic matter occluded copper through exchangeable copper, manganese oxide occluded copper, crystalline iron oxide was negative and very high and the values were -1.302, -0.525 and -1.393 correspondingly.

The direct effect of amorphous iron oxide occluded copper to the available pool was positive and very high (0.892). Indirect effect of amorphous iron oxide occluded copper through specifically adsorbed lead displaceable copper (1.534), acid soluble copper (0.442) and amorphous iron oxide occluded copper (0.873) was very high and positive. The indirect effect of amorphous iron oxide occluded copper through water soluble copper (0.262) was moderate and positive. Whereas the indirect effect of amorphous iron oxide occluded copper through exchangeable copper, manganese oxide occluded copper, crystalline iron oxide was negative and very high and the values were -1.749, -0.577 and -1.587 consequently and through organic matter occluded copper (-0.185) was low and negative.

The direct effect of crystalline iron oxide on available pool was negative and very high (-1.623). The indirect effect of organic matter occluded through specifically adsorbed lead displaceable copper (1.575), acid soluble copper (0.473) and amorphous iron oxide occluded copper (0.873) was very high and positive. And the indirect effect of crystalline iron oxide through water soluble copper (0.265) was positive and moderate. The indirect effect of crystalline iron oxide through exchangeable copper and manganese oxide occluded copper was negative and very high and the values were -

1.727, -0.586 and through organic matter occluded copper (-0.206) was moderate and negative.

4.5.2.3.2. Contribution of different fractions of copper to available pool in April

The direct effect of water soluble copper to available copper was positive and very high (0.604). Indirect effect of water soluble Cu through amorphous iron oxide occluded copper (1.366) and the indirect effect of water soluble copper through exchangeable copper (0.217), manganese oxide bound copper (0.276) was moderate and positive. The indirect effect of water soluble copper through organic matter occluded copper (-0.700) was negative and very high and through specifically adsorbed lead displaceable copper, acid soluble copper and crystalline iron oxide coper was moderate and negative and the values were -0.210, -0.299 and -0.298 correspondingly.

The direct effect of exchangeable copper to available copper was positive and moderate (0.232). Indirect effect of exchangeable copper through water soluble copper (0.567), amorphous iron oxide occluded copper (1.469) and manganese oxide bound copper (0.304) was high and positive. The indirect effect of exchangeable copper through organic matter occluded copper (-0.716) was negative and very high. And the indirect effect of exchangeable copper through acid soluble copper (-0.322) and crystalline iron oxide copper (-0.334) was high and negative and through specifically adsorbed lead displaceable copper (-0.232) was moderate and negative.

The direct effect of specifically adsorbed lead displaceable copper to available copper was positive and moderate (0.242). Indirect effect of specifically adsorbed lead displaceable copper through organic matter occluded copper (0.712) was positive and very high and through acid soluble copper (0.327) and crystalline iron oxide copper (0.337) was positive and high. Indirect effect of specifically adsorbed lead displaceable copper through water soluble copper (-0.525) and amorphous iron oxide occluded copper (-1.494) was negative and very high and through manganese oxide bound copper (-0.315) was high and negative and through exchangeable copper (-0.222) was negative and moderate.

The direct effect of acid soluble copper to available pool was positive and high (0.332). Whereas the indirect effect of acid soluble copper through organic matter occluded copper (0.736) was very high and positive. The indirect effect of acid soluble copper through crystalline iron oxide copper (0.333) was positive and high and through specifically adsorbed lead displaceable copper (0.239) was positive and moderate. The indirect effect of acid soluble copper through water soluble copper (-0.544) and amorphous iron oxide occluded copper (-1.516) was negative and very high and through manganese oxide bound copper (-0.315) was high and negative and through exchangeable copper (-0.224) was negative and moderate.

The direct effect of manganese oxide bound copper to available copper was negative and high (-0.319). The indirect effect of manganese oxide bound copper through organic matter occluded copper (0.721) was positive and very high. The indirect effect of manganese oxide bound copper through acid soluble copper (0.328) and crystalline iron oxide copper (0.339) was positive and high and through specifically adsorbed lead displaceable copper (0.239) was positive and moderate. The indirect effect of manganese oxide bound copper through water soluble copper (-0.523) and amorphous iron oxide occluded copper (-1.497) was negative and very high and through exchangeable copper (-0.221) was negative and moderate.

The direct effect of organic matter occluded copper to available copper was positive and very high (0.750). The indirect effect of organic matter occluded copper through acid soluble copper (0.326) and crystalline iron oxide copper (0.319) was positive and high and through specifically adsorbed lead displaceable copper (0.230) was positive and moderate. The indirect effect of organic matter occluded copper through water soluble copper (-0.564) and amorphous iron oxide occluded copper (-1.487) was negative and very high and through manganese oxide bound copper (-0.306) was high and negative and through exchangeable copper (-0.224) was negative and moderate.

The direct effect of amorphous iron oxide occluded copper to available pool was negative and very high (-1.516). The indirect effect of amorphous iron oxide occluded copper through organic matter occluded copper (0.736) was positive and very high. The indirect effect of amorphous iron oxide occluded copper through acid soluble copper (0.332) and crystalline iron oxide copper (0.333) was positive and high and through specifically adsorbed lead displaceable copper (0.239) was positive and moderate. The indirect effect of amorphous iron oxide occluded copper through water soluble copper (-0.544) was negative and very high and the indirect effect of amorphous iron oxide occluded copper through manganese oxide bound copper (-0.315) was negative and high and through exchangeable copper (-0.224) was negative and moderate.

The direct effect of crystalline iron oxide copper to available copper was positive and high (0.345). The indirect effect of crystalline iron oxide copper through organic matter occluded copper (0.694) was positive and very high. And the indirect effect of crystalline iron oxide copper through acid soluble copper (0.320) was positive and high and through specifically adsorbed lead displaceable copper (0.236) was positive and moderate. The indirect effect of crystalline iron oxide copper through water soluble copper (-0.521) and amorphous iron oxide occluded copper (-1.462) was negative and very high and through manganese oxide bound copper (-0.313) was high and negative and through exchangeable copper (-0.224) was negative and moderate.

Table 76. Correlation between copper fractions

	Ws-Cu	**Ex-Cu**	**Spe.ads.pb.dis-Cu**	**Aci.sol-Cu**	**MnOxi-Cu**	**Org.occl-Cu**	**Amo-FeO**	**Res- Cu**
Ex-Cu	0.921^{**}							
Spe.ads.pb.dis-Cu	-0.830^{**}	-0.827^{**}						
Aci.sol-Cu	-0.670^{**}	-0.654^{**}	0.875^{**}					
MnOxi-Cu	-0.761^{**}	-0.777^{**}	0.920^{**}	0.920^{**}				
Org.occl-Cu	0.871^{**}	0.917^{**}	-0.692^{**}	-0.526^{**}	-0.665^{**}			
Amo-FEO	-0.823^{**}	-0.832^{**}	0.979^{**}	0.876^{**}	0.925^{**}	-0.683^{**}		
Cry-FeO	-0.828^{**}	-0.828^{**}	0.978^{**}	0.853^{**}	0.878^{**}	-0.688^{**}	0.972^{**}	
Res- Cu	0.458^{*}					0.432^{*}		
Tot-Cu								0.669^{**}

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

*Correlation significant at 0.05 level (2-tailed)

Tabel 77. Correlation of copper fractions with soil properties

	Ws-Cu	**Ex-Cu**	**Spe.ads.pb.dis-Cu**	**Aci.sol-Cu**	**MnOxi-Cu**	**Org.occl-Cu**	**Amo-FEO**	**Cry-FeO**	**Res- Cu**
pH	-0.866**	-0.789**	0.883**	0.751**	0.788**	-0.704**	0.878**	0.890**	
EC	0.799**	0.809**	-0.694**	-0.568**	-0.669**	0.805**	-0.705**	-0.679**	
Av.P	-0.566**	-0.534**	0.484**		0.514**	-0.506**	0.483**	0.435*	-0.411*
Av.K	0.654**	0.671**	-0.656**	-0.599**	-0.655**	0.616**	-0.626**	-0.619**	
Av.Ca	0.442*	0.462*				0.533**			0.399*
Av.Mg	0.546**	0.521**				0.592**			0.446*
Av.S	0.583**	0.515**	-0.506**	-0.402*	-0.464**	0.577**	-0.474**	-0.464**	
Av.Zn									
Av.Cu	0.911**	0.976**	-0.942**	-0.828**	-0.899**	-0.702**	-0.961**	-0.956**	
Av.Fe	0.764**	0.627**	-0.599**	-0.477**	-0.496**	0.671**	-0.563**	-0.582**	0.384*
Av.B	0.485**	0.542**	-0.418*		-0.437*	0.659**	-0.375*	-0.387*	

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

*Correlation significant at 0.05 level (2-tailed)

Table 77. Correlation of copper fractions with soil properties (continued)

	Ws-Cu	Ex-Cu	Spe.ads.pb.dis-Cu	Aci.sol-Cu	MnOxi-Cu	Org.occl-Cu	Amo-FEO	Cry-FeO
AEC	0.752**	0.613**	-0.631**	-0.545**	-0.598**	0.599**	-0.630**	-0.631**
CEC			0.391*	0.374*	0.388*			
Mn	0.869**	0.799**	-0.800**	-0.672**	-0.713**	0.745**	-0.780**	-0.776**
EX Na	0.493**	0.432*				0.479**		
Ex K	-0.631**	-0.497**	0.614**	0.520**	0.523**	-0.465**	0.596**	0.594**
Ex Ca	-0.472**		0.378*	0.369*	0.420*		0.366*	
Ex Mg	-0.587**	-0.500**	0.569**	0.565**	0.515**	-0.456*	0.560**	0.563**
Ex Al	0.562**	0.463*	-0.501**	-0.483**	-0.449*	0.397*	-0.519**	-0.490**
Ex Mn			-0.393*		-0.376*		-0.403*	-0.367*
Ex Cu	-0.463*	-0.531**				-0.591**		0.389*
NFB					0.392*			
Dehydro	-0.851**	-0.795**	0.788**	0.682**	0.739**	-0.695**	0.787**	0.753**
MBC	-0.404*	-0.485**	0.488**		0.403*	-0.517**	0.406*	0.501**

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

*Correlation significant at 0.05 level (2-tailed)

Table 78a. Contribution of copper fractions to available copper during October

	Ws-Cu	Ex-Cu	Spe.ads.pb.dis-Cu	Aci.sol-Cu	MnOxi-Cu	Org.occl-Cu	Amo-FeO	Cry-FeO	Correlation coefficients
Ws-Cu	**-0.296**	1.702	-1.413	-0.400	0.498	0.159	-0.791	1.453	0.911
Ex-Cu	-0.278	**1.809**	-1.520	-0.432	0.539	0.172	-0.863	1.549	0.976
Spe.ads.pb.dis-Cu	0.263	-1.730	**1.590**	0.479	-0.588	-0.209	0.861	-1.608	-0.942
Aci.sol-Cu	0.234	-1.546	1.504	**0.506**	-0.559	-0.230	0.780	-1.517	-0.828
MnOxi-Cu	0.238	-1.578	1.512	0.458	**-0.618**	-0.204	0.833	-1.540	-0.899
Org.occl-Cu	0.196	-1.302	1.388	0.485	-0.525	**-0.240**	0.688	-1.393	-0.702
Amo-FEO	0.262	-1.749	1.534	0.442	-0.577	-0.185	**0.892**	-1.587	-0.967
Cry-FeO	0.265	-1.727	1.575	0.473	-0.586	-0.206	0.873	**-1.623**	-0.956

(Values on diagonal are direct effects and values on horizontal lines are indirect effects)

Table 78b. Contribution of copper fractions to available copper during April

	Ws-Cu	Ex-Cu	Spe.ads.pb.dis-Cu	Aci.sol-Cu	MnOxi-Cu	Org.occl-Cu	Amo-FeO	Cry-FeO	Correlation coefficients
Ws-Cu	**0.604**	0.217	-0.210	-0.299	0.276	-0.700	1.366	-0.298	0.956
Ex-Cu	0.567	**0.232**	-0.232	-0.322	0.304	-0.716	1.469	-0.334	0.966
Spe.ads.pb.dis-Cu	-0.525	-0.222	**0.242**	0.327	-0.315	0.712	-1.494	0.337	-0.937
Aci.sol-Cu	-0.544	-0.224	0.239	**0.332**	-0.315	0.736	-1.516	0.333	-0.959
MnOxi-Cu	-0.523	-0.221	0.239	0.328	**-0.319**	0.721	-1.497	0.339	-0.933
Org.occl-Cu	-0.564	-0.221	0.230	0.326	-0.306	**0.750**	-1.487	0.319	-0.953
Amo-FEO	-0.544	-0.224	0.239	0.332	-0.315	0.736	**-1.516**	0.333	-0.959
Cry-FeO	-0.521	-0.224	0.236	0.320	-0.313	0.694	-1.462	**0.345**	-0.924

(Values on diagonal are direct effects and values on horizontal lines are indirect effects)

Experiment 3

4.6. Adsorption study

Adsorption study was carried out to untangle the chemistry behind the nutrient dynamics in *Pokkali* soil. The nutrients phosphorus and copper were selected for this purpose. Five soil samples having different textural classes namely clay, clay loam, sandy clay loam, loam and silt were opted for adsorption study to know the adsorption pattern of copper and phosphorus with varying texture of soil.In order to understand the influence of seasons on adsorption of phosphorous and copper, sample collection was adjusted to coincide with low saline (October) and high saline phases (April) respectively.

4.6.1. Phosphorus

4.6.1.1. Quantity intensity relationship

Adsorption study of P in the collected soil was carried out at 25^0C and 35^0C following the procedure described in 3.3.1.2. Five gram soil was equilibrated with 0, 10, 20, 40, 80 and 100 mg L^{-1} of P solution. The concentration of P in the equilibrium solution was estimated. Concentration of phosphorus in equilibrium solution after equilibration period was considered as intensity factor and the amount adsorbed per unit weight of the soil was considered as quantity factor. The Q-I curves were fitted with this data by plotting concentration of phosphorus in equilibrium solution in X axis and quantity adsorbed per unit weight of the soil in Y axis. The intercept and slope were computed from the best fit curve using regression analysis. The slope of the curve explains the buffer power.

The parameters of the Q-I curve and maximum quantity adsorbed per unit weight of the soil from the added concentration of phosphorus are given in table 84. L-shaped curve was obtained for Pokkali soil. All the textural classes of soil samples were recorded with R^2 value > 0.5 for the linear fit of quantity – intensity curve at both 25^0C and 35^0C for October and April.

The quantity of maximum phosphorus adsorbed was highest in clay textured soil in October and April for both the soil temperatures. The highest copper adsorption was recorded in October compared to April for all the textural classes of the soil. The value of maximum phosphorus adsorption in clay textured soil was 820 mg kg^{-1} and 840.50 mg kg^{-1} in October and April respectively for 25^0C and, 840.25 mg kg^{-1} and 850.60 mg kg^{-1} in October and April respectively for 35^0C. The lowest copper adsorbed was on silt loam textured soil (700 mgkg^{-1}and 720.50 mgkg^{-1}in October and April respectively for 25^{0}C and, 720.10 mg kg^{-1} and 740.60 mg kg^{-1} in October and April respectively for 35^{0}C). Generally, phosphorus adsorption increased in April compared to October and the adsorption increased with increasing soil temperature.

The highest buffer power was observed in clay textured soil (42 and 47.16 L kg^{-1} in October and April respectively for 25^{0}C and 43.78 and 53.35 L kg^{-1} in October and April for 35^{0}C) and the lowest was noticed in silt loam (30.40 and 33.63 L kg^{-1} in October and April respectively for 25 ^{0}C and 31.71 and 36.36 L kg^{-1} in October and April respectively for 35^{0}C).

All the soil samples showed positive values of intercepts ranged from 26.97 (silt loam) to 105.38 (clay) in October and 53.51(silt loam) to 119.85 (clay) in April at a temperature of 25 ^{0}C and 46.29 to128.90 in October and 84.81 to 145.60 in April at the temperature of 35^{0}C.

4.6.1.1.1. Correlation between parameters of Q/I curve and soil properties

Table 79 showed correlation coefficients between parameters of Q/I curve and soil properties. Maximum quantity adsorbed at 25^{0}C was positively and significantly correlated to Fe-P (0.875**), total P (0.797**), residual Cu (0.878**) and positively correlated to occluded P (0.733*) and total Cu (0.747*) and negatively correlated to residual P (-0.649*) and residual P (-0.662*). Maximum quantity adsorbed at 35^{0}C was positively and highly significantly correlated to Fe-P (0.903**), total P (0.826**), residual Cu (0.871**), total Cu (0.825**), maximum adsorption at 25^{0}C (0.978**), buffer power at 25^{0}C (0.927**), intercept at 25^{0}C (0.945**) and positively correlated to occluded P (0.700*) and negatively correlated to residual P (-0.644*).

Buffer power at 25^{0}C was positive and very highly significant with Fe-P (0.851**), occluded P (0.785**), total P (0.782**), residual Cu (0.808**), maximum adsorption at 25^{0}C (0.948**) and total Cu (0.682*) where as it had negative correlation with residual P (-0.706*). Buffer power at 35^{0}C showed positive and highly significant correlation with Fe-P (0.873**), occluded P (0.769**), total P (0.815**), residual Cu (0.769**), maximum adsorption at 25^{0}C (0.901**), buffer power at 25^{0}C (0.979**), intercept at 25^{0}C (0.836**), maximum adsorption at 35^{0}C (0.889**) and water soluble Cu (0.635*), total Cu (0.710*) and had negative correlation with residual P (-0.691*).

Table 79. Parameters of Q-I curve for P adsorption in October and April

Months	25^0C						35^0C				
	Texture	**Equation**	**Maximum copper adsorbed (mg kg^{-1})**	**Buffer power (L kg^{-1})**	**Intercept**	**R^2**	**Equation**	**Maximum copper adsorbed (mg kg^{-1})**	**Buffer power (L kg^{-1})**	**Intercept**	**R^2**
October	**Loam**	$q_e = 31.778c_e + 49.491$	720.40	31.78	49.49	0.9421	$q_e = 33.73\ c_e + 62.65$	735.60	33.73	62.65	0.939
	Sandy clay loam	$q_e = 35.16\ c_e + 60.66$	740.00	35.16	60.67	0.8901	$q_e = 37.05\ c_e + 88.24$	760.40	37.05	88.24	0.924
	Clay loam	$q_e = 37.739\ c_e + 89.98$	760.00	37.74	89.90	0.9404	$q_e = 40.70\ c_e + 98.17$	801.00	40.70	98.17	0.893
	Silt loam	$q_e = 30.397\ c_e + 26.96$	700.00	30.40	26.97	0.8951	$q_e = 31.71\ c_e + 46.29$	720.10	31.71	46.29	0.93
	Clay	$q_e = 41.99\ c_e + 105.38$	820.00	42.00	105.38	0.944	$q_e = 43.78\ c_e + 128.98$	840.25	43.78	128.90	0.876
April	**Loam**	$q_e = 37.54\ c_e + 69.62$	730.00	37.54	69.63	0.946	$q_e = 39.91\ c_e + 71.40$	750.40	39.91	71.40	0.953
	Sandy clay loam	$q_e = 40.56\ c_e + 86.51$	789.00	40.57	86.51	0.926	$q_e = 41.60\ c_e + 109.27$	790.40	41.60	109.20	0.902
	Clay loam	$q_e = 38.84\ c_e + 122.2$	795.30	38.84	122.20	0.9115	$q_e = 40.17\ c_e + 166.03$	812.60	40.16	166.00	0.852
	Silt loam	$q_e = 33.63\ c_e + 53.51$	720.50	33.63	53.51	0.9111	$q_e = 36.37\ c_e + 84.81$	740.60	36.36	84.81	0.907
	Clay	$q_e = 47.16\ c_e + 119.85$	840.50	47.16	119.85	0.9082	$q_e = 53.35\ c_e + 145.65$	850.60	53.35	145.60	0.878

Intercept at 25^{0}C made up positive and very high significant correlation with Fe-P (0.800**), occluded P (0.849**), residual Cu (0.784**), maximum adsorption at 25^{0}C (0.930**), buffer power at 25^{0}C (0.887**), and positively correlated to available Mg (0.733*), available Fe (0.671*), AEC (0.733*), total P (0.685*), total Cu (0.723*) and had negative and very high significantcorrelation with residual P (-0.80**) and had negative correlation with water soluble P 0.690*). Intercept at 35^{0}C was positively and significantly correlated to occluded P (0.808**), maximum adsorption at 25^{0}C (0.895**), buffer power at 25^{0}C (0.799**), intercept 25^{0}C (0.955**), maximum adsorption at 35^{0}C (0.888**) and positively correlated to available Mg (0.655*), available Fe (0.672*), AEC (0.740*), exchangeable Al (0.662*), Fe-P (0.739*), residual Cu (0.764*), total Cu (0.657*), buffer P 35^{0}C (0.741*) and had negative and significant correlation with residual P (-0.816**) and had negative correlation with water soluble P (-0.729*).

Table 80. Correlation between parameters of quantity intensity curve and soil properties

	Maximum quantity adsorbed at 25^{0}C	**Buffer power at 25^{0}C**	**Intercept at 25^{0}C**	**Maximum quantity adsorbed at 35^{0}C**	**Buffer power at 35^{0}C**	**Intercept at 35^{0}C**
Av.Mg			0.733*			0.655*
Av.Fe			0.671*			0.672*
AEC			0.733*			0.740*
Ex Al						0.662*
Ws- P			-0.690*			-0.729*
Fe-P	0.875**	0.851**	0.800**	0.903**	0.873**	0.739*
Occlu-P	0.733*	0.785**	0.849**	0.700*	0.769**	0.808**
Org-P	-0.649*					
Res-P	-0.662*	-0.706*	-0.804**	-0.644*	-0.691*	-0.816**
Tot-P	0.797**	0.782**	0.685*	0.826**	0.815**	
Ws-Cu					0.635*	
Res- Cu	0.878**	0.808**	0.784**	0.871**	0.796**	0.764*
Tot-Cu	0.747*	0.682*	0.723*	0.825**	0.710*	0.657*
Maximum 25^{0}C		0.948**	0.930**	0.978**	0.901**	0.895**
Buffer p 25^{0}C			0.887**	0.927**	0.979**	0.799**
Intercept25^{0}C				0.945**	0.836**	0.955**
Maximum 35^{0}C					0.889**	0.888**
Buffer p35^{0}C						0.741*

** Correlation significant at 0.01 level (2-tailed)
*Correlation significant at 0.05 level (2-tailed)

4.6.1.2. Adsorption isotherms

The data obtained from the adsorption experiments were fitted into linear forms of Langmuir, Freundlich and temkin equations. Freundlich adsorption isotherm was the best to explain P adsorption in soil followed by Tempkin adsorption isotherm and Langmuir adsorption isotherm.

4.6.1.2.1. Langmuir adsorption isotherm

The parameters of Langmuir adsorption isotherm are given in table 81. Silt loam soil did not fit into Langmuir adsorption isotherm during the month of October whereas it fitted into the same during April. The highest value of adsorption maxima (q_m) was recorded in clay soil (840.25 at 25^0C and 820.60 at 35^0C in October and 840.50 at 25^0C and 850.60 at 35^0C min April). The least value of adsorption maxima (q_m) was reported in silt loam soil (700 at 25^0C and 720.14 at 35^0C in October and in 720.50at 25^0C and 740.60 at 35^0C inApril.

The highest value of bonding energy constant (K_L) at 25^0C (0.124 L mg^{-1}) and 35^0C (0.158 L mg^{-1}) was reported in clay soil during October and that in April was 0.198 L mg^{-1} at 25^0C and 0.261 L mg^{-1} at 35^0C. The lowest value of bonding energy constant at 25^0C (0.048 L mg^{-1}) and 35^0C (0.059 L mg^{-1}) was reported in silt loam soil during October and that in April was 0.070 L mg^{-1} at 25^0C and 0.111 L mg^{-1} at 35^0C. A general trend of increasing K_L with increasing temperature was observed.

4.6.1.2.1.1. Correlation between parameters of Langmuir adsorption isotherm and soil properties

Correlation between parameters of Langmuir adsorption isotherm and soil properties are given in table 82.q_m at 25^0C had positive and significant correlation with Fe-P (0.875**), total P (0.797**), residual Cu (0.878**), occluded P (0.733*), total Cu (0.747*) and had negative correlation with organic P (-0.649*), and residual P (-0.662*). $q_m$at 35^0C had positive and significant correlation with Fe-P (0.903**), total P (0.826**), residual Cu (0.871**), total Cu (826**), qmax $q_m$at 25^0C (0.978**), $K_L$at 25^0C (0.874**) and had positive correlation with occluded P (0.700*) and had negative correlation with residual P (-0.644*)

$K_L$at 25^0C was positively and significantly correlated to available Cu (0.772**), AEC (0.801**), Fe-P (0.794**), occluded P (0.907**), qmax 25^0C (0.892**) and positively correlated to available Mg (0.736*), available Fe (0.707*), total P (0.677*), water soluble Cu (0.747*), residual Cu (0.754*), total Cu (0.669*) and negatively correlated to residual P (-0.857**) and water soluble P (-0.697*). $K_L$at 35^0C was positively and significantly correlated to available Cu (0.784**), AEC (0.787**), occluded P (0.896**), water soluble Cu (0.784**), qmax 25^0C (0.867**), $K_L$at 25^0C (0.961**), qmax 35^0C (0.819**), available Fe (0.695*), Fe-P (0.760*), total P (0.633*), exchangeable Cu (0.691*) and residual Cu (0.761*) where as it negatively and significantly correlated to residual P (-0.869**), pH (-0.687*), and water soluble P (-0.685*).

Table 81. Parameters of Langmuir adsorption isotherms for phosphorus adsorption in October and April

Sl.No	Texture	Temperature	Linear equation	q_m (mg kg^{-1})	K_L (L mg^{-1})	R^2
October						
1	**Loam**	25^0C	$c_{e/qe}$ = 0.0004 c_e+ 0.0211	720.40	0.065788	0.70
		35^0C	$c_{e/qe}$ = 0.0006 c_e+ 0.0163	735.60	0.083401	0.78
2	**Sandy clay loam**	25^0C	$c_{e/qe}$ = 0.0005 c_e+ 0.0163	740.00	0.082905	0.89
		35^0C	$c_{e/qe}$ = 0.0008 c_e+ 0.0109	760.40	0.120651	0.97
3	**Clay loam**	25^0C	$c_{e/qe}$ = 0.0006 c_e+ 0.0123	760.00	0.106975	0.87
		35^0C	$c_{e/qe}$= 0.0007 c_e+ 0.0103	801.00	0.101499	0.87
4	**Silt loam**	25^0C	$c_{e/qe}$= 0.00007 c_e+ 0.0297	700.00	0.0481	0.02
		35^0C	$c_{e/qe}$= 0.0003 c_e+ 0.0232	720.14	0.059854	0.31
5	**Clay**	25^0C	$c_{e/qe}$= 0.0007 c_e+ 0.0098	820.00	0.12444	0.93
		35^0C	$c_{e/qe}$= 0.0008 c_e+ 0.0075	840.25	0.158683	0.98
April						
1	**Loam**	25^0C	$c_{e/qe}$= 0.0007 c_e+ 0.012	730.00	0.114155	0.97
		35^0C	$c_{e/qe}$= 0.0008 c_e+ 0.0107	750.40	0.124544	0.97
2	**Sandy clay loam**	25^0C	$c_{e/qe}$= 0.0007 c_e+ 0.0107	789.00	0.118451	0.88
		35^0C	$c_{e/qe}$= 0.0008 c_e+ 0.02085	790.40	0.148845	0.97
3	**Clay loam**	25^0C	$c_{e/qe}$= 0.0009 c_e+ 0.0075	795.30	0.167652	0.99
		35^0C	$c_{e/qe}$= 0.0009 c_e+ 0.0053	812.60	0.232192	0.99
4	**Silt loam**	25^0C	$c_{e/qe}$= 0.0004 c_e+ 0.0197	720.50	0.070453	0.56
		35^0C	$c_{e/qe}$= 0.0007 c_e+ 0.0121	740.60	0.111591	0.90
5	**Clay**	25^0C	$c_{e/qe}$= 0.0009 c_e+ 0.006	840.50	0.198295	0.95
		35^0C	$c_{e/qe}$= 0.0009 c_e+ 0.0045	850.60	0.261253	0.99

Table 82. Correlation between parameters of Langmuir adsorption isotherms and soil properties for P adsorption

	$q_m$at 25^{0}C	$K_L$at 25^{0}C	$q_m$at 35^{0}C	$K_L$at 35^{0}C
pH		-0.685*		-0.687*
Ava. Mg		0.736*		
Ava.Cu		0.772**		0.784**
Ava.Fe		0.707*		0.695*
AEC		0.801**		0.787**
Ws- P		-0.697*		-0.685*
Fe-P	0.875**	0.794**	0.903**	0.760*
Occlu-P	0.733*	0.907**	0.700*	0.896**
Org-P	-0.649*			
Res-P	-0.662*	-0.857**	-0.644*	-0.869**
Tot-P	0.797**	0.677*	0.826**	0.633*
Ws-Cu		0.747*		0.784**
Ex-Cu				0.691*
Res- Cu	0.878**	0.754*	0.871**	0.761*
Tot-Cu	0.747*	0.669*	0.826**	
qmax 25^{0}C		0.892**	0.978**	0.867**
Kl at 25^{0}C			0.874**	0.961**
qmax 35^{0}C				0.819**

** Correlation significant at 0.01 level (2-tailed)
*Correlation significant at 0.05 level (2-tailed)

4.6.1.2.2. Freundlich adsorption isotherm

Parameters of Freundlich adsorption isotherm is given in table 83. All samples at both temperatures showed R^2 values of greater than 0.5. 1/n value of all the soils followed the theoretical value. The highest value of 1/n noticed in silt loam soil at 25^{0}C (1.012 in October and 0.886 in April). General trend of increasing 1/n value with temperature was observed.

The highest value of constant related to adsorption strength (K_F) at 35^{0}C was recorded as 125 during October in clay soil whereas 19.75 was recorded at 35^{0}C during April). The lowest K_F value at 25^{0}C (31.91) and 35^{0}C (4.66) during October was recorded in silt loam soil and during April it was 52.72 (25^{0}C) and 89.92 (c).

Correlation between parameters of Freundlich adsorption isotherm and soil properties are given in table 84.

4.6.1.2.2.1.Correlation between parameters of Freundlich adsorption isotherm and soil properties

Correlation between parameters of Freundlich adsorption isotherm and soil properties are given in table 84.K_F 25^0C was positively and significantly correlated to available Cu (0.780), AEC (0.808**), occluded P (0.899**) and was positively correlated to available magnesium (0.727*), available Fe (0.724*), Fe-P (0.760*), total P (0.636*), water soluble Cu (0.752*), residual Cu (0.732*) and negatively and significantly correlated to residual P (-0.852**), pH (-0.706*) and water soluble P (-0.725*). K_F at 35^0C was positively and significantly correlated to Fe-P (0.812**), occluded P (0.899**),K_F at 25^0C (0.888**) and total P (0.729*), water soluble Cu (0.639*), residual Cu (0.744*) and negatively and significantly correlated to 1/n at 25^0C (-0.850**) and residual P (-0.685*).

1/n at 25^0C had positive and highly significant correlation with residual P (0.853**) and pH (0.739*) and had negative and highly significant correlation with available Cu (-0.786**), available Fe (-0.809**), AEC (-0.838**), occluded P (-0.923**), K_F 25^0C (-0.970**), available magnesium (-0.762*), Fe-P (-0.647*) and water soluble Cu (-0.739*). 1/n at 35^0C showed positive and highly significant correlation with residual P (0.790**), 1/n at 25^0C (-0.908**) and water soluble P (0.661*) whereas it had negative and highly significant correlation with AEC (-0.768**), occluded P (-0.847**), K_F at 25^0C (-0.856**), K_F at 35^0C (-0.835**) and had negative correlation with available Mg (-0.654*), available Cu (-0.659*), available Fe (-0.736*) and water soluble Cu (-0.653*).

Table 83. Parameters of Freundlich adsorption isotherms for phosphorus adsorption in October and April

October						
Sl.No	**Texture**	**Temp**	**Linear equation**	**1/n**	**K_F (mg kg^{-1}) (L kg^{-1}) $^{1/n}$**	**R^2**
1	**Loam**	25^0C	log q_e= 0.896log c_e+ 1.689	0.896	48.865	0.984
		35^0C	log q_e= 0.791 log c_e+ 1.842	0.791	69.502	0.9785
2	**Sandy clay loam**	25^0C	log q_e= 0.8313log c_e+ 1.813	0.8313	65.013	0.9869
		35^0C	log q_e= 0.652log c_e+ 2.059	0.6527	114.551	0.9828
3	**Clay loam**	25^0C	log q_e= 0.788log c_e+ 1.917	0.7888	82.604	0.9708
		35^0C	log q_e= 0.737 1log c_e+ 2.004	0.7369	100.000	0.9694
4	**Silt loam**	25^0C	log q_e= 1.012log c_e+ 1.504	1.0125	31.915	0.9751
		35^0C	log q_e= 0.922 log c_e+ 1.650	0.9222	44.668	0.9696
5	**Clay**	25^0C	log q_e= 0.767log c_e+ 1.996	0.7677	97.723	0.9694
		35^0C	log q_e= 0.694 log c_e+ 2.107	0.6942	125.892	0.971
April						
	Texture	**Temp**	**Linear equation**	**1/n**	**K_F (mg kg^{-1}) (L kg^{-1}) $^{1/n}$**	**R^2**
1	**Loam**	25^0C	log q_e= 0.744log c_e+ 1.941	0.744	87.297	0.9923
		35^0C	log q_e= 0.717 log c_e+ 1.991	0.7175	97.723	0.9942
2	**Sandy clay loam**	25^0C	log q_e= 0.706 log c_e+ 2.021	0.7063	104.713	0.9802
		35^0C	log q_e= 0.684 log c_e+ 2.079	0.6841	117.890	0.9858
3	**Clay loam**	25^0C	log q_e= 0.612log c_e+ 2.145	0.6126	139.636	0.9909
		35^0C	log q_e= 0.554 log c_e+ 2.255	0.5548	117.827	0.9643
4	**Silt loam**	25^0C	log q_e= 0.886log c_e+ 1.722	0.8866	52.723	0.9738
		35^0C	log q_e= 0.731 log c_e+ 1.957	0.731	89.925	0.9819
5	**Clay**	25^0C	log q_e= 0.597log c_e+ 2.213	0.5976	163.305	0.9706
		35^0C	log q_e= 0.582 log c_e+ 2.285	0.5822	192.752	0.9641

Table 84. Correlation between parameters of Freundlich adsorption isotherms and soil properties for P adsorption

	K_F 25^{0}C	1/n at 25^{0}C	K_F 35^{0}C	1/n at 35^{0}C
pH	-0.706*	0.739*		
Ava. Mg	0.727*	-0.762*		-0.654*
Ava. Cu	0.780**	-0.786**		-0.659*
Ava. Fe	0.724*	-0.809**		-0.736*
AEC	0.808**	-0.838**		-0.768**
DEA		0.706*		
Ws- P	-0.725*	0.754*		0.661*
Fe-P	0.760*	-0.647*	0.812**	
Occlu-P	0.899**	-0.923**	0.770**	-0.847**
Res-P	-0.852**	0.853**	-0.685*	0.790**
Tot-P	0.636*		0.729*	
Ws-Cu	0.752*	-0.739*	0.639*	-0.653*
Res- Cu	0.732*		0.744*	
K_F at 25^{0}C		-0.970**	0.888**	-0.856**
1/n at 25^{0}C			-0.850**	0.908**
kf at 35^{0}C				-0.835**

**Correlation significant at 0.01 level (2-tailed)
*Correlation significant at 0.05 level (2-tailed)

4.6.1.2.3. Tempkin adsorption isotherm

The parameters of Tempkin adsorption isotherm is given in table 85. The constant related to strength of bonding (K_T) increased with increasing temperature. The highest value of K_T measured in clay soil (2.09 at 35^{0}C in April and 1.270 at 35^{0}C in October).The lowest value of K_T noticed insilt loam soil (0.408 at 25^{0}C in October and 0.555 at 25^{0}C in April).

The highest value of constant related to heat of adsorption (b) at both temperatures (11.15 J mol^{-1} at 35^{0}C, 10.39 J mol^{-1} at 25^{0}C) was observed in clay loam soil during April, whereas the highest value (10.53 J mol^{-1} at 35^{0}C, 9.32 J mol^{-1} at 25^{0}C) was recorded in sandy clay loam soil during October. Increase in the value of b with increasing temperature and decreasing soil pH (April) was observed.

4.6.1.2.3.1. Correlation between parameters of Tempkin adsorption isotherm and soil properties

Table 86 explains correlation between parameters of Tempkin adsorption isotherm and soil properties. b at 25^0C was positively and significantly correlated to residual P (0.948**) and positively correlated to zinc (0.633*) and AEC (0.708*). b at 35^0C had positive and highly significant correlation with magnesium (0.806**) and had positive correlation with total P (0.647*).

K_T at 35^0C had positive and highly significant correlation with EC (0.769**), Cu (0.839**) and had positive correlation with P (0.642*), exchangeable K (0.663*), exchangeable Ca (0.696*), exchangeable Mg (0.730*), water soluble P (0.697*) and had negative and significant correlation with Fe (-0.806**), exchangeable Al (-0.851**), exchangeable Fe (-0.881**), DEA activity (-0.870**), Fe-P (-0.900**), occluded P (-0.848**), pH (-0.703*), AEC (-0.723*) and manganese (-0.761*).

Table 85. Parameters of Tempkin adsorption isotherms for phosphorus adsorption in October and April

Sl.No.	Texture	Temp	Linear equation	K_T (L kg^{-1})	b (J mol^{-1})	R^2
October						
1	**Loam**	25^0C	$y = 277.33 \ln c_e - 170.98$	0.533	9.131213	0.9566
		35^0C	$y = 254.2 \ln c_e - 80.824$	1.076	10.07361	0.9283
2	**Sandy clay loam**	25^0C	$y = 265.77 \ln c_e - 95.482$	0.698	9.322241	0.9616
		35^0C	$y = 242.96 \ln c_e + 8.338$	1.035	10.53964	0.9712
3	**Clay loam**	25^0C	$y = 265.3 \ln c_e - 30.492$	0.951	9.338756	0.9583
		35^0C	$y = 58.62 \ln c_e + 18.211$	1.073	9.901446	0.942
4	**Silt loam**	25^0C	$y = 298.49 \ln c_e - 267.99$	0.408	8.300352	0.9354
		35^0C	$y = 282.37 \ln c_e - 191.19$	0.508	9.06864	0.9309
5	**Clay**	25^0C	$y = 276.18 \ln c_e + 8.664$	1.032	8.97086	0.9877
		35^0C	$y = 268.09 \ln c_e + 64.301$	1.270	9.551688	0.9873
April						
1	**Loam**	25^0C	$q_e = 234.69 \ln c_e + 3.71$	1.015	10.55679	0.9613
		35^0C	$q_e = 232.85 \ln c_e + 28.54$	1.131	10.99726	0.9593
2	**Sandy clay loam**	25^0C	$q_e = 249.82 \ln c_e + 13.56$	1.055	9.917429	0.9289
		35^0C	$q_e = 248.7 \ln c_e + 50.385$	1.224	10.29639	0.9677
3	**Clay loam**	25^0C	$q_e = 238.37 \ln c_e + 17.75$	1.344	10.39381	0.9842
		35^0C	$q_e = 229.55 \ln c_e + 143.8$	1.871	11.15536	0.9952
4	**Silt loam**	25^0C	$q_e = 281.78 \ln c_e - 165.83$	0.555	8.792576	0.922
		35^0C	$q_e = 243.94 \ln c_e - 16.805$	0.934	10.4973	0.9283
5	**Clay**	25^0C	$q_e = 243.04 \ln c_e + 125.75$	1.680	10.23579	0.9613
		35^0C	$q_e = 247.81 \ln c_e + 182.43$	2.094	10.37524	0.9928

Table 86. Correlation between parameters of Tempkin adsorption isotherms and soil properties for P adsorption

Parameters	b at 25^{0}C	K_T at 35^{0}C	b at 35^{0}C
pH		-0.703*	
EC		0.769**	
P		0.642*	
Mg			0.806**
Zn	0.633*		
Cu		0.839**	
Fe		-0.806**	
AEC	0.708*	-0.723*	
Mn		-0.761*	
Ex K		0.663*	
Ex Ca		0.696*	
Ex Mg		0.730*	
Ex Al		-0.851**	
Ex Fe		-0.881**	
Dehydro		-0.870**	
Ws- P		0.697*	
Fe-P		-0.900**	
Occlu-P		-0.848**	
Res-P	0.948**		
Tot-P			0.647*

**Correlation significant at 0.01 level (2-tailed)
*Correlation significant at 0.05 level (2-tailed)

4.6.1.3. Thermodynamic parameters

The highest value of constant related to heat of adsorption (b) at both temperatures (11.15 J mol^{-1} at 35^{0}C, 10.39 J mol^{-1} at 25^{0}C) was observed in clay loam soil during April, whereas the highest value (10.53 J mol^{-1} at 35^{0}C, 9.32 J mol^{-1} at 25^{0}C) was recorded in sandy clay loam soil during October (table 87). Increase in the value of b with increasing temperature and decreasing soil pH (April) was observed.

Table 87. Thermodynamic parameters of P adsorption in *Pokkali* soil

Soil samples	surface area (m^2 g^{-1})	K^0		ΔG^0 (kcal mol^{-1})		ΔH^0 (kcal mol^{-1})	ΔS (cal mol^{-1} K^{-1})	
		25^0C	35^0C	25^0C	35^0C		25^0C	35^0C
October								
Clay	61.2	1.010	1.00	-0.206	-0.201	1.810	15.1	16.32
Clay loam	59.42	0.791	0.900	-0.139	-0.132	4.246	12.3	12.4
Sandy clay loam	55.47	0.901	0.90	-0.162	-0.165	1.200	11.5	12.01
Loam	53.34	0.902	0.90	-0.261	-0.264	1.400	15.3	15.38
Silt loam	51.69	0.901	0.90	-0.421	-0.422	1.230	15.4	15.01
April								
Clay	61.2	1.121	1.22	-0.203	-0.241	1.890	15.6	16.74
Clay loam	59.42	0.701	0.71	-0.210	-0.201	4.230	12.5	12.61
Sandy clay loam	55.47	0.854	0.850	-0.162	-0.112	1.320	11.9	12.41
Loam	53.34	0.884	0.889	-0.620	-0.640	1.840	15.4	15.17
Silt loam	51.69	0.810	0.892	-0.451	-0.462	1.360	15.6	15.31

4.6.2. Copper

4.6.2.1. Quantity intensity relationship

Soil samples were equilibrated with different concentrations of copper nitrate as detailed in section 3.7. Concentration of copper in equilibrium solution after equilibration period was considered as intensity factor and the amount adsorbed per unit weight of the soil was considered as quantity factor. The Q-I curves were fitted with this data by plotting concentration of copper in equilibrium solution in X axis and quantity adsorbed per unit weight of the soil in Y axis. The intercept and slope were computed from the best fit curve using regression analysis. The slope of the curve explains the buffer power.

The parameters of the Q-I curve and maximum quantity adsorbed per unit weight of the soil from the added concentration of copper are given in table 88. All the textural classes of soil samples were recorded with R^2 value > 0.5 for the linear fit of quantity – intensity curve at both 25^0C and 35^0C for October and April.

The quantity of maximum copper adsorbed was highest in clay textured soil in October and April for both the soil temperatures. The highest copper adsorption was recorded in October compared to April for all the textural classes of the soil. The value of maximum copper adsorption in clay textured soil was 781 mg kg^{-1} and 760 mg kg^{-1} in October and April respectively for 25^{0}C and, 810 mg kg^{-1} and 800 mg kg^{-1} in October and April respectively for 35^{0}C. The lowest copper adsorbed was on silt loam textured soil (728 mgkg^{-1}and 732 mgkg^{-1}in October and April respectively for 25^{0}C and, 765.3 mg kg^{-1} and 752.6 mg kg^{-1} in October and April respectively for 35^{0}C). Generally, copper adsorption increased in October compared to April and the adsorption increased with increasing soil temperature.

The highest buffer power was observed in clay textured soil (24.488 and 27.282 L kg^{-1} in October and April respectively for 25^{0}C and 24.143 L kg^{-1} in October and April for 35^{0}C) and the lowest was noticed in silt loam (18.965 and 19.353 L kg^{-1} in October and April respectively for 25 ^{0}C and 24.41 and 19.73 L kg^{-1} in October and April respectively for 35^{0}C). Dominance of buffer power of different texture of soil samples followed the same trend as maximum copper adsorbed by *Pokkali* soil.

All the soil samples showed positive values of intercept. Highest intercept values were observed during October for both the soil temperatures. Among the soil samples, clay textured soil (121.36 and 135.94 in October and April respectively for 25^{0}C and 109.57 in October and April for 35 ^{0}C) followed by clay loam soil (119.52 and 110.45 in October and April respectively for 25^{0}C and 144.36 and 130.04 in October and April respectively for 35^{0}C) recorded highest values of intercept.

Table 88. Parameters of Q-I curve for copper adsorption in October and April

Months	25^0C						35^0C				
	Texture	**Equation**	**Maximum copper adsorbed (mg kg^{-1})**	**Buffer power (L kg^{-1})**	**Intercept**	**R^2**	**Equation**	**Maximum copper adsorbed (mg kg^{-1})**	**Buffer power (L kg^{-1})**	**Intercept**	**R^2**
October	**Loam**	$q_e = 19.943c_e + 106.26$	730	19.943	106.26	0.6975	$q_e = 23.394\ c_e + 137.37$	785.6	23.394	137.37	0.7067
	Sandy clay loam	$q_e = 20.661\ c_e + 113.29$	740	20.661	113.29	0.6885	$q_e = 22.186\ c_e + 132.74$	800.2	22.186	132.74	0.6959
	Clay loam	$q_e = 22.206\ c_e + 119.52$	779	22.206	119.52	0.6929	$q_e = 22.92\ c_e + 144.36$	805	22.92	144.36	0.6868
	Silt loam	$q_e = 18.965\ c_e + 114.98$	728	18.965	114.98	0.6522	$q_e = 24.41\ c_e + 147.7$	765.3	24.41	147.7	0.6719
	Clay	$q_e = 24.488\ c_e + 121.36$	781	24.488	121.36	0.7175	$q_e = 27.282\ c_e + 135.94$	810	24.143	109.57	0.7513
April	**Loam**	$q_e = 20.191\ c_e + 85.994$	739	20.191	85.994	0.7151	$q_e = 20.733\ c_e + 85.899$	760.3	20.733	85.899	0.7174
	Sandy clay loam	$q_e = 20.619\ c_e + 100.57$	742.3	20.619	100.57	0.6972	$q_e = 20.883\ c_e + 106.59$	760.3	20.883	106.59	0.6959
	Clay loam	$q_e = 21.754\ c_e + 110.45$	755.2	21.754	110.45	0.7168	$q_e = 22.602\ c_e + 113.04$	780.2	22.602	130.04	0.719
	Silt loam	$q_e = 19.359\ c_e + 76.452$	732.4	19.359	76.452	0.7101	$q_e = 19.734\ c_e + 78.14$	752.6	19.734	78.74	0.7125
	Clay	$q_e = 23.392\ c_e + 107.92$	760.45	27.282	135.94	0.706	$q_e = 24.143\ c_e + 109.57$	800.2	24.143	109.57	0.7513

4.6.2.1.1. Correlation coefficients between parameters of Q/I curve and soil properties

Correlation coefficients between parameters of Q/I curve and soil properties are furnished in table 89. Maximum quantity adsorbed at 25^0C was significantly and positively correlated to total copper (0.820**), buffer power at 25^0C (0.733*), maximum quantity adsorbed at 35^0C (0.740*), iron bound phosphorous (0.757*), total phosphorous (0.721*) and residual phosphorous (0.678*). Buffer power at 25^0C had positive and high significant correlation with iron bound phosphorous (0.965**), total phosphorous (0.933**), residual copper (0.886**), total copper (0.876**), intercept at 25^0C (0.731*) and maximum quantity adsorbed at 35^0C (0.683*). Buffer power at 25^0C was negatively correlated with organically occluded phosphorous (-0.707*). Intercept at 25^0C was positively and significantly correlated to maximum quantity adsorbed at 35^0C (0.807**), buffer power at 35^0C (0.876**), iron bound phosphorous (0.633*) and total copper (0.666*). Maximum quantity adsorbed at 35^0C had positive and significant correlation with microbial biomass carbon (0.769**), buffer power at 35^0C (0.664*), total copper (0.668*) and had negative correlation with available boron (-0.654*). Buffer power at 35^0C was positively correlated to intercept at 35^0C (0.683*), acid soluble copper (0.642*), amorphous iron oxide (0.639*) and was negatively correlated to electrical conductivity (-0.714*) and available boron (-0.668*). Intercept at 35^0C had positive correlation with exchangeable magnesium (0.715*) and had negative and significant correlation with aluminium bound phosphorous (-0.851*), organically occluded copper (-0.696*) and available boron (-0.668*).

Table 89. Correlation between parameters of quantity intensity curve and soil properties for Cu adsorption

	Maximum quantity adsorbed at 25^0C	**Buffer power at 25^0C**	**Intercept at 25^0C**	**Maximum quantity adsorbed at 35^0C**	**Buffer power at 35^0C**	**Intercept at 35^0C**
Maximum quantity adsorbed at 25^0C						
Buffer power at 25^0C	0.733^{*}					
Intercept at 25^0C		0.731^{*}				
Maximum quantity adsorbed at 35^0C	0.740^{*}	0.683^{*}	0.807^{**}			
Buffer power at 35^0C			0.876^{**}	0.664^{*}		
Intercept at 35^0C					0.683^{*}	
Al-P						-0.851^{**}
Fe-P	0.757^{*}	0.965^{**}	0.633^{*}			
Org-P		-0.707^{*}				
Tot-P	0.721^{*}	0.933^{**}				
Aci.sol-Cu					0.642^{*}	
MnOxi-Cu						
Org.occl-Cu						-0.696^{*}
Amo-FeO					0.639^{*}	
Res- Cu	0.678^{*}	0.886^{**}				
Tot-Cu	0.820^{**}	0.876^{**}	0.666^{*}	0.668^{*}		
EC					-0.714^{*}	
Ava. B				-0.654^{*}	-0.688^{*}	-0.668^{*}
Ex. Mg						0.715^{*}
MBC				0.769^{**}		

4.6.2.2. Adsorption isotherms

Among the isotherms attempted in the present study Freundlich adsorption isotherm was found as the best to explain copper adsorption in *Pokkali* soil followed by Tempkin adsorption isotherm.

4.6.2.2.1. Langmuir adsorption isotherm

Linear form of Langmuir adsorption isotherm was fitted by plotting equilibrium concentration (Ce) on X axis and Ce/qe on Y axis. Linear equation of Langmuir adsorption isotherm is $Ce/qe= (1/(qm*K_L) + (1/qm)*Ce)$. The parameters of Langmuir isotherm are qm and K_L, derived from the slope and intercept of the graph where qm is the maximum amount of adsorbent that can be adsorbed (monolayer) and K_L is the constant related to the binding strength.

The parameters of Langmuir adsorption isotherm are given in table 90. The data from *Pokkali* soils could not be fitted into Langmuir adsorption isotherm as the Langmuir adsorption isotherms showed very low R^2 values (<0.5).

4.6.2.2.2. Freundlich adsorption isotherm

The linear form of Freundlich adsorption isotherm was fitted by plotting logarithmic value of equilibrium concentration on X axis and logarithmic value of quantity adsorbed per unit weight of soil on Y axis. Slope of the linear equation of Freundlich adsorption isotherm ($logqe= \log K_F + (1/n) \log Ce$) is the constant 1/n which indicates adsorption intensity. The intercept on Y axis represents the logarithmic value of Freundlich constant K_F, indicating the strength of adsorption.Parameters of Freundlich adsorption isotherm is given in table 91.

All the soil samples showed R^2 values greater than 0.5, the values for 1/n remaining similar and ranging from 1.71 to 1.87 in October and 1.82 to 1.87 in April. Freundlich adsorption constant was highest in October at 35^0C for all the soil samples. This adsorption strength coefficient was ranged from 0.16 to -0.411 in October and -0.265 to -0.623 in April.

4.6.2.2.2.1. Correlation between Freundlich adsorption isotherm and soil properties

Correlation between Freundlich adsorption isotherm and soil properties are given in table 92. K_F at 25^0C was significantly and positively correlated to iron bound phosphorous (0.637*), total copper (0.724*) and had negative correlation with boron (-0742*) and l/n at 25^0C (-0.640*).

Table 90. Parameters of Langmuir adsorption isotherms for copper adsorption in October and April

Sl.No	Texture	Temperature	Linear equation	q_m (mg kg^{-1})	K_L (L mg^{-1})	R^2
October						
1	**Loam**	25^{0}C	$c_{e/qe} = 0.0007c_e + 0.0252$	730	0.054	0.067
		35^{0}C	$c_{e/qe} = 0.0009\ c_e + 0.0131$	785.6	0.097	0.1894
2	**Sandy clay loam**	25^{0}C	$c_{e/qe} = 0.0008\ c_e + 0.0209$	740	0.065	0.0916
		35^{0}C	$c_{e/qe} = 0.0008\ c_e + 0.0159$	800.2	0.079	0.1411
3	**Clay loam**	25^{0}C	$c_{e/qe} = 0.0007\ c_e + 0.0206$	779	0.062	0.083
		35^{0}C	$c_{e/qe}= 0.0008\ c_e + 0.0148$	805.4	0.084	0.1529
4	**Silt loam**	25^{0}C	$c_{e/qe}= 0.0006\ c_e + 0.0306$	728	0.045	0.0342
		35^{0}C	$c_{e/qe}= 0.0009\ c_e + 0.0119$	765.3	0.11	0.181
5	**Clay**	25^{0}C	$c_{e/qe}= 0.0008\ c_e + 0.0135$	781	0.098	0.175
		35^{0}C	$c_{e/qe}= 0.0009\ c_e + 0.01$	810	0.123	0.2361
April						
1	**Loam**	25^{0}C	$c_{e/qe}= 0.0006\ c_e + 0.0291$	739	0.047	0.0413
		35^{0}C	$c_{e/qe}= 0.0005\ c_e + 0.031$	760.3	0.042	0.027
2	**Sandy clay loam**	25^{0}C	$c_{e/qe}= 0.0015\ c_e + 0.0023$	742.3	0.674	0.757
		35^{0}C	$c_{e/qe}= 0.0007\ c_e + 0.0236$	760.3	0.056	0.0679
3	**Clay loam**	25^{0}C	$c_{e/qe}= 0.0008\ c_e + 0.0174$	755.2	0.076	0.143
		35^{0}C	$c_{e/qe}= 0.0008\ c_e + 0.0172$	777.5	0.075	0.1338
4	**Silt loam**	25^{0}C	$c_{e/qe}= 0.0005\ c_e + 0.0347$	732.4	0.03	0.025
		35^{0}C	$c_{e/qe}= 0.0004\ c_e + 0.0359$	752.6	0.037	0.0177
5	**Clay**	25^{0}C	$c_{e/qe}= 0.0009\ c_e + 0.0148$	760.45	0.089	0.1647
		35^{0}C	$c_{e/qe}= 0.0009\ c_e + 0.0135$	800.2	0.093	0.185

Table 91. Freundlich adsorption isotherms parameters for copper adsorption in October and April

Sl.No	Texture	Temp	Linear equation	1/n	K$_F$ (mg kg^{-1}) (L kg^{-1})$^{1/n}$	R^2
October						
1	**Loam**	25^{0}C	$\log q_e = 1.7864 \log c_e + 0.4453$	1.7865	61.094	0.9119
		35^{0}C	$\log q_e = 1.7375 \log c_e + 0.6955$	1.7375	72.11	0.8454
2	**Sandy clay loam**	25^{0}C	$\log q_e = 1.8678 \log c_e + 0.3885$	1.8678	54.57	0.8864
		35^{0}C	$\log q_e = 1.827 \log c_e + 0.5181$	1.827	73.79	0.8697
3	**Clay loam**	25^{0}C	$\log q_e = 1.8161 \log c_e + 0.5123$	1.8161	73.62	0.8997
		35^{0}C	$\log q_e = 1.7891 \log c_e + 0.6066$	1.7891	71.61	0.8726
4	**Silt loam**	25^{0}C	$\log q_e = 1.7893 \log c_e + 0.4177$	1.7893	67.14	0.8985
		35^{0}C	$\log q_e = 1.7502 \log c_e + 0.7487$	1.7502	72.28	0.8217
5	**Clay**	25^{0}C	$\log q_e = 1.8236 \log c_e + 0.5725$	1.8236	65.46	0.8699
		35^{0}C	$\log q_e = 1.8084 \log c_e + 0.6912$	1.8084	665.31	0.8731
April						
	Texture	**Temp**	**Linear equation**	**1/n**	**K$_F$ (mg kg^{-1}) (L kg^{-1})$^{1/n}$**	**R^2**
1	**Loam**	25^{0}C	$\log q_e = 1.8583 \log c_e + 0.3071$	1.8583	65.517	0.9151
		35^{0}C	$\log q_e = 1.8686 \log c_e + 0.2998$	1.8686	66.99	0.9151
2	**Sandy clay loam**	25^{0}C	$\log q_e = 1.8559 \log c_e + 0.3646$	1.855	65.51	0.907
		35^{0}C	$\log q_e = 1.8596 \log c_e + 0.3713$	1.8596	72.95	0.9047
3	**Clay loam**	25^{0}C	$\log q_e = 1.8158 \log c_e + 0.4867$	1.8158	56.23	0.8876
		35^{0}C	$\log q_e = 1.8267 \log c_e + 0.4878$	1.8267	74.13	0.8882
4	**Silt loam**	25^{0}C	$\log q_e = 1.8633 \log c_e + 0.2412$	1.8633	66.52	0.9245
		35^{0}C	$\log q_e = 1.8708 \log c_e + 0.2381$	1.8708	65.46	0.9233
5	**Clay**	25^{0}C	$\log q_e = 1.8163 \log c_e + 0.5312$	1.8163	64.26	0.8782
		35^{0}C	$\log q_e = 1.8179 \log c_e + 0.5436$	1.8179	65.61	0.8758

1/n at 35^{0}C was positively and significantly correlated to 1/n at 25^{0}C (0.893**), electrical conductivity (0.707*), manganese (0.725*), aluminium bound phosphorous (0.753*), organically occluded copper (0.648*) and was negatively correlated to dehydrogenase enzyme activity (-0.641*), specifically adsorbed lead displaced copper (-0.680*), acid soluble copper (-0.666*), amorphous iron oxide (-0.729*) and crystalline iron oxide (-0.678*). K$_F$ at 35^{0}C had positive and significant correlation with amorphous iron oxide (0.768**), K$_F$ at 25^{0}C (0.847**), exchangeable calcium (0.656*), exchangeable magnesium (0.665*), dehydrogenase enzyme activity (0.666*), specifically adsorbed lead displaced copper (0.730*), acid soluble copper (0.722*), manganese oxide copper (0.710*) and crystalline iron oxide (0.722*). K$_F$ at 35^{0}C had negative and significant correlation with electrical conductivity (-0.784**), boron (-0.803**), l/n at 25^{0}C (-0.790**), l/n at 35^{0}C (-0.883**), exchangeable calcium (-0.714), exchangeable manganese (-0.654*), aluminium bound phosphorous (-0.757*), exchangeable copper (-0.637*) and organically occluded copper (-0.682*).

Table 92. Correlation between Freundlich adsorption isotherms parameters and soil properties for Cu adsorption

	K$_F$ at 25^{0}C	**1/n at 35 ^{0}C**	**K$_F$ at 35^{0}C**
EC		0.707*	-0.784**
B	-0.742*		-0.803**
Mn		0.725*	-0.714*
Ex Ca			0.656*
Ex Mg			0.665*
Ex Mn			-0.654*
Dehydro		-0.641*	0.666*
Al-P		0.753*	-0.757*
Fe-P	0.637*		
Ex-Cu			-0.637*
Spe.ads.pb.dis-Cu		-0.680*	0.730*
Aci.sol-Cu		-0.666*	0.722*
MnOxi-Cu			0.710*
Org.occl-Cu		0.648*	-0.682*
Amo-FEO		-0.729*	0.768**
Cry-FeO		-0.678*	0.722*
Tot-Cu	0.724*		
1/n at 25^{0}C	-0.640*	0.893**	-0.790**
K$_F$ at 25^{0}C			0.847**
1/n at 35^{0}C			-0.883**
K$_F$ at 35^{0}C			

** Correlation significant at 0.01 level (2-tailed)
*Correlation significant at 0.05 level (2-tailed)

4.6.2.2.3. Tempkin adsorption isotherm

Linear form of Tempkin adsorption isotherm was fitted by plotting natural logarithm of equilibrium concentration (lnCe) on X axis and quantity adsorbed per unit weight of the soil (qe) on Y axis. A linear form of the Tempkin isotherm can be expressed as

$$qe = (RT/b) \ln K_T + (RT/b) \ln Ce$$

It is also assumed here that the heat of adsorption of all molecules in the layer decreases linearly as a result of increase in surface coverage and that adsorption is characterized by uniform distribution of upto maximum binding energy. Tempkin adsorption constant K_T is the equilibrium binding energy constant related to maximum binding energy which indicates the adsorbent-adsorbate interaction. The constant b is related to heat of adsorption. These constants were derived from slope and intercept of the linear plot of Tempkin adsorption isotherm.

Parameters of Tempkin adsorption isotherm are given in table 93. All the soil samples analysed well fitted into tempkin adsorption isotherm as the R^2 value was more than 0.5. The highest value of b ranged from 0.783(25^{0}C) to 1.132 (35^{0}C) and 0.806 (25^{0}C) to 1.215 (35^{0}C) in October and April respectively. Higher K_T values were observed at lower temperature in both months and the values were -0.261(25^{0}C) to -0.628 (35^{0}C) in October and -0.194(25) to -0.351(35) in April respectively. Variations in K_T and b values among soil textures were negligible.

4.6.2.3.1. Correlation between Tempkin adsorption parameters and soil properties

Correlation between Tempkin adsorption parameters and soil properties are presented in table 94. The constant b at 25^{0}C had positive and high significant correlation with K_T at 25^{0}C (0.948**), cation exchange capacity (0.633*), boron (0.806**), K_T at 35^{0}C (0.647*). and exchangeable magnesium (0.708*). K_T at 35^{0}C had positive and significant correlation with electrical conductivity (0.769**), manganese (0.839**), copper (0.642*), aluminium bound phosphorous (0.663*), water soluble copper (0.696*), exchangeable copper (0.730*) and organically occluded copper (0.697*). K_T at 35^{0}C had significant and negative correlation with exchangeable calcium (-0.806**), specifically adsorbed lead displaced copper (-0.851**), acid soluble copper (-0.881**), manganese oxide copper (-0.870**), amorphous iron oxide (-0.900**), crystalline iron oxide (-0.848**), pH (-0.703*), exchangeable magnesium (-0.723*) and dehydrogenase enzyme activity (-0.761*).

4.6.2.4. Thermodynamic parameters

Thermodynamic parameters of Cu adsorption in *Pokkali* soil are given in table 95. Highest value of thermodynamic equilibrium constant (K^0) was reported in clay soil (1.01 to 1.00 in October and in 1.12 to 1.22 in April). All the soil samples reported with negative value of change in Gibbs free energy and positive value of change in entropy and change in free energy. Change in entropy was found to increase with increase in temperature.

Table 93. Parameters of Tempkin adsorption isotherms parameters for copper adsorption in October and April

Sl.No.	Texture	Temp	Linear equation	K_T (L kg^{-1})	b (J mol^{-1})	R^2
October						
1	**Loam**	25^0C	y = 232.29 ln c_e - 102.94	0.6421	10.66	0.8212
		35^0C	y = 256.95 ln c_e- 75.472	0.746	9.96	0.8995
2	**Sandy clay loam**	25^0C	y = 251.47 ln c_e- 137.87	0.5781	9.85	0.8458
		35^0C	y = 264.1 ln c_e- 119.37	0.6357	9.69	0.8715
3	**Clay loam**	25^0C	y = 251.72 ln c_e- 104.85	1.1317	47.90	0.8333
		35^0C	y = 260.1 ln c_e- 86.37	0.7174	9.84	0.8673
4	**Silt loam**	25^0C	y = 225.49 ln c_e- 96.084	0.6531	10.98	0.7629
		35^0C	y = 258 ln c_e- 60.717	0.7903	9.92	0.8921
5	**Clay**	25^0C	y = 265.54 ln c_e- 106.54	0.6696	9.33	0.8842
		35^0C	y = 269.55 ln c_e- 68.43	0.7758	9.50	0.8917
April						
1	**Loam**	25^0C	q_e= 240.49 ln c_e- 143.12	0.5515	10.30	0.8008
		35^0C	q_e = 246.17 ln c_e- 147.54	0.5492	10.40	0.7982
2	**Sandy clay loam**	25^0C	q_e = 244.19 ln c_e- 133.11	0.581	10.27	0.814
		35^0C	q_e= 248.11 ln c_e- 131.91	0.588	10.32	0.8181
3	**Clay loam**	25^0C	q_e = 251.69 ln c_e- 120.46	0.62	9.84	0.8674
		35^0C	q_e = 261.13 ln c_e- 126.07	0.6171	9.80	0.8677
4	**Silt loam**	25^0C	q_e = 235.09 ln c_e- 150.49	0.5273	10.53	0.7753
		35^0C	q_e = 239.4 ln c_e- 152.6	0.5286	10.69	0.7762
5	**Clay**	25^0C	q_e = 257.74 ln c_e- 115.53	0.6389	9.61	0.8891
		35^0C	q_e = 264.62 ln c_e- 118.06	0.6401	9.67	0.8959

Table 94. Correlation between of Tempkin adsorption isotherms parameters and soil properties for Cu adsorption

Soil samples	Surface area (m^2 g^{-1})	K^0		ΔG^0 (kcal mol^{-1})		ΔH^0 (kcal mol^{-1})	ΔS (cal mol^{-1} K^{-1})	
		25^{0}C	35^{0}C	25^{0}C	35^{0}C		25^{0}C	35^{0}C
October								
Clay	61.2	1.010	1.00	-0.206	-0.201	1.810	15.1	16.32
Clay loam	59.42	0.791	0.900	-0.139	-0.132	4.246	12.3	12.4
Sandy clay loam	55.47	0.901	0.90	-0.162	-0.165	1.200	11.5	12.01
Loam	53.34	0.902	0.90	-0.261	-0.264	1.400	15.3	15.38
Silt loam	51.69	0.901	0.90	-0.421	-0.422	1.230	15.4	15.01
April								
Clay	61.2	1.121	1.22	-0.203	-0.241	1.890	15.6	16.74
Clay loam	59.42	0.701	0.71	-0.210	-0.201	4.230	12.5	12.61
Sandy clay loam	55.47	0.854	0.850	-0.162	-0.112	1.320	11.9	12.41
Loam	53.34	0.884	0.889	-0.620	-0.640	1.840	15.4	15.17
Silt loam	51.69	0.810	0.892	-0.451	-0.462	1.360	15.6	15.31

Table 95. Thermodynamic parameters of Cu adsorption in *Pokkali* soil

Parameters	b at 25^{0}C	$K_T$at 35^{0}C	b at 35^{0}C
pH		-0.703*	
EC		0.769**	
Cu		0.642*	
B			0.806**
CEC	0.633*		
Mn		0.839**	
Ex Ca		-0.806**	
Ex Mg	0.708*	-0.723*	
DEA		-0.761*	
Al-P		0.663*	
Ws-Cu		0.696*	
Ex-Cu		0.730*	
Spe.ads.pb.dis-Cu		-0.851**	
Aci.sol-Cu		-0.881**	
MnOxi-Cu		-0.870**	
Org.occl-Cu		0.697*	
Amo-FeO		-0.900**	
Cry-FeO		-0.848**	
$K_T$at 25^{0}C	0.948**		
$K_T$at 35 ^{0}C			0.647*

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

*Correlation significant at 0.05 level (2-tailed)

DISCUSSION

5. DISCUSSION

One eighty soil (lowland and upland soils) samples and one eighty water samples (field and nearby brackish water) collected from different land uses (paddy alone, paddy-shrimp, shrimp alone, mangrove and fallow land) of *Pokkali* tract were characterized initially keeping the moisture status as in field and adopting wet analysis for lowland soil and dry analysis for upland soil as detailed in the chapter 3. Lowland soil samples collected fromall the fifteen locations during the period October and April, wherein drastic pH could be noticed, were subjected to fractionation to quantify the content of major nutrient P and micronutrient Cu. In the succeeding experiment, pattern and thermodynamics of sorption of phosphorus and copper were studied in the selected soil samples (based on variation in texture) again in the month of October and April. The results obtained are critically discussed in this chapter in the light of supporting research findings on this line.

Experiment no.1

5.1 Characterization of soil samples

Physical, chemical and biological analyses were carried out in both lowland and upland soil samples.

5.1.1 Physical properties

5.1.1.1 Texture

Soil texture refers to the relative proportion of sand, silt and clay content in the soil on weight basis and it is more or less a static property affecting almost all other soil properties. In this study, sand, silt and clay fractions ranged from 31 to 70%, 8 to 27% and 12 to 60% respectively in lowland soils whereas upland soil showed it as 50 to 85%, 3 to 19% and 5 to 38% respectively (table 5). Soil texture varied from sandy clay loam to clay in lowland soil and sandy clay loam to clay loam in upland soil. Upland soils showed dominance of sand compared to lowland soils due to the prevailing tropical climate with high rainfall leading to migration of clay resulting in accumulation of coarser fractions at the surface. Lowland soils dominated in terms of clay content.

This can be attributed to the deposition of alluvial and colluvial deposits of fine sediments in low lying lands.

5.1.1.2 Bulk density

Pokkali soils generally showed lower bulk density. Lowland and upland soils were observed with the bulk density ranged from 0.69 to 0.90 Mg m^{-3} and 0.67 to 0.88 mg M^{-3} respectively across the seasons (tables 6a and 6b). Sasidharan (2004) also reported the bulk density of *Pokkali* soil as 0.67 Mg m^{-3}. Spatial and temporal variation of bulk density was non-significant for both lowland and upland soils. Since organic matter is lighter than an equal volume of solid soil and is more porous, a soilwith higher organic matter will have lower bulk density. Under this study, tables 14 and 15 revealed that *Pokkali* soil samples showed a very high organic carbon (1-4%) content.

5.1.1.3. Soil temperature

Temperature is a measure of the heat energy that regulates evaporation, aeration and chemical reactions taking place in the soil. The maximum soil temperature was observed as 31.53°C in April in lowland and 32.33°C in upland soils where the minimum soil temperature was 27.60°C (lowland) and 25°C (upland) in the month of December (tables 7a and 7b). Soil temperature varied throughout the day and depended on the time of soil sampling. The minimum and maximum soil temperature reported in December (winter) and April (summer) can be related to seasonal variation.

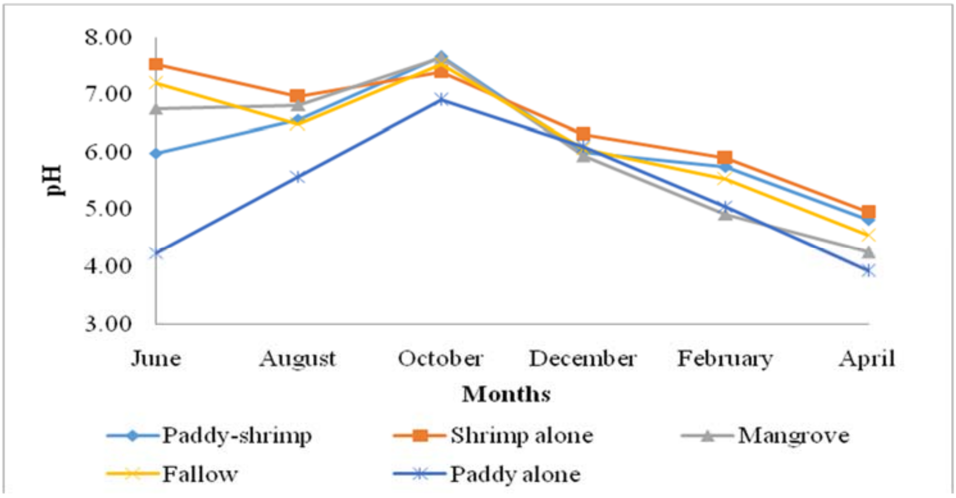
5.1.2. Chemical properties

5.1.2.1. Soil reaction

Soil pH is a dynamic parameter, with significant spatial (Behera and Shukla, 2015) and temporal differences (Kariuki *et al*., 2010). The mean value of soil pH of lowland soil varied from 4.49 to 7.42 (very strongly acidic to neutral pH) where acidic pH was observed in April and neutral pH was in October (figure 1 and plate 3). The extreme acidity noticed in *Pokkali* soils from February to April might be due to the presence of soluble salts in the high saline phase (December to May). Increased salt concentration in the soil tends to decrease pH by forcing exchangeable H^+ ions into the soil solution (Rengel, 2014). Hindar *et al.,* (1994) reported that direct addition of Na^+ saline solution resulted in an exchange of Na^+ ion with H^+ and Al^{3+} ions, causing acidification. Earlier studies in lowland soils and sediments have also reported a decrease in pH with increasing salt concentration (Farrel *et al.*,1998). The neutral pH reported in October can be attributed to the removal of active acidity from top soil by South West monsoon followed by the continuous submergence of the *Pokkali* soil. The acidic pH reported in RRS, Vyttila at the initial stage of the crop and during high saline phase can be explained by the oxidation of sulphide compounds in the soil due to the draining of water from the field by the time Pokkali rice is harvested.

Upland soils of *Pokkali* tract showed lower pH than lowland soil with values ranging from 4.39 to 4.82 (very strongly acidic) across the seasons and 3.16 to 6.36 (ultra acidic to slightly acidic) among land uses (table 8c). Upland soils are always subjected to aeration and hence oxidation of sulphide minerals caused high acidity throughout the year.

Fig.1. Temporal variation of soil pH under different land uses



5.1.2.2. Electrical conductivity (EC)

Electrical conductivity in soil water system is a measure of concentration of soluble salts and it implies the extent of salinity in the soil. *Pokkali* lands are situated below mean sea level and continuous inundation of sea water into the field caused the electrical conductivity to increase from 1.80 to 6.25 dSm^{-1} over the periodamong the months and 2.02 to 6.38 dSm^{-1} among the land uses (figure 2 and plate 4). From June to October, the electrical conductivity decreased due to the dilution of soluble salts in water by South West monsoon. Mohan and Sreelatha (2016) also observed that electrical conductivity decreased from mound preparation (June) to harvest stage

(October) of *Pokkali* rice cultivation. An immense increase in electrical conductivity was noticed from December to April (high saline phase) due to saline water intrusion into the field. Low EC values reported at RRS, Vyttila compared to other locations during high saline phase might be due to the controlled sea water intrusion into the field and also it being located far away from the brackish water unlike all others situated adjacent to the brackish water. Upland soil also exhibited same trend for electrical conductivity as lowland soil (figure 3). Highest electrical conductivity values registered in upland soils during April might be the result of evaporation of saline water in summer months leading to precipitation of salts.

Fig.2. Temporal variation of soil EC under different land uses

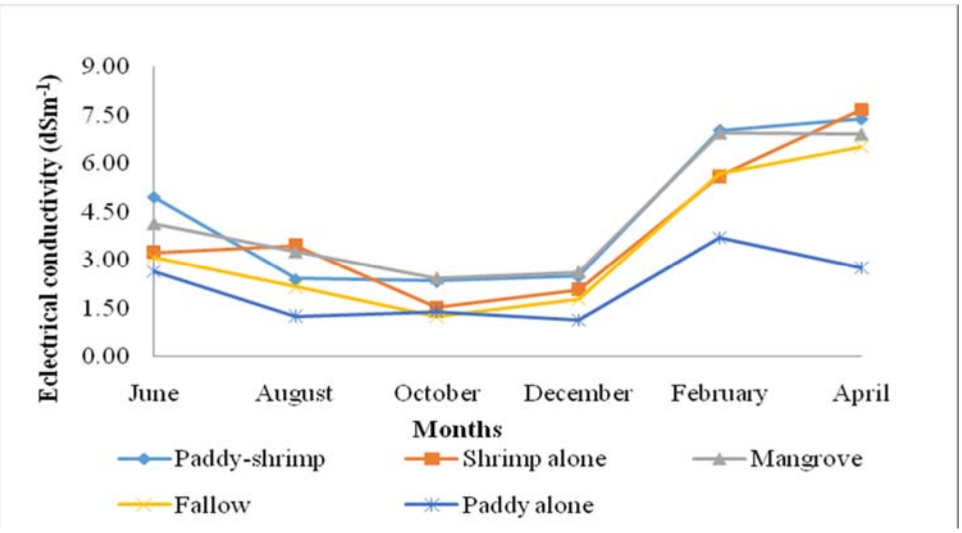


Fig.3. Temporal variation of soil EC in uplands

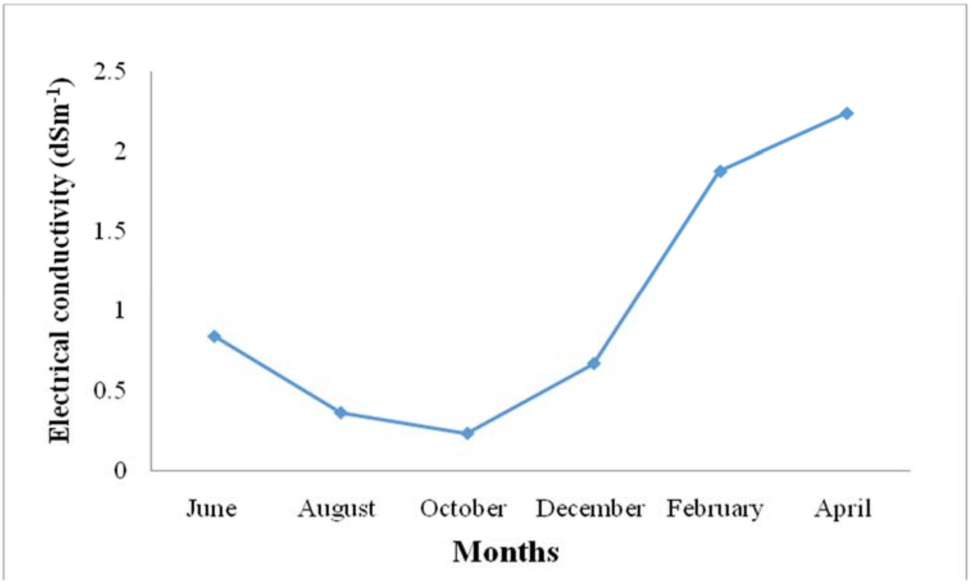
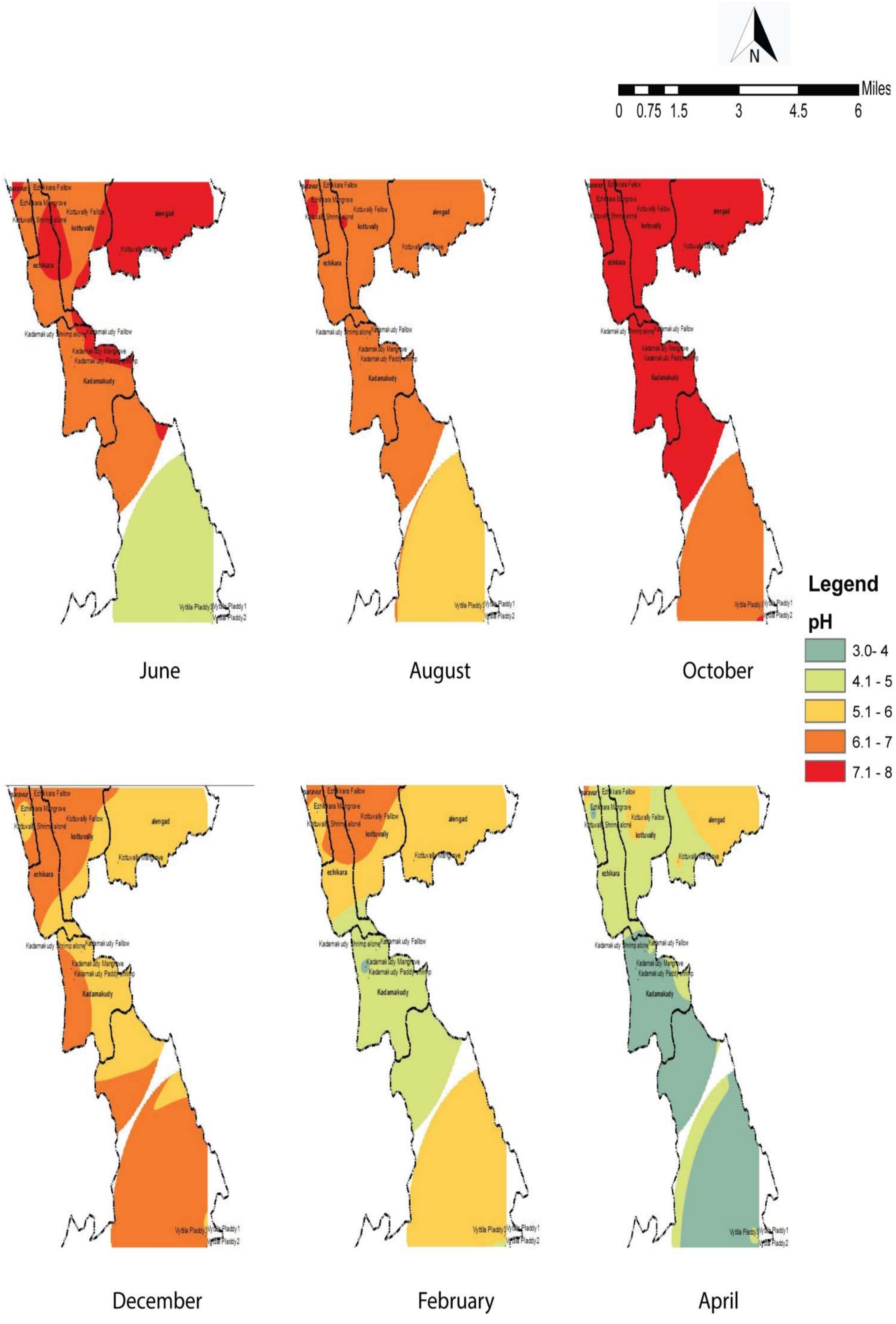


Plate 3. Spatial and temporal variation in pH of lowland



June

August

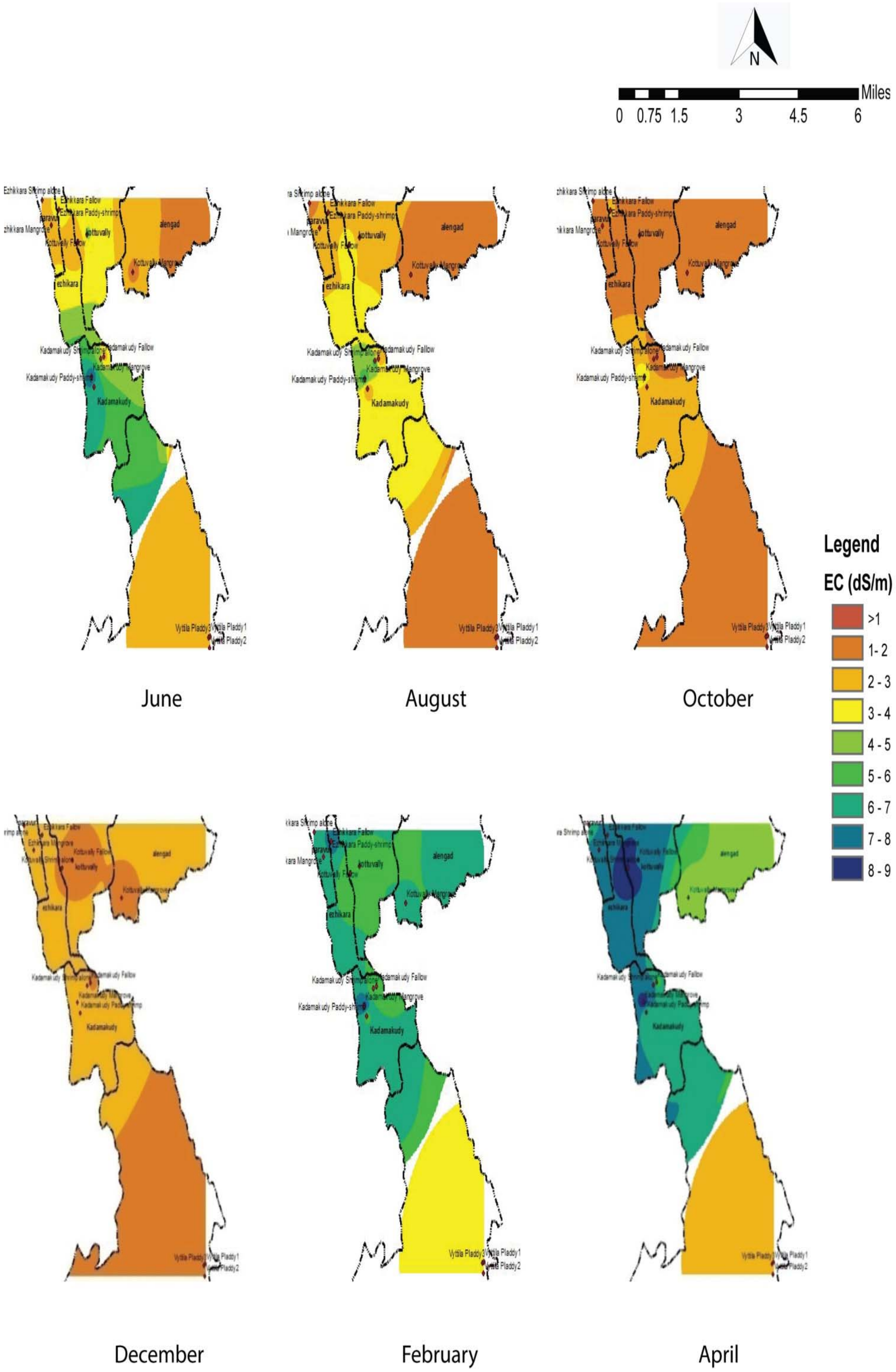
October

December

February

April

Plate 4. Spatial and temporal variations in EC of lowland


June

August

October

December

February

April

5.1.2.3. Redox potential (RP)

Redox potential is the single electrochemical property that serves to distinguish a submerged soil from a well-drained soil. The gradual decrease in the redox potential of lowland soil from June (-177 mV) to October (-300mV) (figure 4 and plate 5) might be due to the reduction of Fe^{3+} and Mn^{4+} resulted from the continuous submergence of soil. Reduction of soil is a consequence of anaerobic respiration by soil bacteria, and the source of energy is the organic matter. It should be pointed out that *Pokkali* soil contained high amount of organic matter content (table 11a) and rich in Fe and Mn components (tables 18a and 19a). The increase in the redox potential in February (-240mV) and April (-97mV) can be related to high salinity and low soil pH was reported in these months. Ponnamperuma (1967) ascribed the high salinity effect to the direct influence of the ionic strength and a depression effect on the biological activities of the soil micro-organisms. In this study, a negative relationship between soil pH and redox potential was evident. The hydrogen ion concentration affects Eh values by direct participation in the oxidation- reduction or by affecting the dissociation of oxidants and reductants (Ponnamperuma, 1972). The positive values of redox potential measured in April (320 to 360 mV) at RRS, Vyttila indicated a total soil dryness after the harvest of *Pokkali* rice and the subsequent decrease from 120 to 160 mV observed in June can be related to the water logging following south west monsoon onset.

Fig.4. Temporal variation of redox potential under different land uses

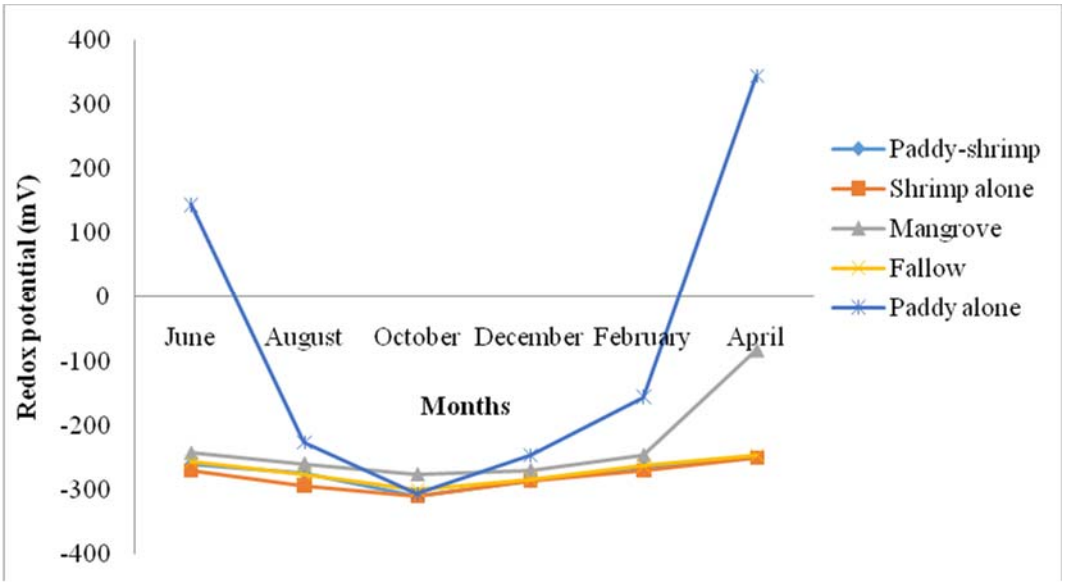
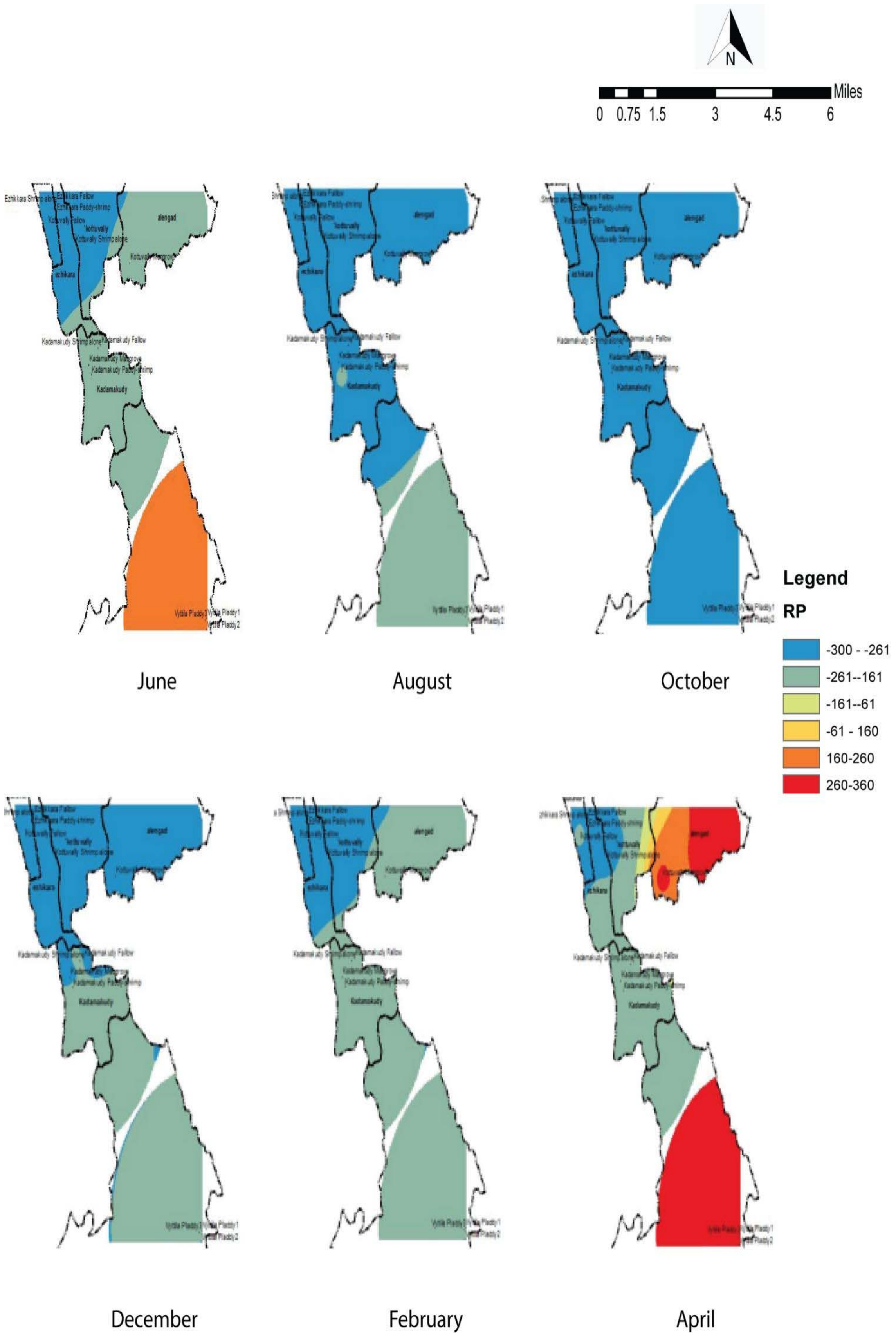


Plate 5. Spatial and temporal variations in redox potential of lowland



5.1.2.4. Organic carbon (OC)

Organic carbon is an index of soil fertility, considering the availability of nutrients from organic matter. Both lowland and upland *Pokkali* soils showed high status of organic carbon (>1.5%) (tables 11a and 11b) due to deltaic deposition of organic matter. Koruth *et al.* (2014) reported that *Pokkali* soils have medium to high organic carbon status. Lowland soil showed higher organic carbon content than upland soil and this might be due to the restricted mineralisation in lowland soil under anaerobic condition.

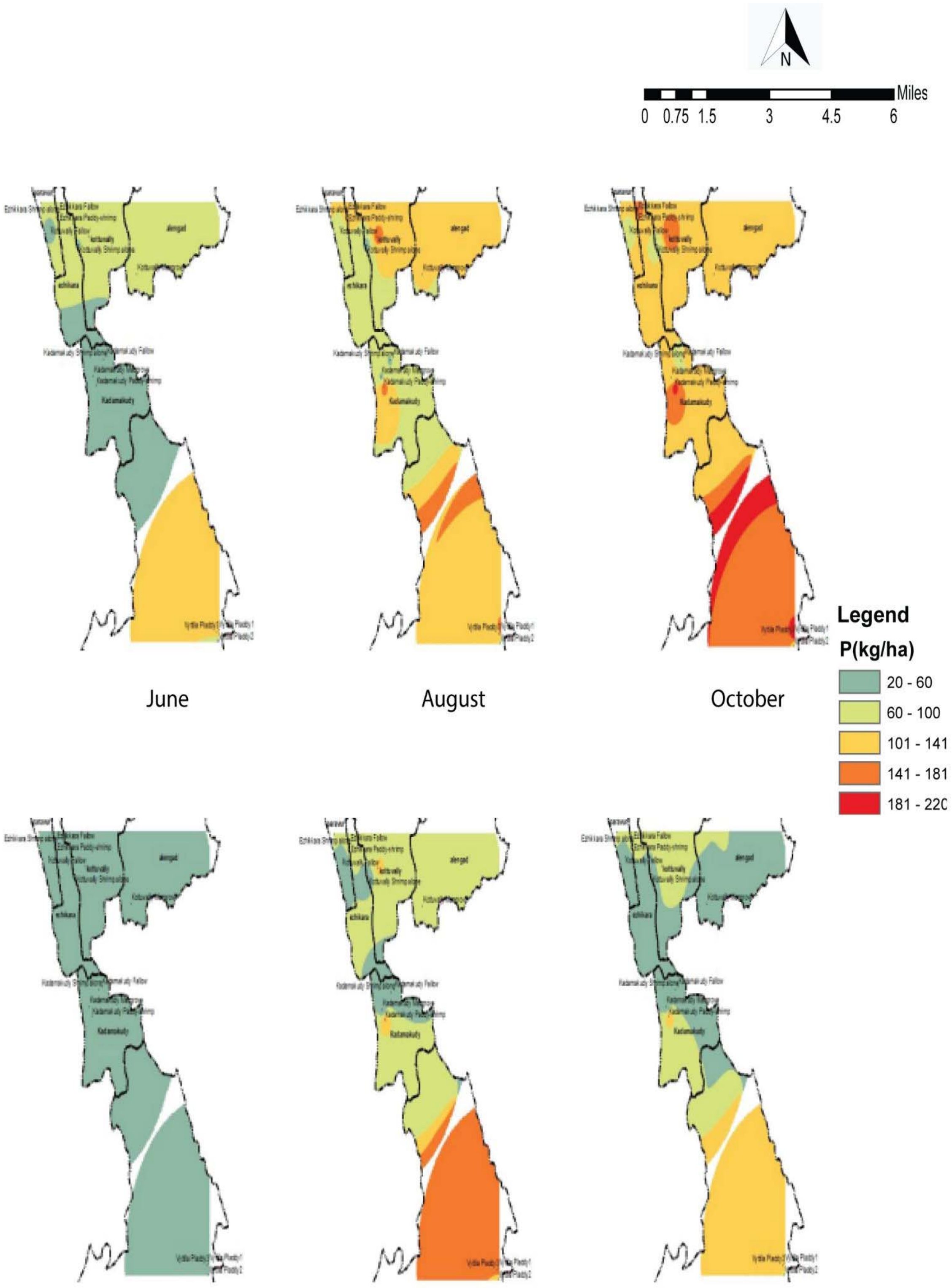
5.1.2.5. Total nitrogen (TN)

Total nitrogen content in both lowland and upland soil followed the same trend of organic carbon content. Data on upland soil revealed a spatial variability in total nitrogen from 0.122 to 0.230 % (table 12b),but not temporal. More than 95 % of nitrogen in soils exists in organic form associated with organic matter. This might be the reason for the absence of temporal variation in total nitrogen in *Pokkali* soil as well.

5.1.2.6. Available phosphorus

Available phosphorus, the second primary nutrient was high (>24 kg ha^{-1}) in all the soil samples irrespective of land uses in lowland and upland soils (figure 5 and plate 6). In lowland soil, gradual increase in available P from June (75.55 kg ha^{-1}) to October (134.33 kg ha^{-1}) was noticed. It might be due to the elevation of soil pH to neutral by the continuous submergence of the soil (Chacon *et al.,* 2006). A sudden decrease in available phosphorus during high saline phase when the soil pH turned to acidic range was another salient observation. There is all possible reason to believe the occlusion of phosphorus during precipitation of hydrous oxides of iron and aluminium at lower soil pH (figure 6). Complex formation of phosphorus with copper at lower soil pH could be also possible in this acid saline soil (figure 7). Upland soil showed non-significant variation in available phosphorus among the months (table 13c). Paddy alone land use in RRS,Vyttila recorded highest phosphorus status (137.87 kg ha^{-1}) among the land uses.

Plate 6. Spatial and temporal variations in available phosphorus of lowland



June August October

December February April

5.1.2.7. Available potassium

As regards potassium, the third primary nutrient, available status was high (>275 kg ha^{-1}) in all soil samples collected from lowland (table 14a) and upland (table 14c). The decrease in available potassium from June (955.91kg ha^{-1}) to October (636.51kg ha^{-1}) (figure 8 and plate 7) can be related to rainfall received. South West monsoon during low saline phase (June to October) caused the leaching losses of available potassium.Available potassium increased from December to April (high saline phase) due to inundation of sea water into the field (Joseph, 2014). The direct effect of land uses on available K was absent.

Fig.5. Temporal variation of available phosphorus under different land uses

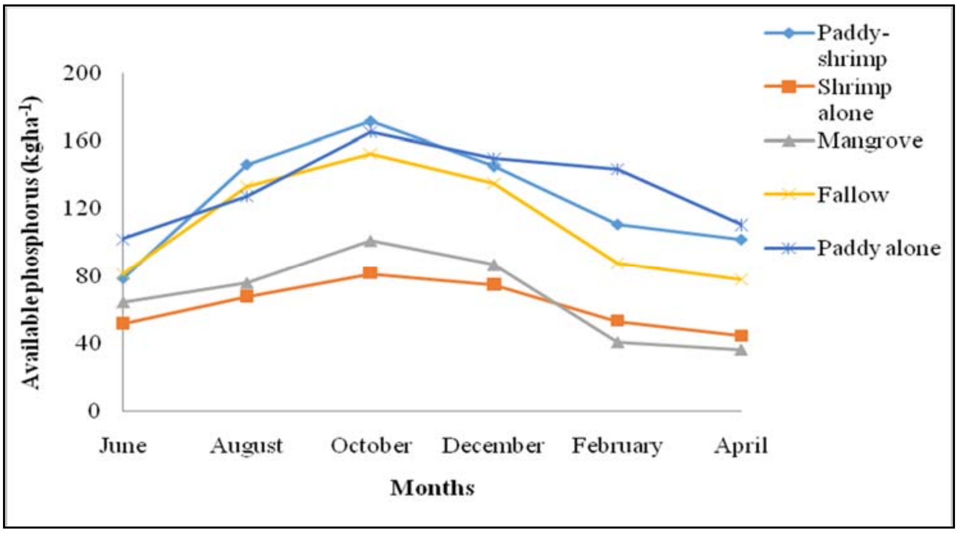


Fig.6. Available phosphorus and iron with varying soil pH

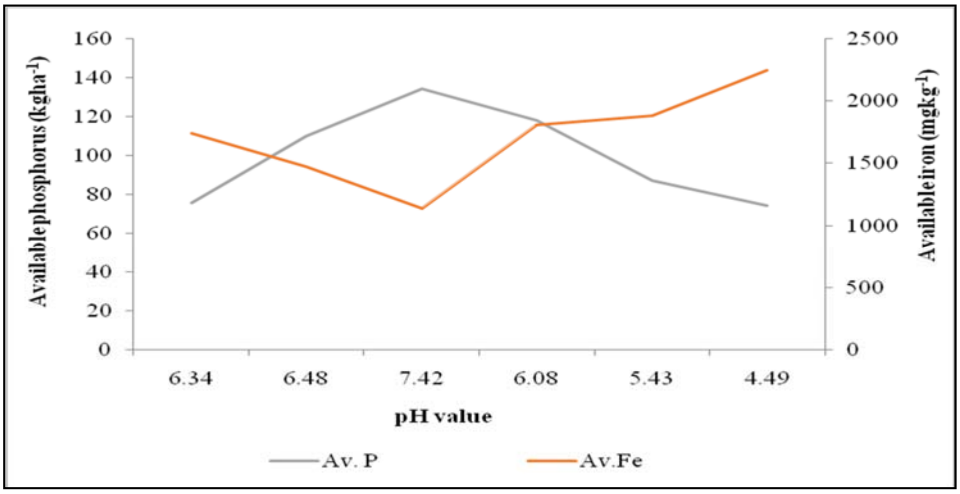


Fig.7. Available phosphorus and copper with varying soil pH

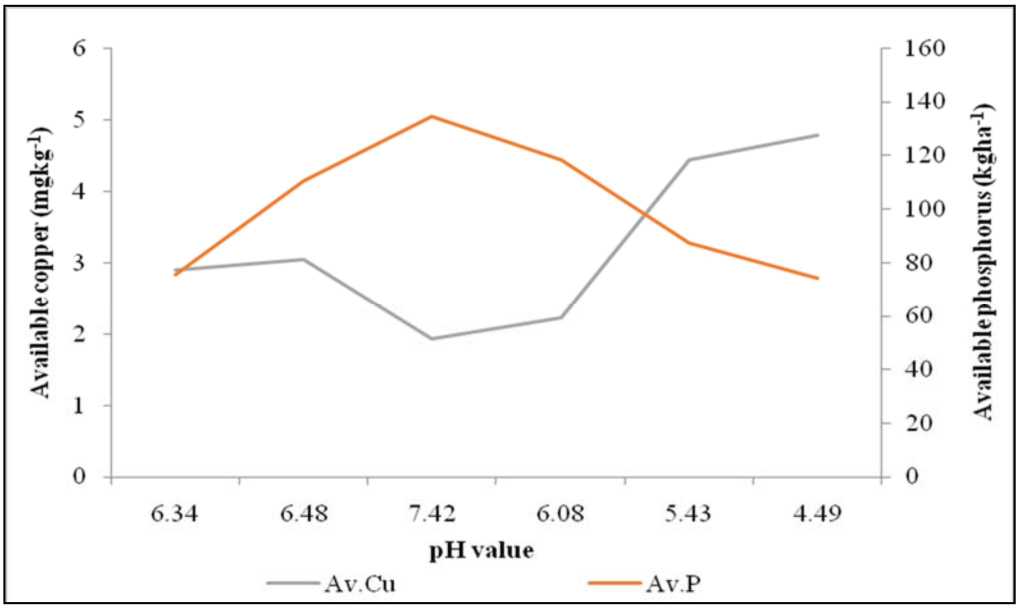


Fig.8. Temporal variation of available potassium under different land uses

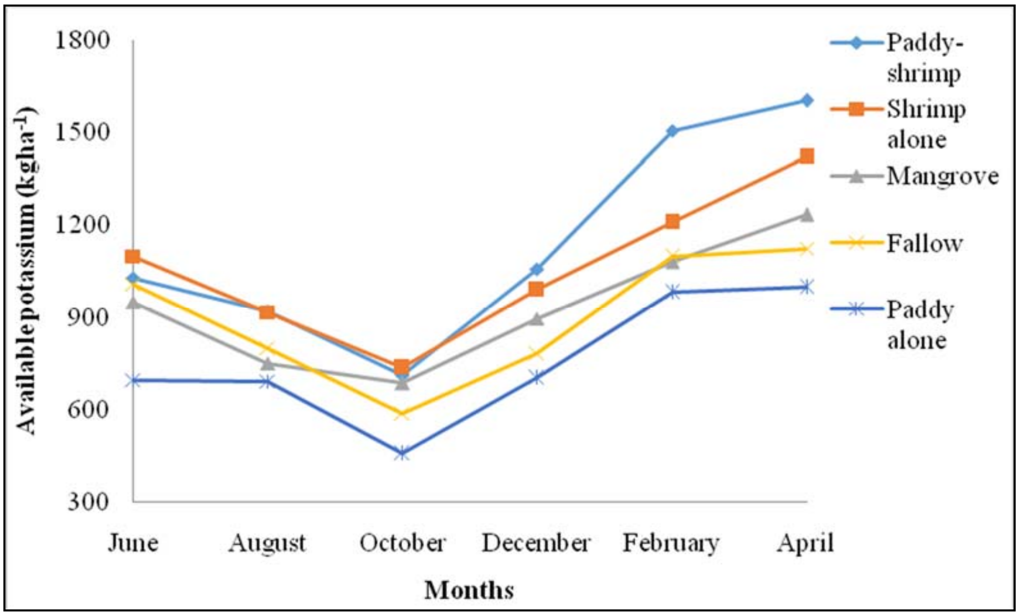
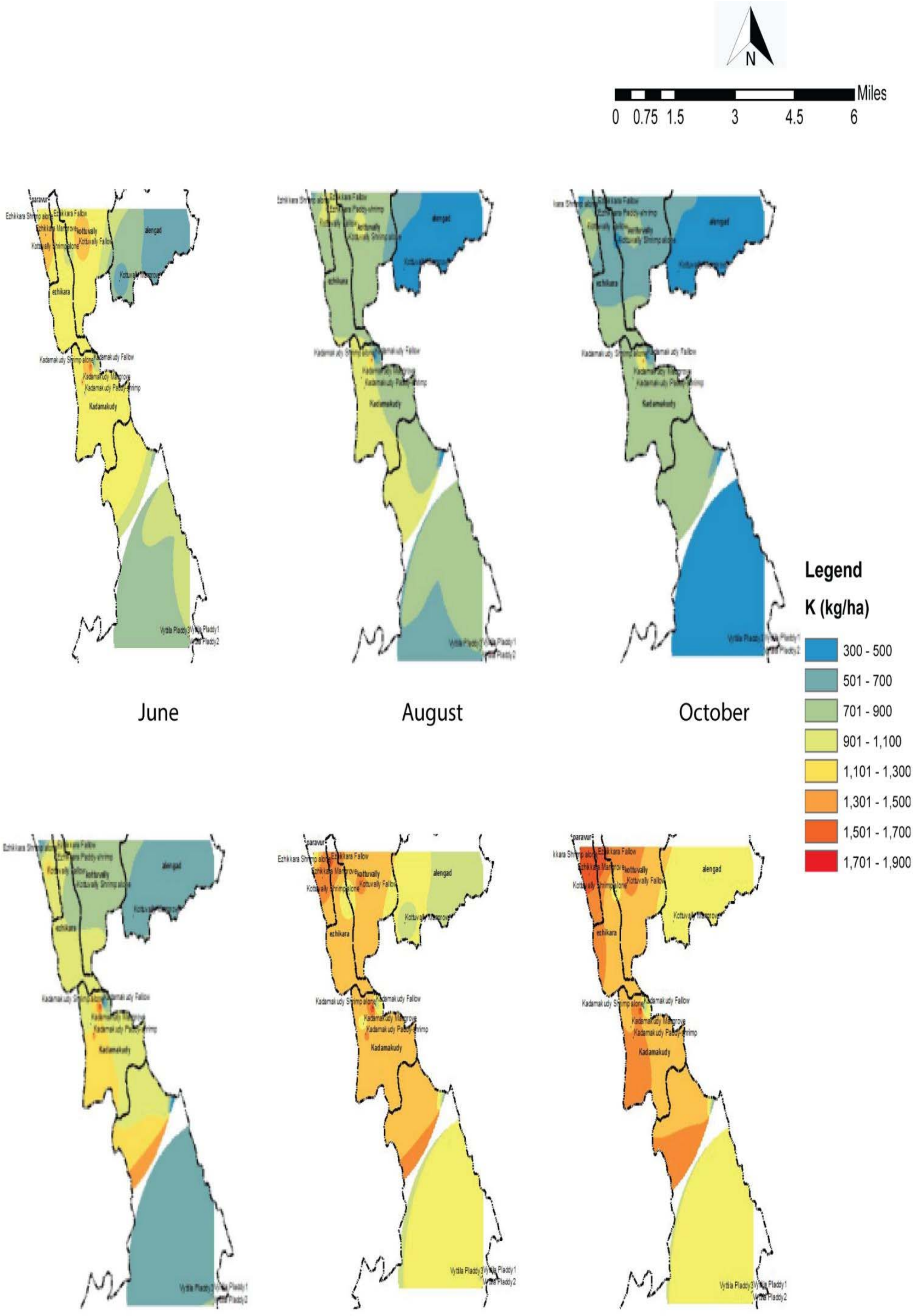


Plate 7. Spatial and temporal variations in available potassium of lowland



June August October

December February April

5.1.2.8. Available calcium and magnesium

In terms of secondary nutrients analysed**,** secondary nutrients, sufficient amount of calcium (>300mgkg^{-1}) and magnesium (>120mgkg^{-1}) were recorded in both lowland and upland *Pokkali* soils. In lowland soil, calcium and magnesium ranged from 686.64 to 1134.72 mgkg^{-1} (figure 9 and plate 8) and 557.76 to 1365.22 mgkg^{-1} (figure 11 and plate 9) respectively across the seasons. Bhindhu (2017) observed high content of calcium and magnesium in lowland *Pokkali* which the scientist related to high electrical conductivity. In upland soil, calcium and magnesium did not show significant variation among the months (table 15). These elements were very high during high saline phase (December to April) compared to low saline phase in both lowland and upland soils. This might be attributed to saline water intrusion into the field during high saline phase. Soluble salts in the form of $CaSO_4$, $CaCl_2$, $MgSO_4$, $MgCl_2$ etc in the sea water contributed to the very high levels of available calcium and magnesium. The decrease can be attributed to its higher hydrated ionic radii which make the magnesium less strongly bound to soil colloids. Even though the spatial variation of available Ca and Mg was observed in both lowland and upland soil, direct effect of land uses on available Ca and Mg was not observed.Figure 10 and 12 showed deficiency of available Ca and Mg respectively in some land uses of various locations. Calcium and magnesium deficiency reported in uplands might be due to the leaching losses and also could be predicted that external fertilizer application was absent there.

Fig.9. Temporal variation of available calcium under different land uses

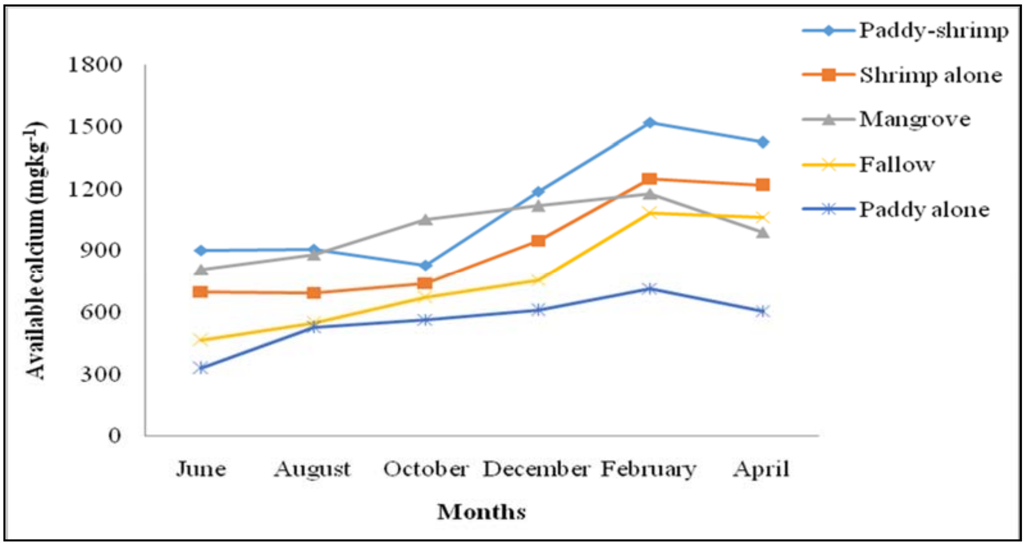


Fig.10. Spatial variation of available calcium in uplands

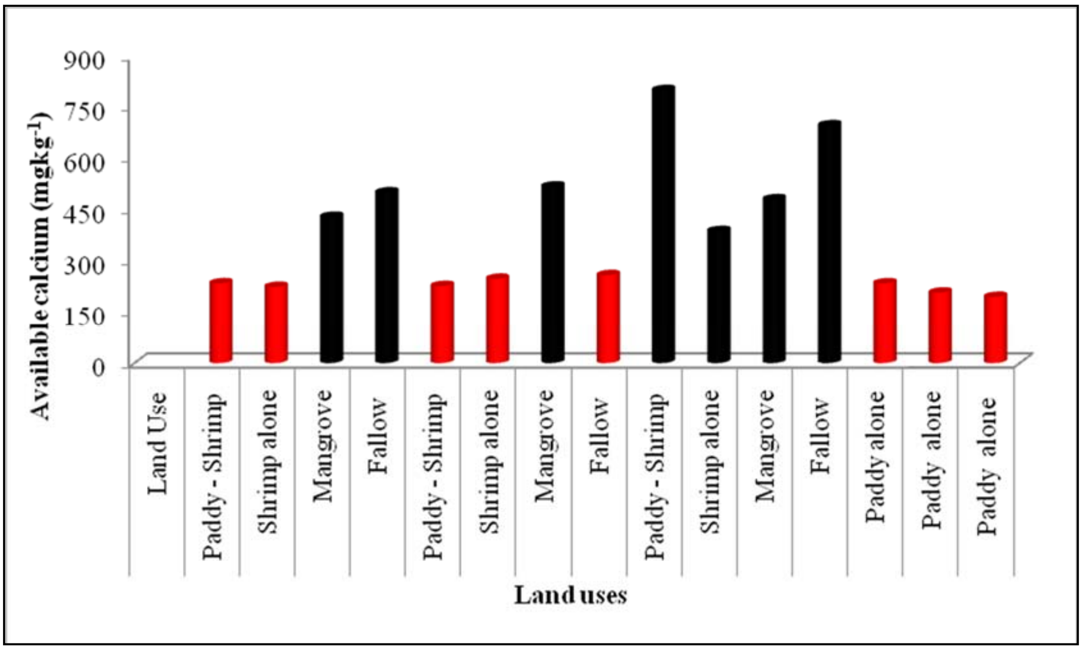


Fig.11. Temporal variation of available magnesium under different land uses

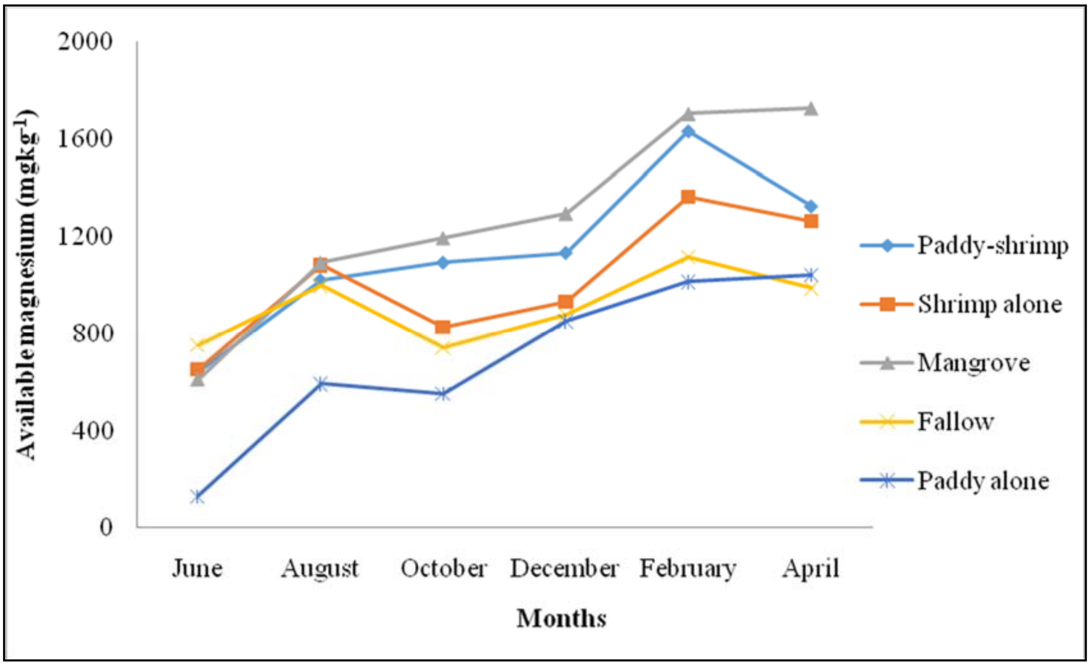
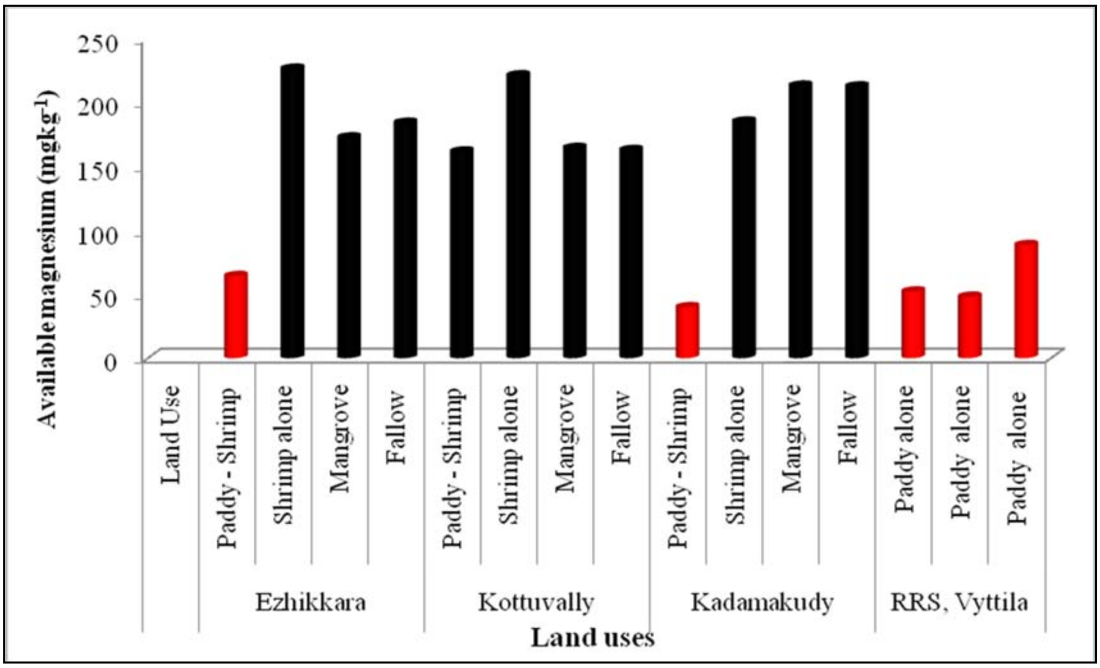


Fig.12. Spatial variation of available magnesium in uplands



5.1.2.9. Available sulphur

Available sulphur was reported as sufficient (>10mgkg^{-1}) throughout the months in both lowland and upland soils. A decreasing trend for available sulphur from June (2459.32 mgkg^{-1}) to October (1711.18 mgkg^{-1}) was observed in lowland soil (figure 13 and plate 10). This can be related to the South West monsoon during low saline phase. Saline water intrusion into the field during high saline phase caused very high values of available sulphur in February and April. In upland soil, available sulphur was found to be significant among the months and the values ranged from 282.18 to 476.64mgkg^{-1} (table 17a). The intensive leaching losses of soluble sulphates from upland soil caused a reduction in the content of available sulphur compared to lowland soil.

5.1.2.12. Available Fe

The most important chemical change that takes place when a soil is submerged is the reduction of iron and accompanying increase in its solubility. In this study, available iron was in toxic level (>5mgkg^{-1}) and found that solubility of iron was more in April (2248.38 mgkg^{-1}) followed by February (1882.35 mgkg^{-1}) where the pH of the soil was acidic. The available content was the lowest in October with the pH turning to neutral (1135.62 mgkg^{-1}) (figure 14 and plate 11). Neutral pH conditions promote the precipitation of poorly ordered Fe minerals (ferrihydrite), whereas reducing and acid conditions promote the mobilization of Fe minerals (Lindsay 1988). During low saline phase, available Fe was found to be decreased from June to October. This reduction in the available Fe can be explained by the precipitation of Fe^{2+} as $FeCO_3$ and Fe-S compounds. High organic matter (>0.75%) in *Pokkali* soil also enhanced the rate of reduction of iron. Upland soil showed a gradual increase in the Fe^{2+} content throughout the months (table 18b). The iron content in the lowlands was higher than the uplands due to reduction of Fe^{3+} to soluble ferrous form (Fe^{2+}) under submerged anaerobic condition.

Fig.13. Temporal variation of available sulphur under different land uses

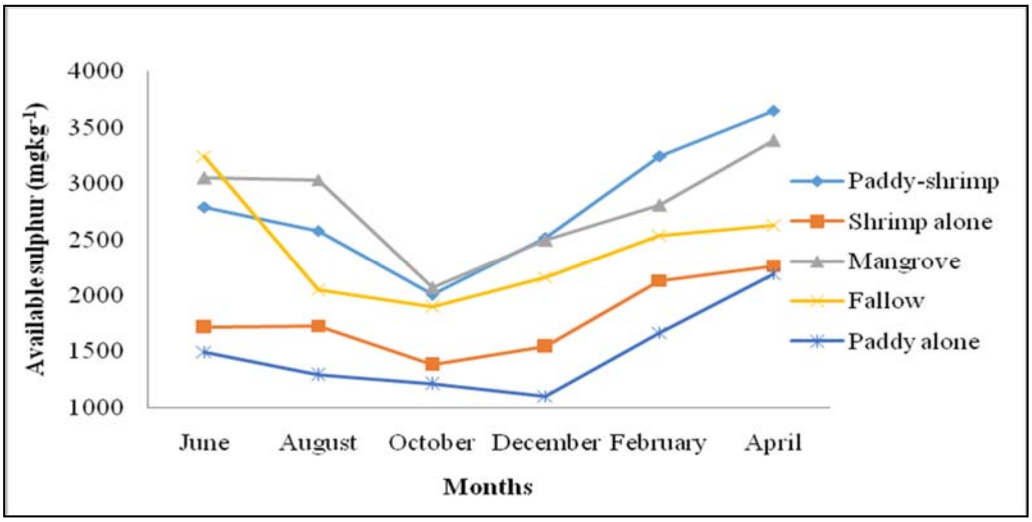


Fig.14. Temporal variation of available iron in lowlands and uplands

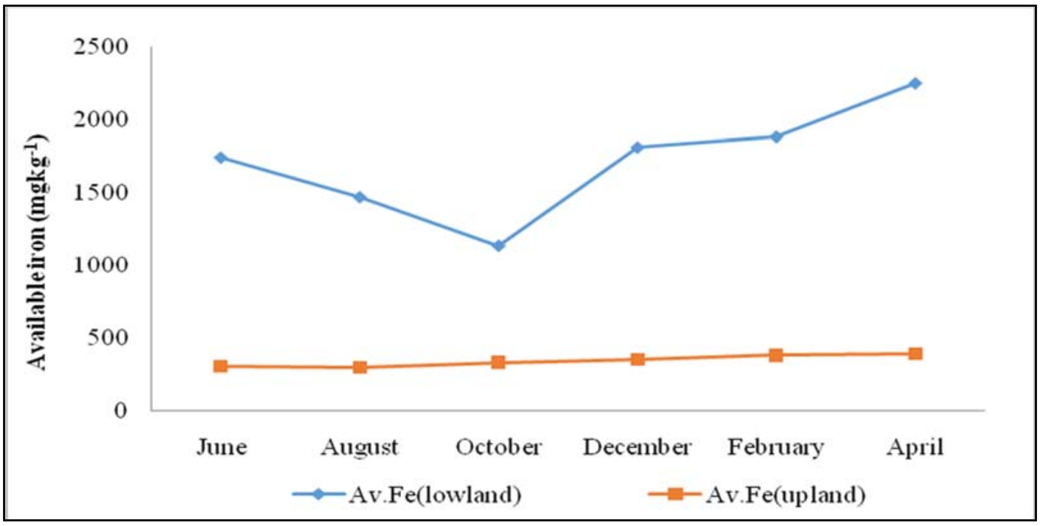
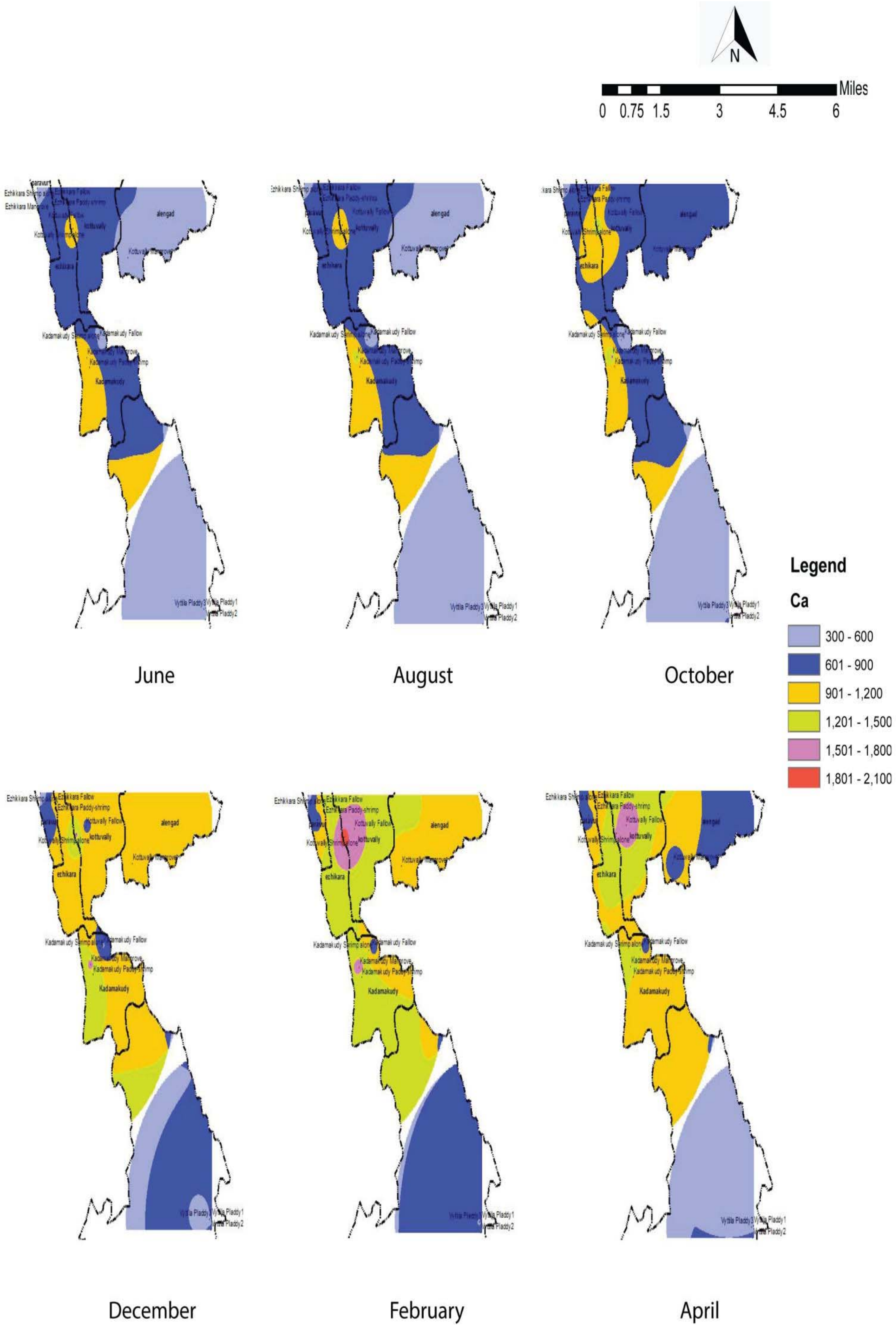


Plate 8. Spatial and temporal variations in available calcium of lowland



June

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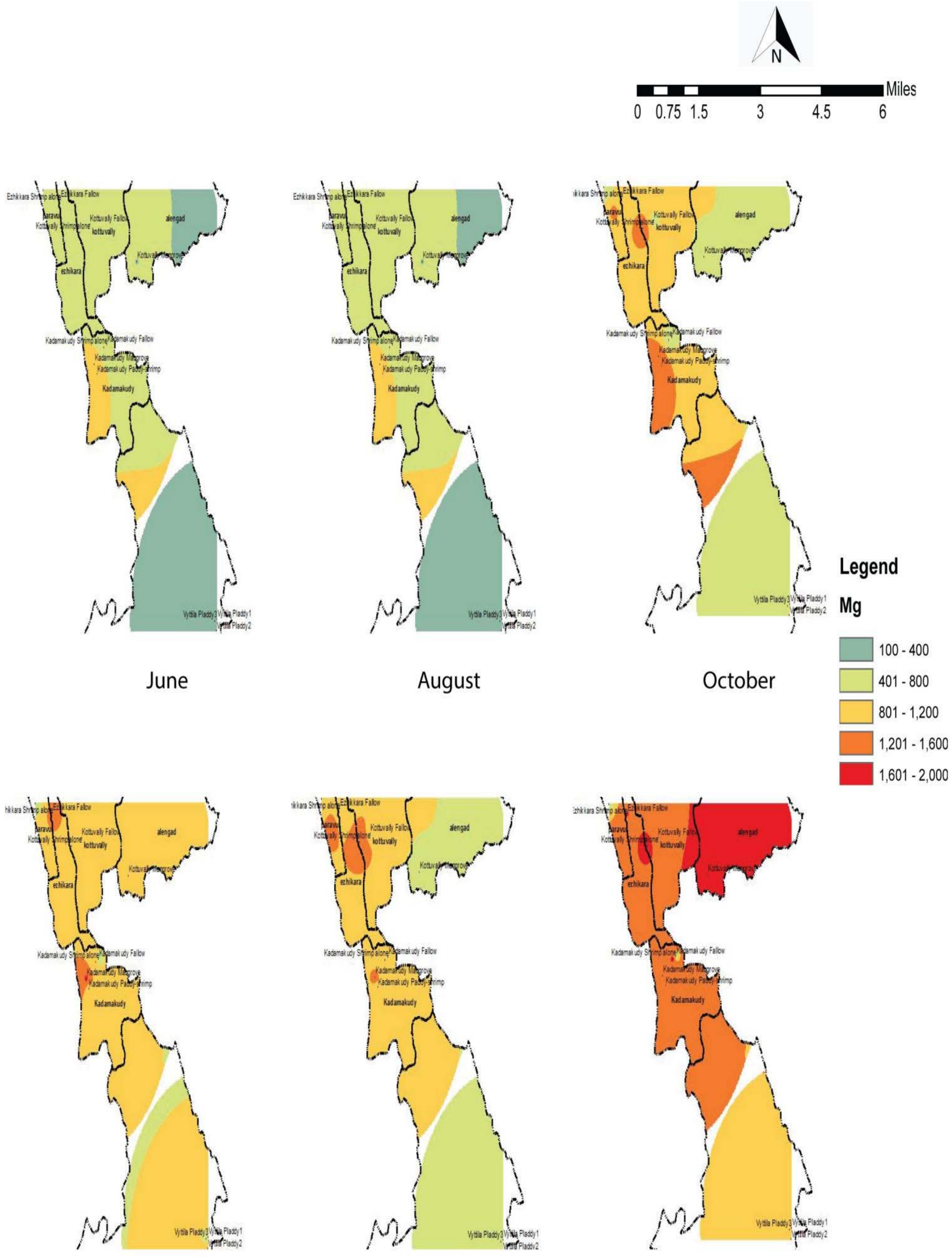
April

Plate 9. Spatial and temporal variations of available magnesium in lowland



June

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Plate 10. Spatial and temporal variation of available sulphur in lowland

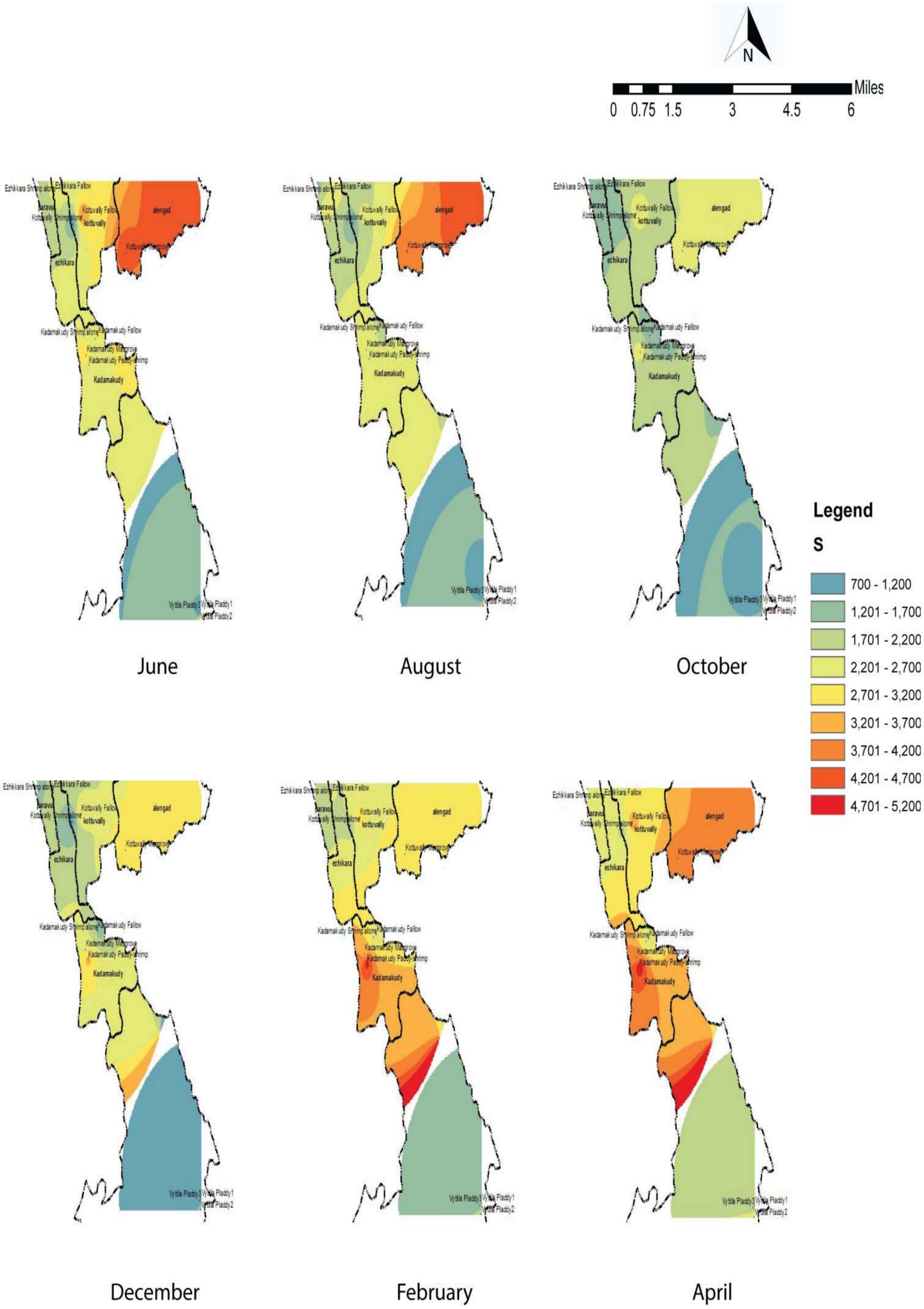
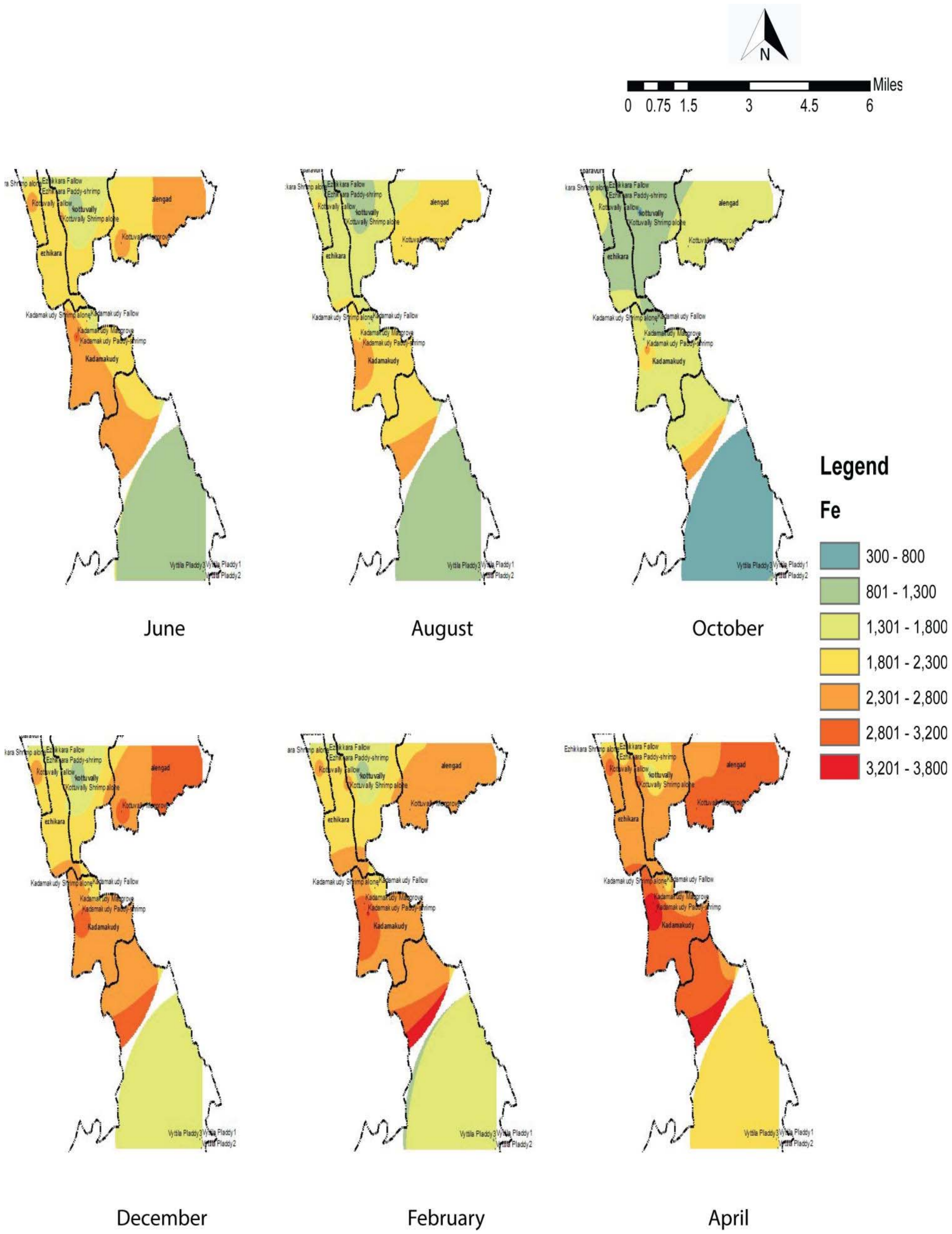


Plate 11. Spatial and temporal variation of available iron in lowland



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December

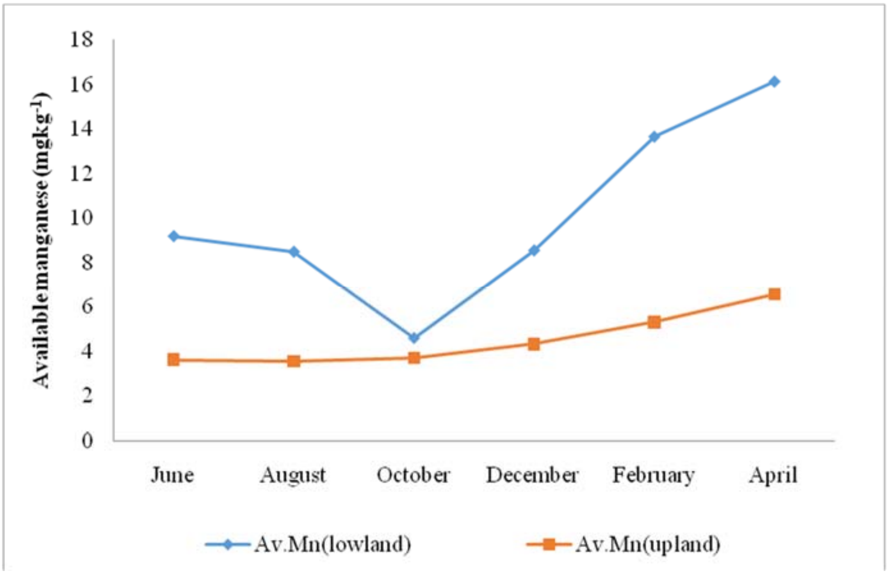
February

April

5.1.2.13. Available Manganese

The main transformation of manganese in submerged soil is the reduction of manganese (Mn^{4+}) to manganous (Mn^{2+}). Like iron, transformation of manganese is also governed by redox equilibria system. Available manganese in lowland soil was found to be sufficient (>1mgkg^{-1}) and decreased from June (9.18 mgkg^{-1}) to October (4.59 mgkg^{-1}) and then increased till April (16.11 mgkg^{-1}) (figure 15 and plate 12). The decrease in available Mn from June to October might be due to the precipitation of Mn^{2+} on $MnCO_3$ and $(MnOH)_2$ in the soil solution (Ponnamperuma, 1972). A low pH or low Eh favours the reduction of insoluble manganese oxides and increases the solubility of Mn^{2+}. The Mn^{2+} ion is released from solids by spontaneous dissolution or cation exchange, especially under acidic or reducing conditions (McBride, 1994). This might be the reason for the increase in available Mn towards the month of April. Upland soil showed high Mn^{2+} content during high saline phase (December to April) than low saline phase (June to October) (table 19c). Land uses didn't show direct effect on available Mn status in both lowland and upland soils.

Fig.15. Temporal variation of available Mn in lowlands and uplands



5.1.2.10. Available Zinc

Available Zn was sufficient (>1mgkg^{-1}) in both lowland and upland soils. According to Das (2015), the availability of zinc was proved to be highly pH dependent, showing a decrease on increasing soil pH and an increase by decreasing soil pH. This was evidenced in lowland *Pokkali* soil (figure 16 and plate 13). Upland soil exhibited an increasing trend of available Zn from June (6.38 mgkg^{-1}) to April (10.70 mgkg^{-1}). With the summer months, February to April, alone recording a significant difference in available zinc (table 20a). Both in low land and upland, the values on available zinc was the lowest in samples from RRS,Vyttila which may be due to the higher P status in these soils. Figure 17 clearly poited towards the precipitation of available phosphorus with available zinc in acidic pH of *Pokkali* soil.

Fig.16. Temporal variation of available zinc in lowlands and uplands

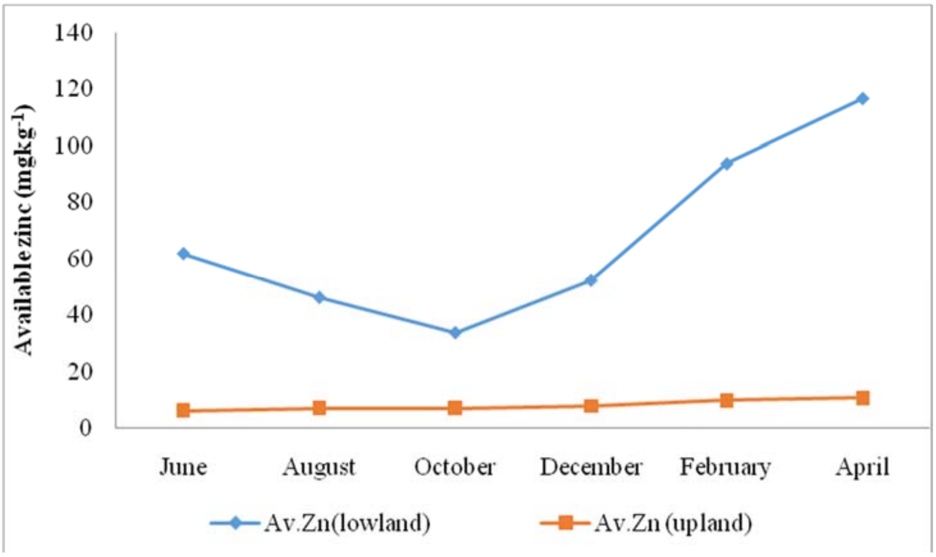


Fig.17. Available Zn and P with varying soil pH

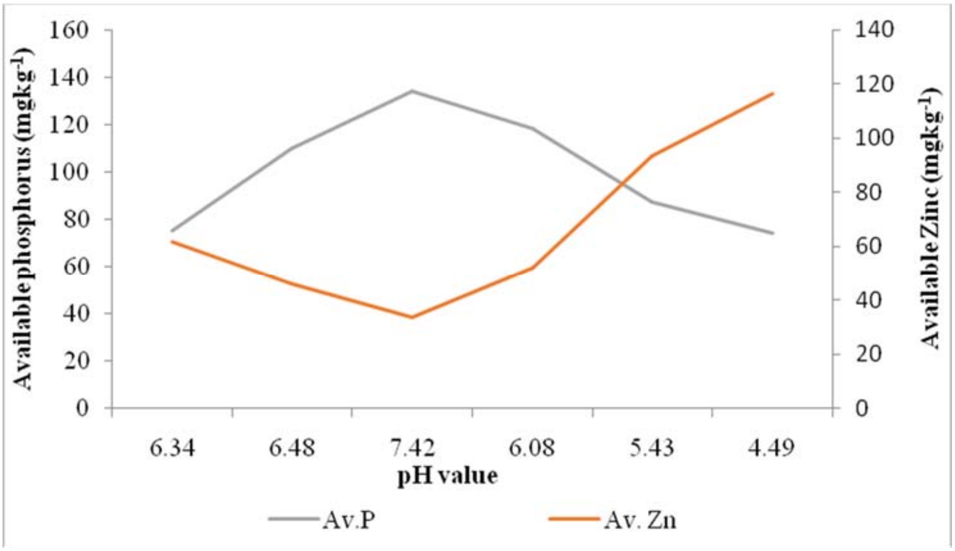
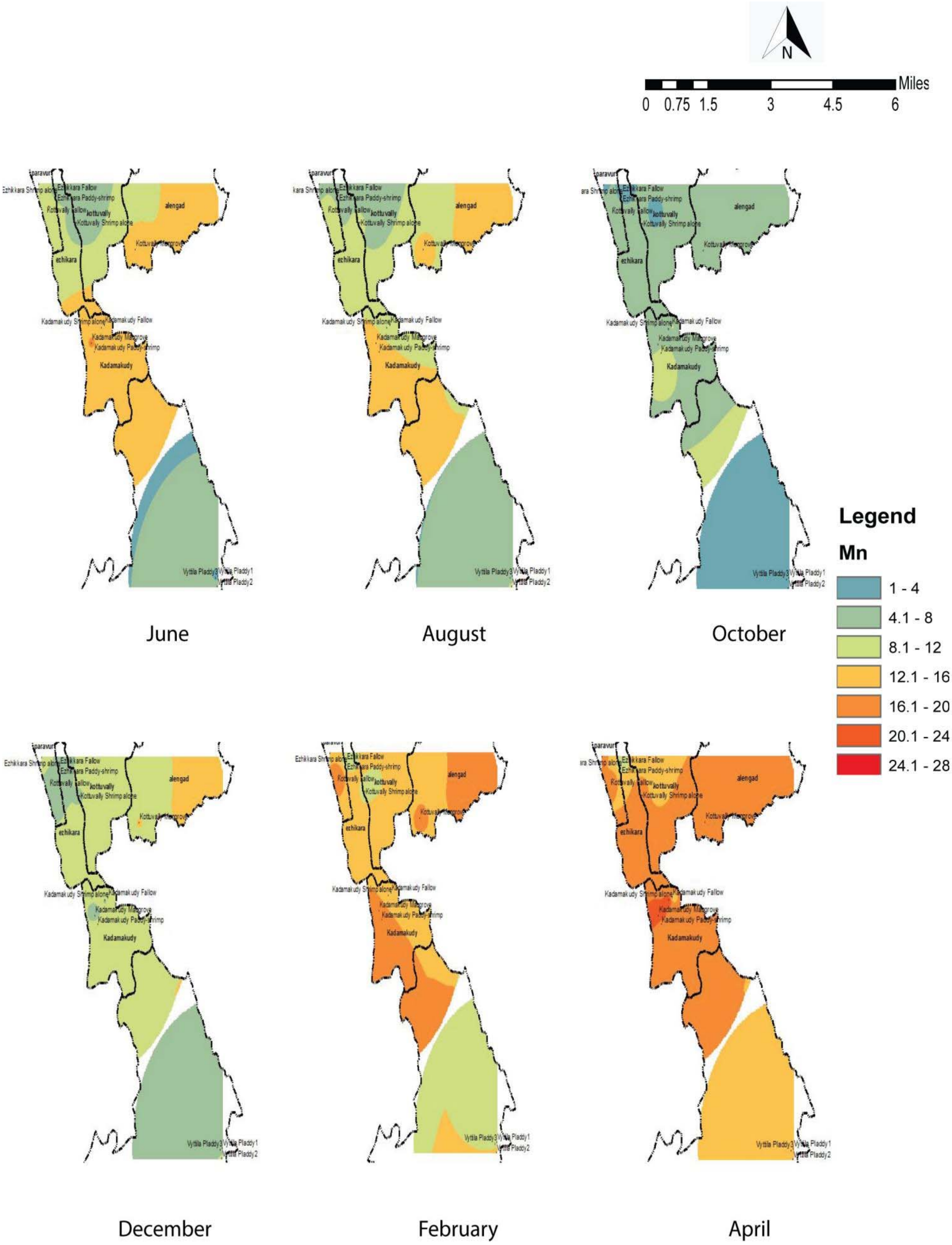


Plate 12. Spatial and temporal variation of available manganese in lowland



June

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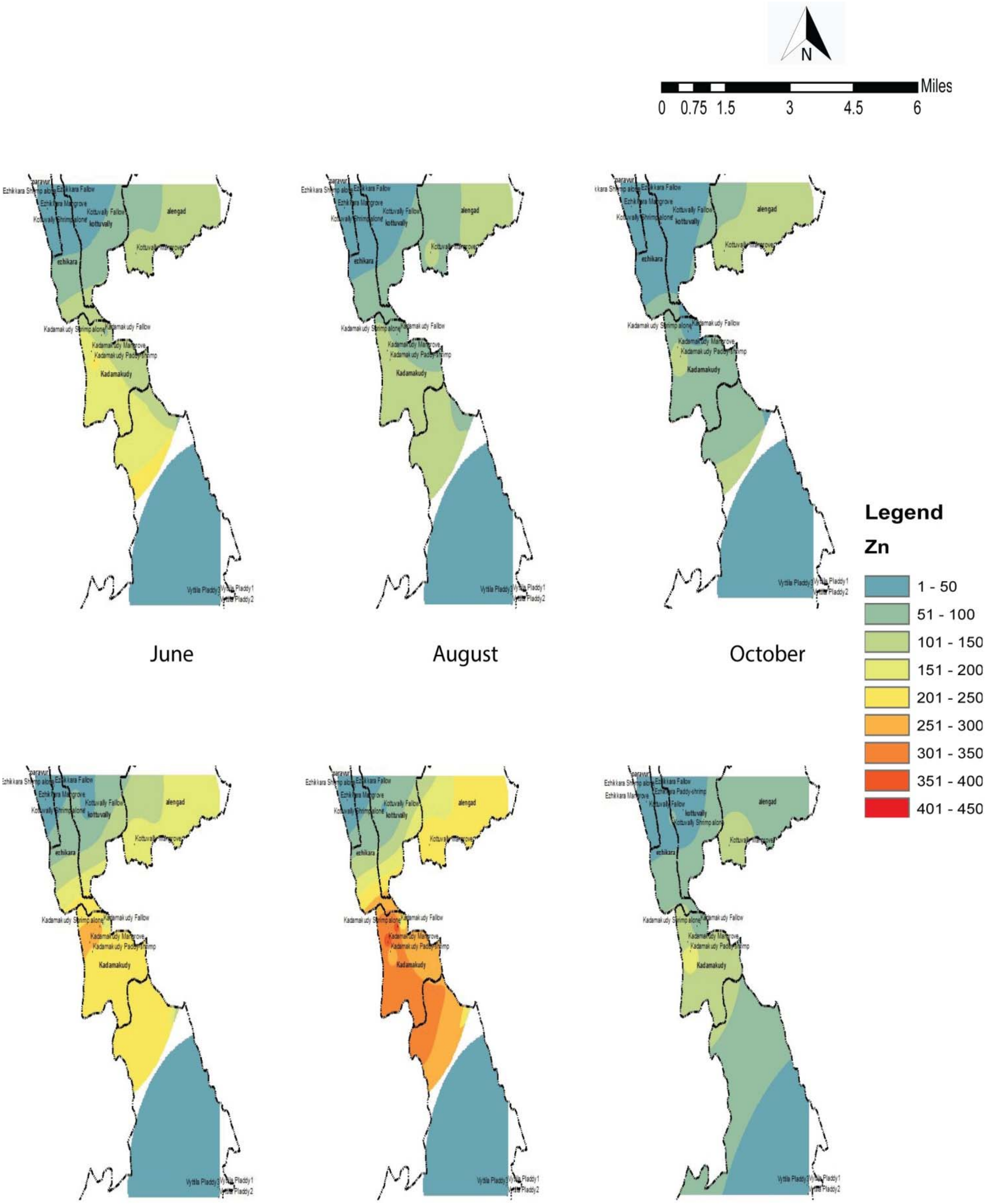
Plate 13. Spatial and temporal variation of available zinc in lowland



June August October

December February April

5.1.2.11. Available Cu

Available Cu in lowland (figure 18 and plate 14) and upland soil (table 21c) ranged from 1.93 (October) to 4.44 (April) mgkg^{-1} and 1.53 (June) to 2.24 mgkg^{-1} (February) respectively throughout the months. Available Cu in lowland and upland soils was sufficient (>1mgkg^{-1}) and higher values were observed in February and April which were significantly different from other months. Higher amount of available Cu on February and April can be related to acidic pH observed on these months. Solubility of Cu is also dependent on soil pH and it increased with decreasing soil pH (Das, 2015). Paddy alone land use in RRS, Vyttila (a) registered highest available copper (5.34 mgkg^{-1}) in lowland soil whereas upland soil didn't show any significant variation among the land uses.

5.1.2.14. Available Boron

Available boron was sufficient (>0.5mgkg^{-1}) in *Pokkali* soil and very high during high saline phase (5.61 to 9.12 mgkg^{-1}) than low saline phase (3.94 to 4.91 mgkg^{-1}) which was suggestive of the marine influence on *Pokkali* land during high saline phase. Also, an increasing trend of available boron was noticed from June (3.94 mgkg^{-1}) to October (4.91 mgkg^{-1}) might be due to increase in soil pH towards the month of October (figure19 and plate 15). Uplands of *Pokkali* tract showed the available boron content ranging from 0.281 (October) to 0.556 mgkg^{-1} (April) which indicated the deficiency (<0.5mgkg^{-1}) of available boron across the seasons (table 22c). This might be due to the leaching process associated with soils under humid tropical conditions. In soil, boron exists mostly in readily soluble form which get subjected to losses through leaching. Land uses didn't show direct effect on available B status in lowland and upland soil.

The predominance of available micronutrients in lowland and upland of *Pokkali* tract followed the order as Fe>Zn>Mn>B>Cu and Fe>Zn>Mn>Cu>B respectively.

5.1.2.15. Heavy metals

In the study area, available status of heavy metals *viz.,* nickel, lead, cobalt, arsenic and mercury was very much negligible whereas toxicity due to cadmium and chromium could be detected in a few of the land uses covered. Further description follows on this.

Fig.18. Temporal variation of available Cu in lowlands and uplands

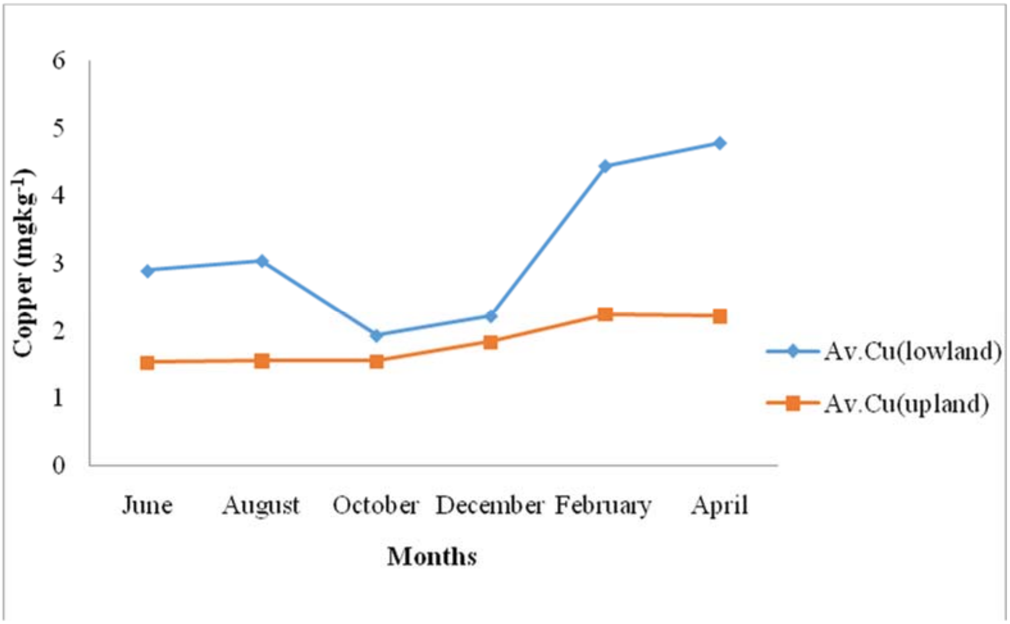


Fig.19. Temporal variation of available B in lowland

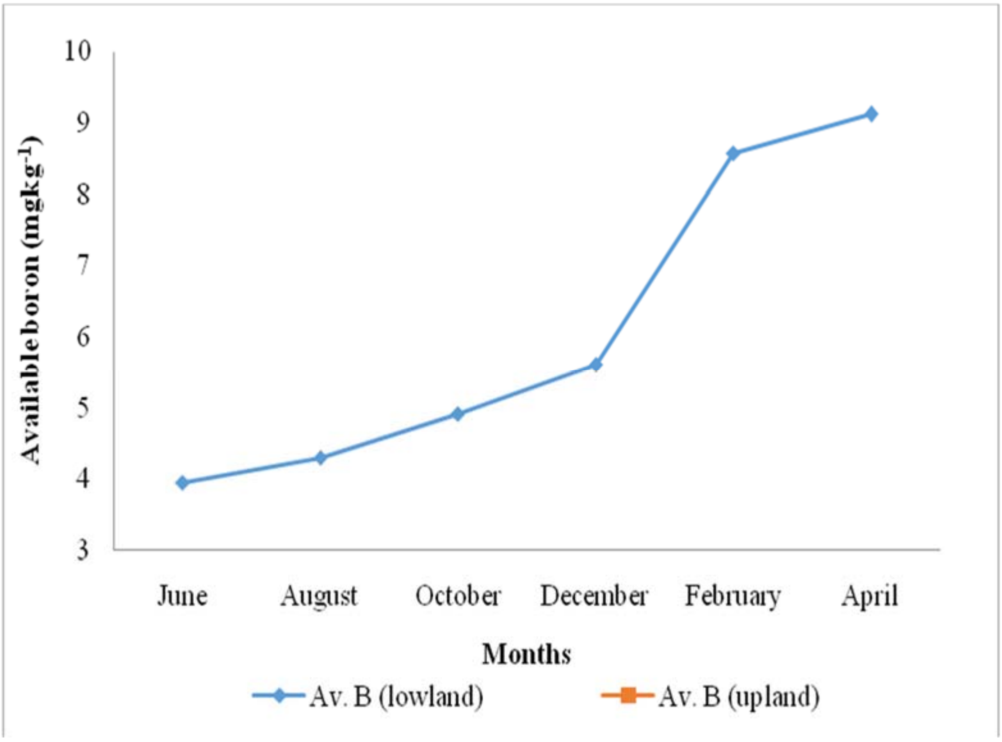
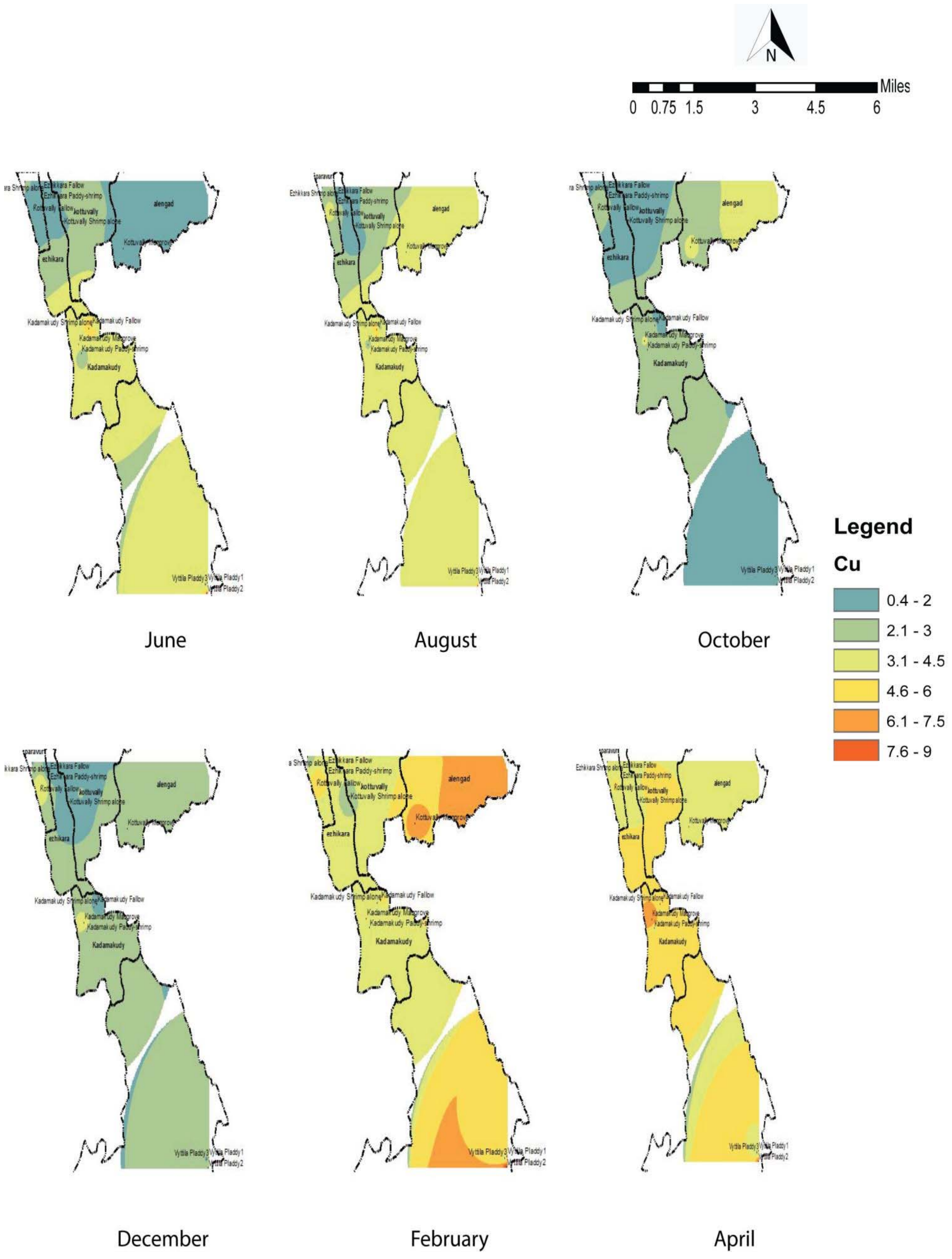


Plate 14. Spatial and temporal variation of available copper in lowland



June

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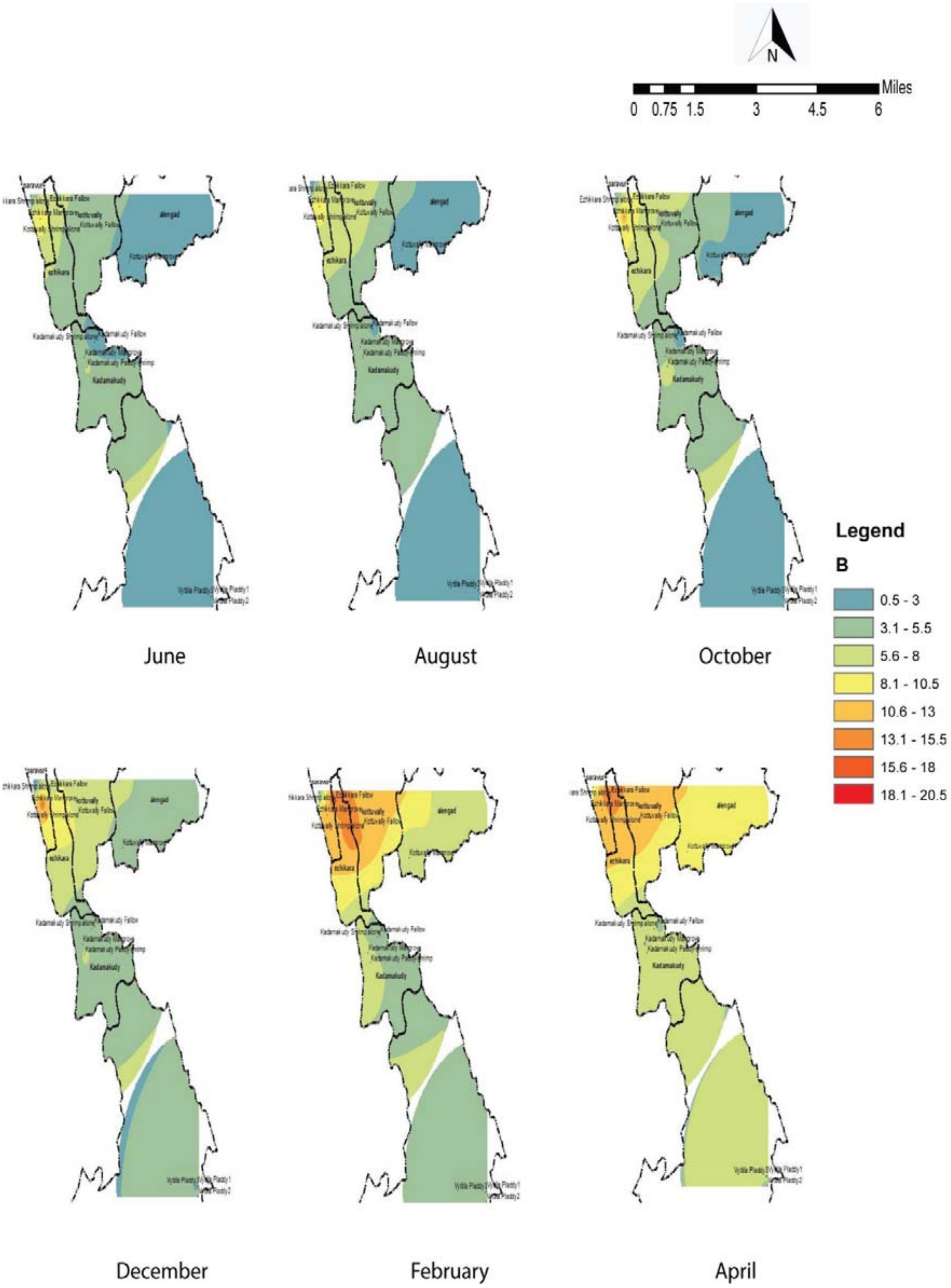
Plate 15. Spatial and temporal variation of available boron in lowland



5.1.2.15.1. Available Nickel

The metal, nickel is toxic, carcinogenic and dangerous for humans, plants and animals. Available nickel in lowlands ranged from 0.812 (October) to 1.245 mgkg^{-1} (April)throughout the seasons and 0.204 (fallow land in Kottuvally) to 2.382 mgkg^{-1} (mangrove in Kadamakudy) among land uses (table 23a). The lowest value of available nickel was found inOctober when the pH tends to neutral. Metal solubility is less in neutral soil reaction (Thornton, 1996). In upland soil available nickel was non-significant among the months (table 23b). Among the land uses, highest value was recorded in mangrove in Kottuvally (0.587mgkg^{-1}). The values of available Ni in soil were below the recommended maximum concentration (50 mgkg^{-1}) as per the WHO/FAO (2001).

5.1.2.15.2. Available cadmium

Available cadmium ranged from 1.56 (August) to 1.80 mgkg^{-1}(February) which was below the recommended maximum concentration (3 mgkg^{-1}) in soil as per the WHO/FAO (2001). Even though the variation in available Cd was negligible among the months, the highest and lowest value reported in August and February was significantly different. Solubility of cadmium is known to increase with decreasing soil pH (Brallier*et al.*, 1996) which was evident in this study(table 24a). Mangrove in Kottuvally (4.505mgkg^{-1}), paddy-shrimp (4.544mgkg^{-1}), shrimp alone (7.109mgkg^{-1}) and mangrove (6.524mgkg^{-1}) in Kadamakudy recorded very high values of available cadmium indicating cadmium toxicity. This might have reached these land uses from river water contaminated by sewage. Cadmium is potentially bio-available for plant uptake and is of great concern with regard to food chain contamination (Zhang *et al.,* 2009). Hence possibility of cadmium gaining access to human food chain through paddy and shrimp cannot be overruled. In upland soil, significant variation in available cadmium was not reported among the months and soil samples from all land uses recorded very low in available cadmium content (table 24b).

5.1.2.15.3. Available chromium

Temporal variation in available chromium of lowlands soil was non-significant. According to WHO/FAO (2001), cadmium toxicity occurs when cadmium concentration is above the recommended maximum concentration of 3 mgkg^{-1}. Chromium toxicity was reported in Paddy- shrimp (3.679mgkg^{-1}) and shrimp alone (3.256mgkg^{-1}) land uses from Ezhikkara, mangrove (3.519mgkg^{-1}) from Kottuvally and paddy-shrimp (4.284mgkg^{-1}) from Kadamakudy (table25a). Disposal of industrial waste into the river might be the reason for cadmium toxicity. Possibility of accumulation of heavy metals through Periyar River from Eloor-Edayar industrial belt cannot be ignored in this context. All the soil samples from upland soils were below the recommended maximum concentration of available chromium (3 mgkg^{-1}) (table 25b).

5.1.2.15.4. Available lead

Lead is a well known metal toxicant and the variation in available lead in lowland (0.093 to 0.123mgkg^{-1}) and upland soils (0.098 to 0.155mgkg^{-1}) were non-significant among the months (tables 26a and 26b). Most of the soil samples from different land uses in both lowlands and uplands were absent in available lead and all others below the recommended maximum concentration of available lead (50 mgkg^{-1}) as per WHO/FAO (2001).

5.1.2.15.5. Available cobalt

Being a beneficial element, that can promote plant growth, the soil status of available cobalt was quantified both in lowlands and uplands and was found to vary from 0.702 (August) to 0.786mgkg^{-1} (April) and 0.198 (June) to 0.295mgkg^{-1} (April) respectively (tables 27a and 27b). Even the variation in available Co was very negligible. Mobilization of available cobalt in April was high and it might be due to low soil reaction (Zhang*et al.*, 2009). Among land uses, shrimp alone in Kadamakudy (1.698mgkg^{-1}) and paddy-shrimp in Kottuvally (0.450mgkg^{-1}) recorded highest values of available Co in lowland and upland soil respectively. All the soil samples were below the recommended maximum concentration of available cobalt (24 mgkg^{-1}) as per Crommentuijn*et al.*(1997).

5.1.2.15.6. Available arsenic

Available arsenic in lowland and upland soils were very low which was below the recommended maximum concentration of available arsenic (20 mgkg^{-1}) as per WHO/FAO (2001). The values ranged from 0.106 (October) to 0.194 mgkg^{-1}(April) and 0.043 (June) to 0.073 mgkg^{-1} (April) in lowland and upland respectively (tables 28a and 28b). Higher solubility of arsenic content in April indicated the acidic soil reaction where the solubility of arsenic was high (Chuan*et al.*, 1996). Fallow land (0.290mgkg^{-1}) in Ezhikkara and paddy alone in RRS, Vyttila (0.240mgkg^{-1}) recorded highest values of available arsenic in lowland and upland respectively. Higher values of arsenic content in lowland compared to upland might be due to the availability of more reduced form of arsenic in waterlogged condition.

5.1.2.15.7. Available mercury

Mercury is regarded as a phytotoxic and genotoxic metal. In the present investigation, available mercury was present in miniscule amount in both lowland and upland soils. Among the heavy metals studied, mercury was the least abundant one. The highest values were 0.007mgkg^{-1}(April) and 0.013mgkg^{-1} (April) in lowland and upland soil respectively (tables 29a and 29b). The low concentration of mercury detected in both lowlands and uplands compared to other heavy metals can be attributed to the fact that Hg easily evaporates into organo-mercury forms (Yogesh, 2000). All the soil samples from different land uses were below the recommended maximum concentration of available mercury (2 mg kg^{-1}) as per WHO/FAO (2001).

5.1.2.16. Exchangeable cations and cation exchange capacity

Cation exchange capacity of lowland *Pokkali* soil across the seasons has been given in the table 39a and the data disclosed that it varied from 7.18 (February) to 9.57 cmol(+) kg^{-1} (October). Higher cation exchange capacity in October (neutral pH) and lower CEC in April (acidic pH) points out the positive relationship of CEC with soil pH. The mean value of barium chloride (0.01 M) extractable sodium and aluminium was very high inApril (588.47 mgkg^{-1}and 98.34 mgkg^{-1}) compared to October (372.93 mgkg^{-1}and 58.26 mgkg^{-1}). This can be attributed to the sea water inundation into the field during high saline phase. Exchangeable iron, manganese, copper and zinc were higher in April than October might be due to the acidic soil pH. Iron was the dominant exchangeable cation among the micro nutrients while zinc, manganese and copper were negligible as evidenced by their very low values. Highest cation exchange capacity was observed in shrimp alone land use in Kottuvally.

In upland soils, cation exchange capacity showed non significant variation throughout the seasons(table 39b). All the exchangeable cations were lesser in uplands against lowlands. Sea water inundation into the field and presence of high amount of clay percentage might have led to higher exchangeable cations in lowlands than uplands. Land uses didn't show any direct effect on CEC of soil.

5.1.2.17. Anion exchange capacity (AEC)

The positive charges associated with the surface of kaolinite, iron and aluminium oxides and allophane attract anions, such as chloride and nitrate and this phenonmenon is called as anion exchange capacity of the soils and usually AEC decreases with rise in pH which was true in this research work also as reflected from the data on AEC of *Pokkali* (table 40a). A non significant variation in anion exchange capacity was observed across the seasons. The higher values of AEC in *Pokkali* soils might be due to the presence of kaolinite clay minerals in soil. Kaolinites can have an AEC as high as 40 cmol(e^-)kg^{-1} at pH 4.7 (Schell and Jordan, 1959). Upland soils exhibited lower values of anion exchange capacity compared to lowland soils (table 40b) due to the lower clay percentage in upland soils compared to lowland soils.

Fig.20. Temporal variation of exchangeable cations in lowlands

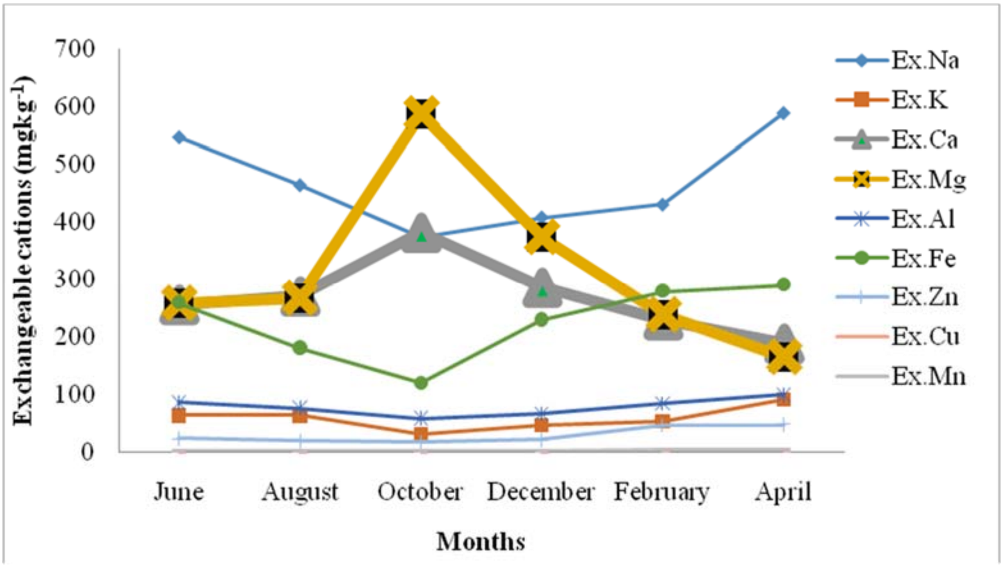
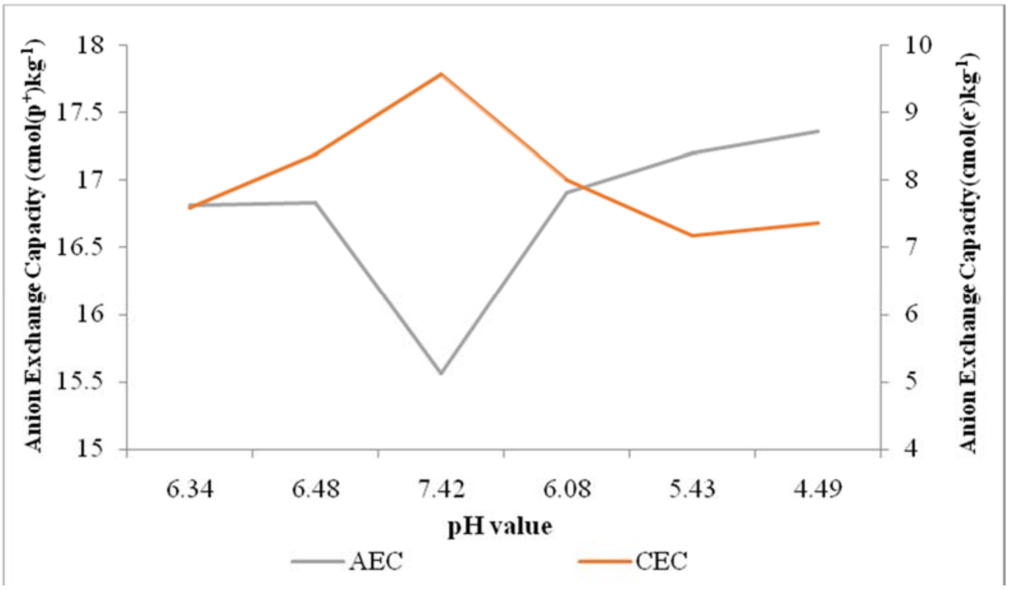


Fig.21. CEC and AEC with varying soil pH

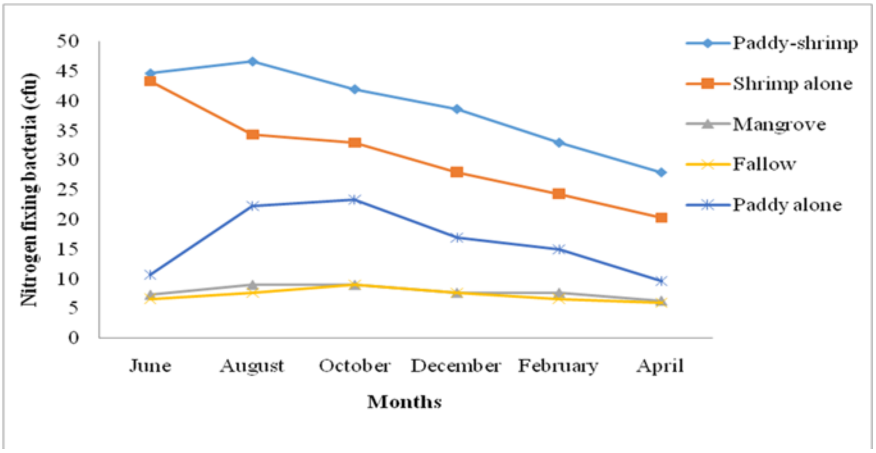


5.1.3. Biological properties

5.1.3.1. Population of nitrogen fixing bacteria (NFB)

Nitrogen fixing bacteria plays a crucial role in improving soil fertility while considering the process of nitrogen fixation in soil. Population of NFB in lowland (figure 22) and upland soils (table 41b)ranged from 14.07x10^3 (April) to 24.00x10^{3}cfu (August) and 7.67 x10^3 (April) to 18.47 x10^{3}cfu (June) respectively across the months. It was noticed that high salinity on February and April, adversely affected the population of NFB in both lowland and upland soils. Kayasth *et al* (2014) reported that counts of free living NFB decreased from 6.12 to 3.70 log cfu gram^{-1} soil with increasing salinity level (2 to 16 dSm^{-1}). More number of NFB observed in waterlogged soil than upland soil might be due to the tendency of wetland system to shift towards the neutral pH throughout the year. Among land uses, paddy-shrimp land use (83.67x10^{3}cfu) in Kadamakudy and mangrove (30.83x10^{3}cfu) in Kottuvally were reported with the highest number of nitrogen fixing bacteria in lowland and upland soils respectively.

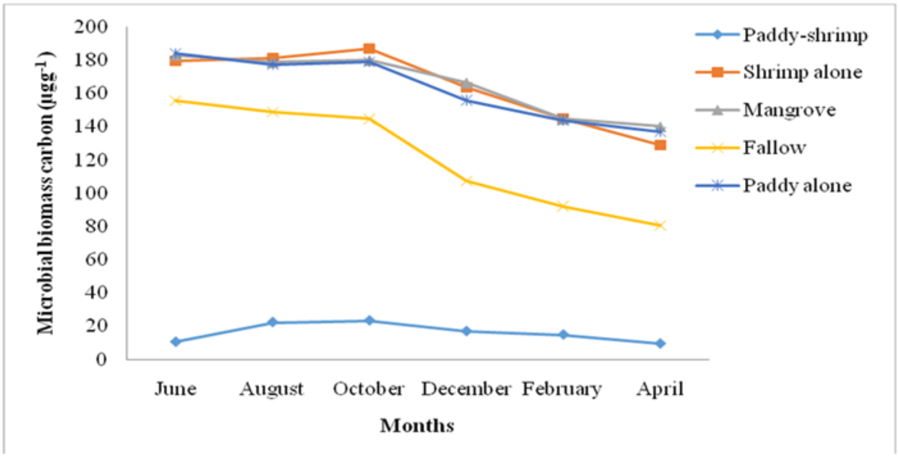
Fig.22. Temporal variations of NFB under different land uses



5.1.3.2. Microbial biomass carbon (MBC)

Microbial biomass carbon is a measure of the carbon contained within the living component of soil organic matter. In the present study, MBC ranged from 175.08 to 117.82 µgg^{-1} and 82.86 to 62.42 µgg^{-1} in lowlands (figure 23) and upland (table 42b) respectively. The trend of decreasing MBC from low saline phase (June to October) to high saline phase (December to April) might be due to the combined effect of high acidity and salinity during high saline phase. Inverse relationship of salinity with microbial biomass carbon during all the seasons in acid saline soils of Goa was reported by Mahajan*et al*.(2015), which was in line with that reported by Iwai (2012). Least microbial biomass carbon in fallow lands in Ezhikkara, Kottuvally and Kadamakudy might be due to the negative impact of toxic substances accumulated in the fallow land.

Fig.23. Temporal variations of MBC under different land uses



5.1.3.3. Dehydrogenase enzyme activity (DEA)

Being the biological indicator of soil fertility, analysis of dehydrogenase enzyme has an important role in fertility status of *Pokkali* soil. Very high status of dehydrogenase enzyme activity was observed in both lowland (1673.41 to 4892.13 µgTPFg^{-1}day^{-1}) (figure 24) and upland soil (245.41 to 994.19 µgTPFg^{-1}day^{-1}) (table 43b). But the activity of enzyme was less in upland soil compared to lowland soil(figure 25) emphasizing that flooded condition favours dehydrogenase activity (Beena *et al*., 2017). High salt content coupled with acidity during the high saline phase caused a negative impact on enzyme activity in both upland and lowland soil. Among land uses, mangrove (4053.17µgTPFg^{-1}day^{-1}) and paddy-shrimp in Kottuvally (2089.73µgTPFg^{-1}day^{-1}) recorded highest enzyme activity in lowland and upland soils respectively.

Fig.24. Temporal variations of DEA under different land uses

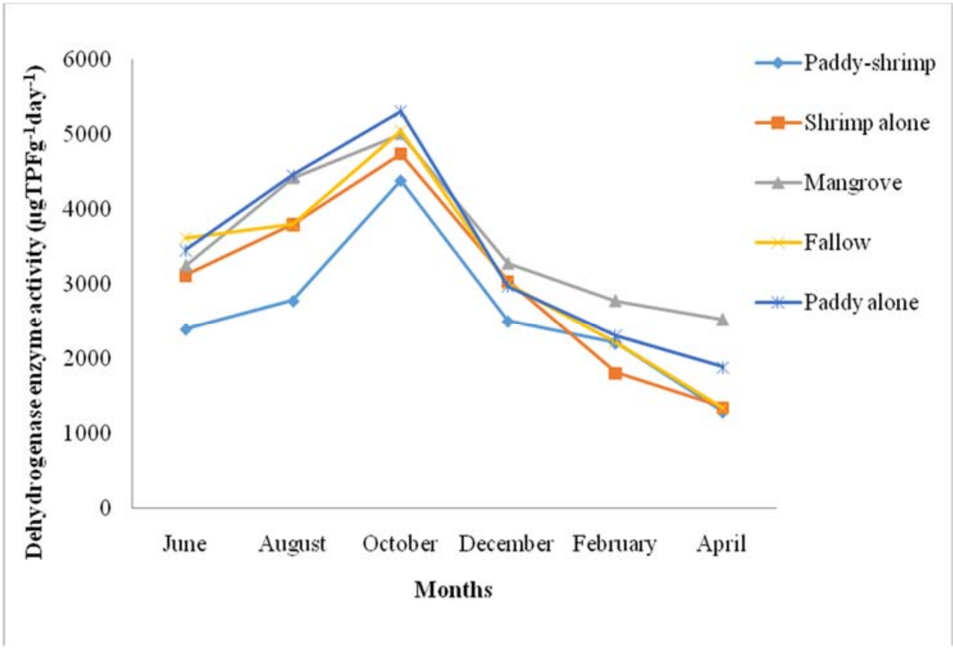
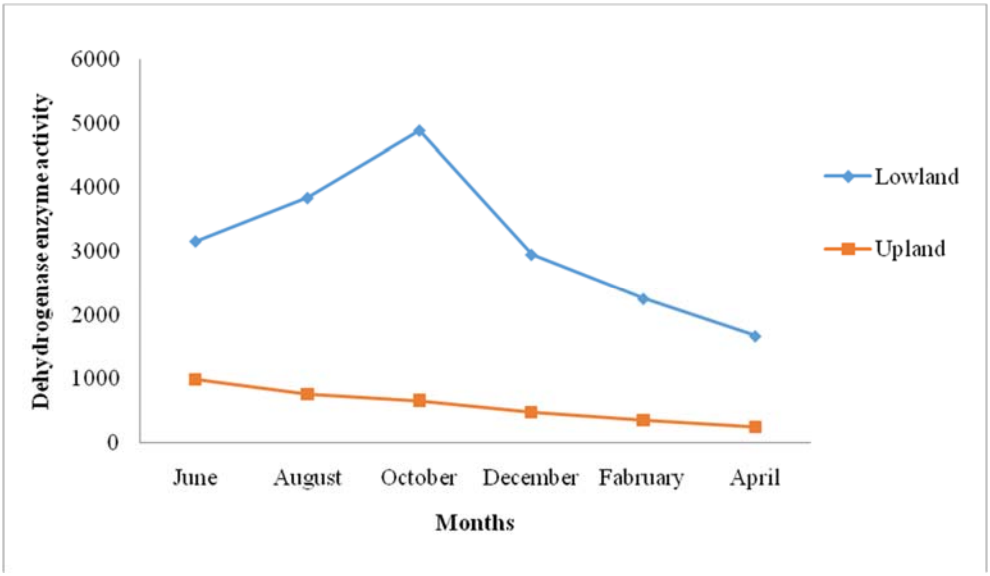


Fig.25. Temporal variations of DEA in lowlands and uplands



5.2. Water analysis

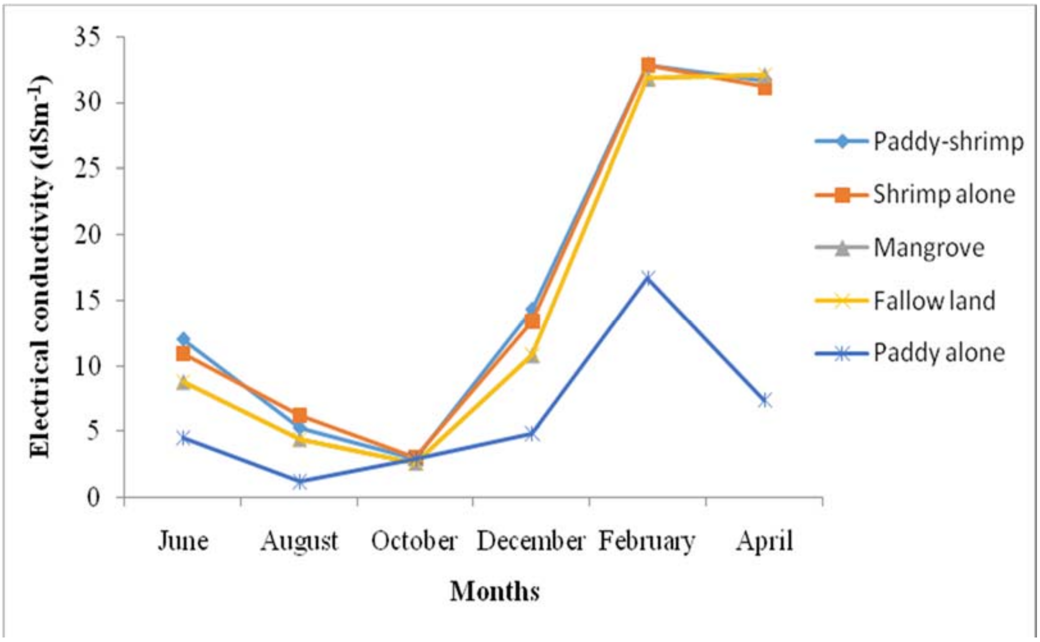
5.2.1. pH

As shown in tables 44a and 44b, pH of field and source water varied from 7.18 (October) to 8.11 (December) and 7.33 (August) to 8.01 (December) respectively. Drastic variation in pH was not detected in both field and source water. Higher values of pH were observed in the month of December. This can be attributed to higher bicarbonate concentration on December in both field and source water. As the bicarbonate concentration increases pH of sea water also increases but not beyond pH of 9.0 (Zeebee, R. 2006). The bicarbonate and carbonate ions are responsible for the buffering capacity of seawater.

5.2.3. Electrical conductivity (EC) and Total soluble salt (TSS)

The conductivity of a solution depends on the concentration of all the ions, greater their concentrations, the greater the conductivity. Across the months, the EC values ranged from 2.78 (October) to 29.33 dSm^{-1}(February) in field water (figure 45a) and 2.04 (October) to 26.69 dSm^{-1} (February) in source water (table 45b). Temporal variation of electrical conductivity decreases from June to October and increases from December to April. This variation can be explained by the presence of higher concentration of soluble salt in water samples during high saline phase. The cations (calcium, magnesium, sodium and potassium) and anions (borate, sulphate, phosphate and chloride) quantified in the water samples in this present investigation showed the same pattern as electrical conductivity followed. The decrease in EC values during low saline phase can be related to the South West monsoon.

Fig.26. Temporal variations of EC in field water



Water having the EC value of greater than 3dSm^{-1} is not suited for irrigation purpose (Talabi *et al.*,1974). Paddy alone land use in RRS, Vyttila showed an EC value of greater than 3 in the month of June which was the initial stage of the crop. Later, EC value decreased (<3) upto the harvest of crop (October) creating a favourable environment for crop growth.

A positive relationship was noticed between the total soluble salt and electrical conductivity. Higher TSS values were observed during high saline phase (7749.9 to 18773 mg L^{-1}) than low saline phase (1778.4 to 5599.5 mg L^{-1}) in field water due to saline water intrusion into the field. The highest value of TSS was reported on February as 18773 mg L^{-1} and 17079 mgl^{-1} in field and source water respectively (table 46a and 46b). This can be ascribed to increased evaporation rate of field and source water during summer.

5.2.4. Concentration of cations

The mean concentration of water soluble calcium (figure 27), magnesium (figure 27), sodium (figure 28) and potassium (figure 27) were found to be higher during high saline phase (December to April) than low saline phase (June to October) in field water. This can be assigned to the saline water inundation into the field during high saline phase. Concentration of all the cations except magnesium, was highest in February (calcium-222.91 mg L^{-1}, sodium-7157.2 mg $L^{-1}$and potassium-279.47 mg L^{-1}) which was on par with the month of April (calcium-222.25 mg L^{-1}, sodium-6713.6 mg $L^{-1}$and potassium-271.03 mg L^{-1}). Magnesium was highest in April (782.8 mg L^{-1}) followed by February (746.0 mg L^{-1}).

In the source water, all these cations were at peak level inFebruary (calcium-219.57 mg L^{-1}(table 47b), magnesium-792.3 mg L^{-1}(table 48b), sodium-6513.5 mg L^{-1}(table 49b), and potassium-261.45 mg L^{-1}(table 50b) followed by April (calcium-203.72 mg L^{-1}, magnesium-774.3 mg L^{-1}, sodium-6306.5 mg L^{-1} and potassium-252.09 mg L^{-1}). Higher concentration of cations in dry season (February-April) can also be related with high evaporation rate. Land uses did not show any direct effect on concentration of cations in field and source water.

5.2.5. Concentration of anions

The concentration of bicarbonate (tables 51a and 51b), Nitrate (tables 52a and 52b), Phosphate (Tables 53a and 53b) and borate (tables 54a and 54b) did not show much variation between low saline and high saline phases. Whereas concentration of chloride (figure 55a and table 55b and 104) and sulphate (figure 27, table 56a and 56b) in field (1171 to 12878 mg L^{-1} for chloride and 74.61 to 435.54 mg L^{-1} for sulphate) and source water (106 to 12094 mg L^{-1} for chloride and 71.70 to 499.62 mg L^{-1} for sulphate) showed the temporal variation markedly. The high values of chloride and sulphate during high saline phase could be credited to contributions from the saline water from the Arabian Sea. Land uses didn’t show any direct effect on concentration of anions in field and source water.

Fig.27. Temporal variations of Ca^{2+}, $Mg^{2+,}$ K^+ and SO_4^{2-} in field water

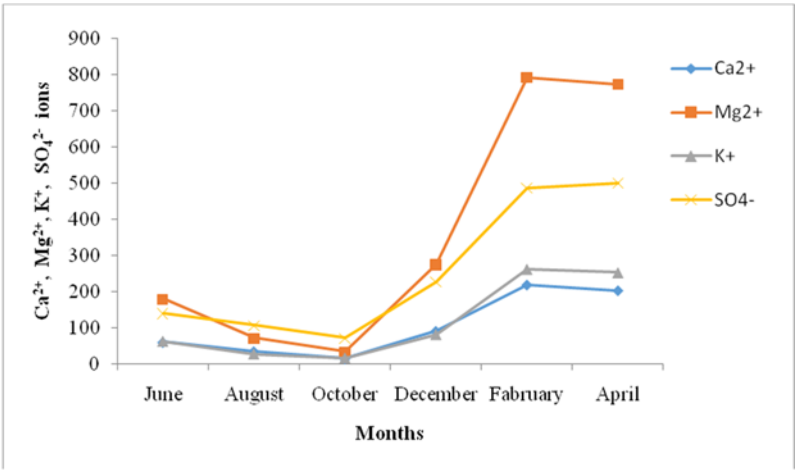
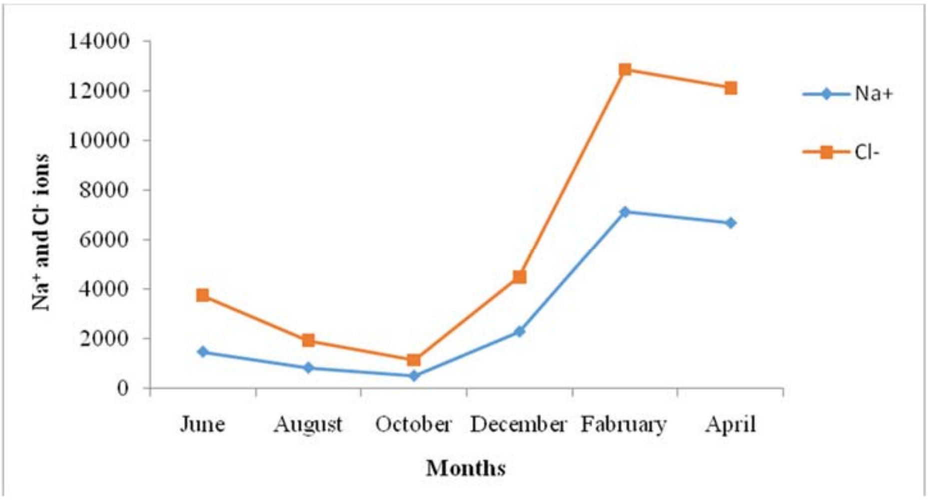


Fig.28. Temporal variations of Na^+ and Cl^- in field water



5.2.6. Heavy metals

All the heavy metals (nickel (table 57a and 57b), chromium (table 58a and 58b, lead (table 59a and 59b), cobalt (table 119 and 120), arsenic (table 63a and 63b) and mercury (table 61a and 61b) were below the detectable limit. Cadmium was detected below the recommended maximum concentration ($0.010 mgL^{-1}$) as per FAO/WHO (2001) in field and source water (tables 62a and 62b).

5.3. Weather parameters

5.3.1. Average rain fall

The principal rainy seasons in Kerala are South-West monsoon (June-September) and North-East monsoon (October-November). The pre-monsoon months (March-May) account for the major thunderstorm activity in the state and the winter months (December-February) are characterized by minimum clouding and rainfall. The average rainfall received in various months during soil sample collection in 2017 can be represented in the order August> June> October> April> February> December for Ezhikkara and Kottuvally. In Kadamakudy and Vyttilathis order can be rearranged as October>August>June> February> April> December (figure 29**).**

5.3.2. Relative humidity

Relative humidity expresses the amount of water vapour present in air in percentage. Highest relative humidity was recorded in June (wet season) and the lowest in February (dry season) (figure 30) in all the locations. Relative humidity maintained a positive relationship with rainfall.

Fig.29. Average rainfall (mmday^{-1}) in locations during soil sampling

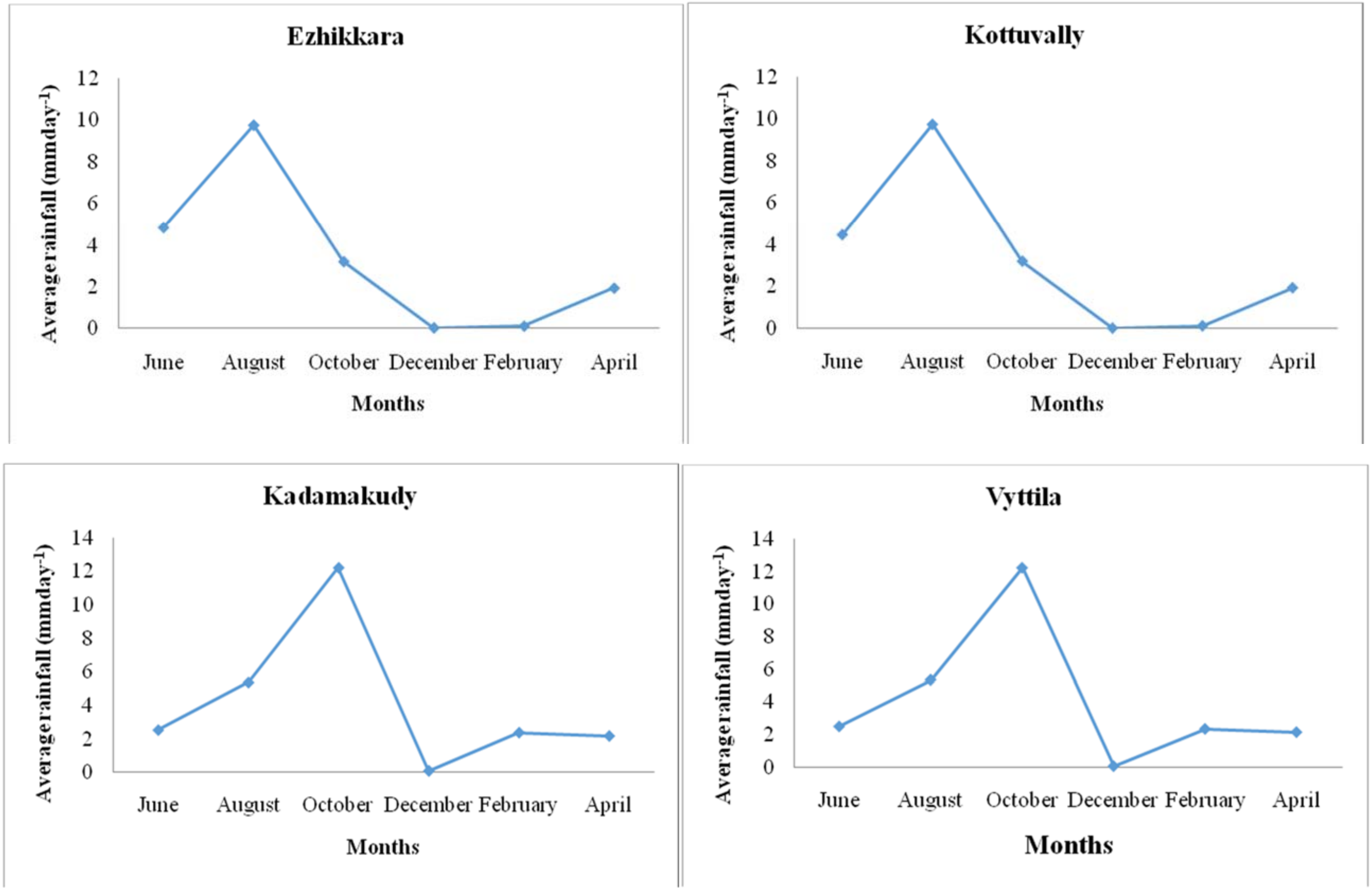
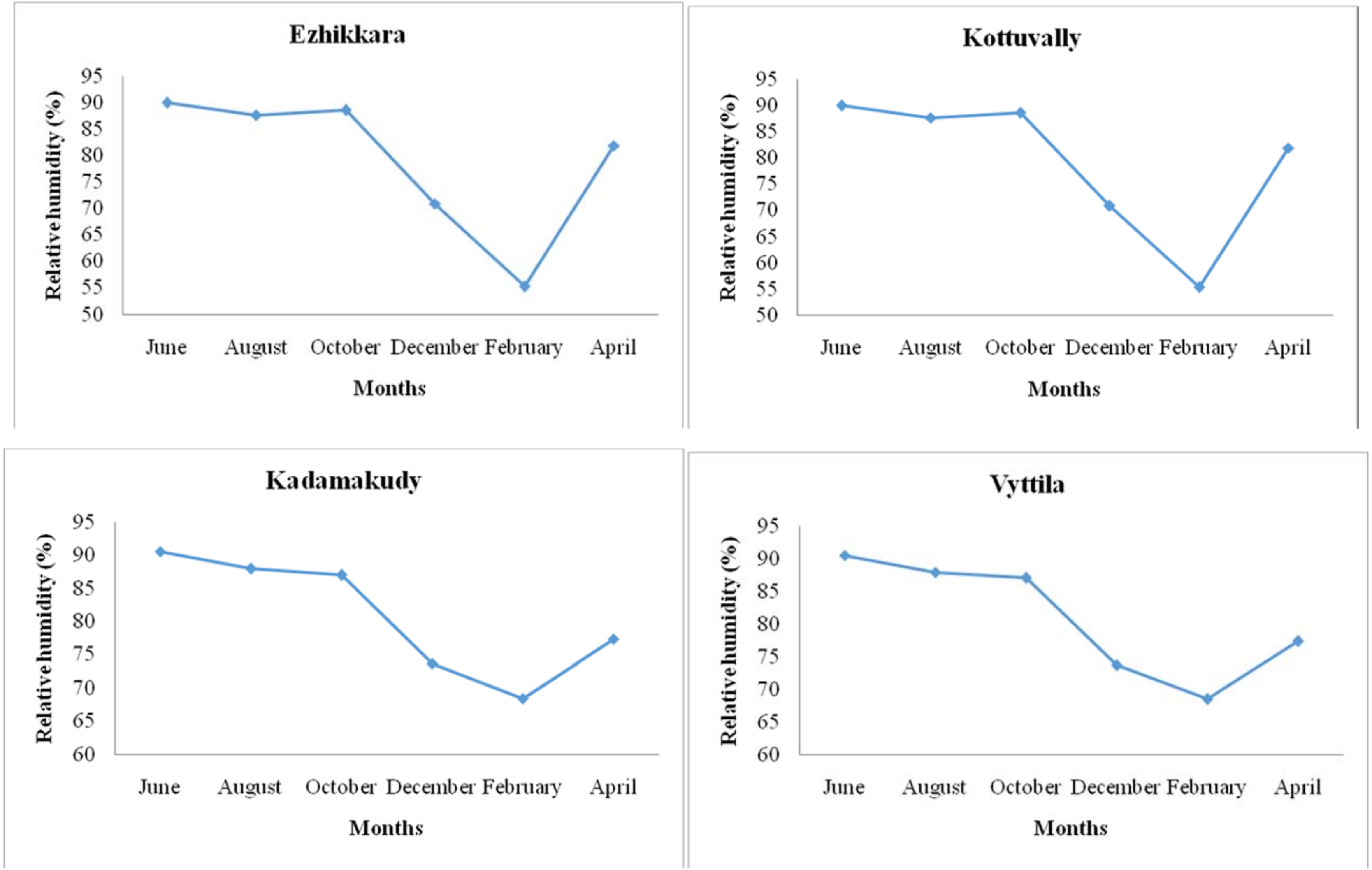


Fig.30. Relative humidity in locations during soil sampling



5.4. Correlation study

The relationship between different soil parameters were studied through correlation analysis and the results are interpreted in the background of similar studies conducted elsewhere. The unique caharacteristics of *Pokkali* soils viz; low pH, high Ec, high content of bases and acidic cations like Fe,Al and Zn would have vitiated the data to certain extent at least in a few cases.

5.4.1. Relationship between electro-chemical properties and nutrient status of the lowlands

Soil pH is negatively and significantly correlated with redox potential, electrical conductivity and available nutrients except available phosphorus in lowland soil (table 66). Negative correlation of soil pH with electrical conductivity might be due to the abundance of soluble salts of calcium, magnesium and potassium gaining entry through marine influence and high content of exchangeable iron and aluminium.

In this investigation, negative correlation between soil pH and micro nutrients are justifiable because, acidic condition in soil promotes the solubility of micro nutrients. Whereas, high content of major nutrients in acidic condition could be explained by the saline water inundation during high saline phase (December to April). Hindar *et al.,* (1994) reported that direct addition of Na^+ ion containing solution resulted in an exchange of Na^+ ion with H^+ and Al^{3+} ions, causing acidification. Earlier studies in wetland soils and sediments have reported a decrease in pH with increasing salt concentration (Khattak *et al.,* 1989).

Except available phosphorus, all nutrients were positively correlated with electrical conductivity. Saline water intrusion into the fields during high saline phase (December to April) caused high nutrient status during this period. The decrease in available phosphorus from low saline phase to high saline phase might be due to the precipitation of available phosphorus with iron and aluminium in acidic condition (high saline phase). This reason also defends the highly significant and negative correlation of available phosphorus with EC.

5.4.2. Relationship between electro-chemical properties, exchangeable cations, anion exchange capacity and nutrient status of lowlands

Soil pH and anion exchange capacity were significantly and negatively correlated (table 67). Increase in pH increases the negative charge and decreases the positive charge on surface and hence CEC increased and AEC decreased with increase in pH (Shamshuddin and Ismail, 1995).

Positive correlation of exchangeable sodium with electrical conductivity revealed the contribution of sodium salt towards increasing electrical conductivity. Also the positive correlation of exchangeable sodium with available nutrients (available potassium, calcium, magnesium, iron, magnesium and boron) might be due to the marine influence.

Negative correlation of exchangeable calcium with electrical conductivity indicated the rise in electrical conductivity during high saline phase which decreased the exchangeable calcium in soil which subsequently could have got exchanged with sodium and other cations following sea water intrusion.

Positive correlation of soil pH with exchangeable calcium, magnesium, potassium and copper paved way to higher cation exchange capacity in October (low saline phase) than April. During high saline phase (acidic condition), these exchangeable cations were found to be decreased. But, at the same time, the available calcium, magnesium and potassium were very high during high saline phase due to marine influence.

Negative correlation of exchangeable aluminium with soil pH revealed the role of exchangeable aluminium in decreasing soil pH. Negative correlation of exchangeable aluminium and available phosphorus explain the reason for the lower availability of phosphorus during high saline phase (lower soil pH). Phosphorus would have precipitated with aluminium and iron in acidic condition of the soil.

5.4.3. Relationship between the weather parameters, biological and chemical properties of lowlands

High rainfall leads to leaching loss of bases from top soil and increasing acidity of soil. This is evident in this study from the positive correlation of soil pH and rainfall (table 68). Available potassium, calcium, magnesium and boron were negatively correlated with rainfall. These nutrients were susceptible to leaching losses during S-W monsoon (low saline phase) and their lower concentration was lower during low saline phase compared to high saline phase.

The positive correlation of dehydrogenase enzyme activity to soil pH and its negative correlation to high salinity level inversely affected the overall activity of the enzyme dehydrogenase in *Pokkali* soil.

5.4.5. Relationship between electrochemical properties and nutrient status of uplands

Positive and significant correlation of soil pH with available potassium, calcium and magnesium clearly showed the less availability of these nutrients in acidic soil pH (table 69). Negative correlation of soil pH with available iron specified the less solubility of iron in neutral pH. Positive correlation of organic carbon with total nitrogen was suggestive of the high fertility status of *Pokkali* soil. Available phosphorus was negatively correlated with available zinc and iron which explained the precipitation of available phosphorus with available zinc and iron in acidic pH. Positive correlation of electrical conductivity with available potassium, magnesium, sulphur copper and boron supported the contribution of salt of these nutrients towards the soil salinity.

5.4.6. Relationship between textural fractions, exchangeable cations and chemical properties of uplands

Positive relation of clay content with organic carbon, total nitrogen, available potassium, magnesium, iron and boron ensured the role of exchangeable sites of clay minerals in nutrient availability of soil (table 70). Available nutrients have significant and positive correlation with CEC and negative correlation with AEC. The significant and negative correlation of exchangeable zinc with available phosphorus signified the association of phosphorus with zinc. The precipitation of Phosphorous with zinc would have been aggravated by the acidic condition of soil prevailing in *Pokkal*i tracts.

5.4.7. Relationship between weather parameters, biological properties, electro-chemical properties and nutrient status of uplands

Positive relation of soil pH with biological properties reflected the promotional effect of higher pH on biological activity, especially while shifting towards neutral range (table 71). Negative correlation of electrical conductivity with biological properties implied that salt content adversely affected the biological properties of soil. Positive and significant correlation of relative humidity with nitrogen fixing bacteria, dehydrogenase enzyme activity and microbial biomass carbon would mean that humidity promotes the growth of biological organisms and their activity in *Pokkali* soil.

5.4.8. Relationship between chemical properties of field water, source water and lowlands

Significant and positive correlation of water pH with bicarbonate in field water (table 72) was in conformity with the result of Zeebee (2006)that, bicarbonate concentration increases pH of sea water but not beyond pH of 9.0. All the cations and anions except nitrate significantly and positively correlated with EC and TSS values thereby ensuring the contribution of cations and anions in the field and source water towards salinity build up(tables 72 and 73).

In source water, a positive correlation of pH with EC and TSS conveyed that increasing salinity leads to increase in water pH which was opposite to the reaction found in soil samples. The positive correlation of chemical properties of field water with source water (table 74) indicated the contribution of cations and anions from source water to field water.

Correlation between chemical properties of field water and lowland soils (table 75) depicted how the cations and anions present in the water samples influenced the soil properties. The positive and significant correlation of cations and anions in the water samples with soil EC and their negative but significant correlation with soil pH was well manifested in the present study. Also, all the cations and anions in the water samples significantly and positively correlated to all the available nutrients except available phosphorus which emphasised that marine influence elevated the content of all nutrients except phosphorus during high saline phase in *Pokkali* soil. High acidity resulted from salinity during high saline phase forms high amount of iron and aluminium which could be precipitated with available phosphorus.

While looking into the biological parameters in *Pokkali* soil, it could be seen that all the cations and anions present in the field water had negative and significant correlation with microbial biomass carbon and dehydrogenase enzyme activity (table 75) which disclosed the negative influence of salinity on biological activity.

5.2. Fractionation of phosphorus and copper in *Pokkali* soil

Spatial and temporal variation of soil pH was clearly evident in October and April months in the experiment 1, on characterisation of *Pokkali* soil. Soil samples from all the land uses were selected during October and April and subjected to fractionation study to understand the nutrient dynamics with varying salinity and soil pH levels across the seasons.

5.2.1. Fractionation of phosphorus

Temporal variation of all the P fractions was clearly evident in *Pokkali* soil (figure 31). All the fractions except water soluble and calcium phosphorus were higher during the month of April. The data on percentage distribution of P fractions in different land uses under various locations in *Pokkali* soil is depicted in figure 32 and 33. Among the fractions, water soluble fractions accounted for the least percentage from 0.32 – 1.32 % of total P in October and 0.02 to 0.21 % of total P in April. Whereas, the residual P contributed the highest percentage from 26.48 to 86.41 % of total P and 5.53 to 72.37 % of total P in October and April respectively. The values of water soluble P fractions were higher in October than April which pointed towards the availability of P in neutral soil pH. The high content of Fe-P (5.05 to 35.24 % of total P) and Al-P (3.69 to 11.84 % of total P) in April (high saline phase) pointed towards the precipitation of P with Fe and Al in acidic pH where the available P was found to be low compared to low saline phase. Birru (2000) revealed that limited availability of soil P to plants in intensively weathered and sesquioxide rich acidic soils might be attributed to high degree of P fixation and its precipitation as iron and aluminum phosphates.

High amount of Ca-P (2.48 to 11.04 % of total P) in October could be due to the marine influence. High organic matter mineralisation in neutral pH might have decreased the organic P fractions in the month of October which was contributed from

1.63 to 13.63 % of the total P. All the fractions except water soluble and Ca-P fractions present in higher quantity during the month of April. Very high content of water soluble calcium from saline water leads to precipitation of phosphorus with calcium in neutral soil pH which was reported in the month of October. The percentage contribution of calcium P was 2.64 to 16.62 % and 2.48 to 11.04 % of total P in October and April respectively. Occluded P contributed from 2.80 to 9.41 % of total P and 5.80 to 13.37 % of total P in October and April respectively. Higher amount of occluded P during the month of April indicated occlusion of P during the precipitation of Fe-P and Al-P. The order of arrangement of P fractions in descending order in the month of October and April was Fe-P > Ca-P > Org-P > Occl-P > Al-P > Ws-P and Fe-P > Occl-P > Org-P > Al-P > Ca-P > Ws-P correspondingly.

Spatial variation of different phosphorus fractions in *Pokkali* soil was depicted in figure 32 and 33. High content of organic P was observed in shrimp land use in all the location. This might be due to the high organic matter content in soil and the organic content in the feeding materials used for shrimp farming. The highest calcium P detected in shrimp alone land use in Ezhikkara, Kotuvally and Kadamakudy could be due to the deposition of shrimp shell in the field. But in the case of other P fractions like Fe-P, Al-P, Occlu-P and water soluble P, land uses didn't have any direct effect.

5.2.1.1. Correlation of phosphorus fractions with soil properties

Correlation coefficients between different fractions of P and correlation of P fraction with soil properties, exchangeable cations and AEC are shown in tables 77 and 78 respectively. Water soluble P and Al-P were found to be significantly and negatively correlated. Asmare *et al* (2015) found that exchangeable Al in intensively weathered and sesquioxide rich acidic ($pH < 5.5$) soils enters into the soil solution causing P deficiency through precipitation as Al-P. Significant and negative correlation of Fe-P, Al-P and occluded P with residual P disclosed the possibility of forming less residual P in acid soil where aluminium and iron are abundant. Significant and positive relation between Al-P and Fe- P could be explained by the high content of aluminium and iron in April (acidic pH). Positive and significant relationship of Fe-P with total P indicated contribution of Fe-P towards the total P in *Pokkali* soil.

Positive relationship of water soluble P and soil pH showed the availability of phosphorus in neutral pH. However, the negative correlation of micro nutrients viz., Zn, Cu, and Mn with water soluble P was a proof of their acidic soil pH.

Al-bound phosphorus was positively correlated with EC and negatively correlated with soil pH. High salt content in April decreased the soil pH resulting in the formation of Al bound P. Negative relationship of aluminium bound P with dehydrogenase enzyme activity and microbial biomass carbon evidenced that decrease in available P had negative impact on these biological parameters.

Positive correlation of calcium bound P and organic bound P with EC, available Ca, Cu and Mn was an indirect effect of both salinity and acidity in *Pokkali* soil. Acidic pH with high electrical conductivity in *Pokkali* soil during April caused high available Ca, Cu, Al, Fe and Mn which promoted the P precipitation during high saline phase

Negative correlation of organic P with available P indicates mineralisation of organic matter leading to formation of available P. Negative correlation of available P with Al-P and occluded P confirm the precipitation of phosphorus with aluminium and occlusion of P with Al-P and Fe-P precipitation respectively during the April. Positive correlation of Ca-P with available P might be due to the precipitation of calcium with P in neutral soil pH where available P was found to be high. This high amount of available P during October might be due to the release of P from iron, aluminium and occluded form. Here, it is interesting to notice that release of P from iron is very high than Ca-P formation in October which pointed towards the dominance of iron in *Pokkali* soil.

5.2.1.2. Contribution of fractions to available pool of phosphorus

Except Ca-P, available pool of phosphorus was significantly and negatively correlated to their respective fractions (table 77) and the path analysis showing the direct and indirect effect of different fractions on available pool through path coefficients offered a clear picture.

The path coefficients of different fractions of phosphorus in October as per table 79a, revealed the contribution of P fractions to available pool during October. Very high and negative direct effect of water soluble P to available pool indicated that water soluble P did not directly contribute to available pool whereas the indirect effect of Fe-P, Al-P, Org-P, and Occl-P to available P through water soluble P was very high and positive. At the same time, the direct effect of Fe-P, Al-P, Org-P, and Occl-P to available pool was negative. So it could be concluded thatt water soluble P might not be present alone in soil solution. It could be always in immediate equilibrium with Fe-P, Al-P, Org-P, and Occl-P. Very high and direct effect of organic matter bound P revealed that neutral soil pH favoured P mineralisation in *Pokkali* soil.

The path coefficients of different fractions of phosphorus in April were given in table 79b. Contradict to October, water soluble P made up direct and positive effect on available P. This could be due to the marine influence in *Pokkali* fields during high saline phase. The phosphate content in marine water might have directly contributed to available pool. Direct and negative effect of Fe-P, Occlu-P and organic P to available P indicated precipitation of P with iron, occlusion of P during sesquioxide formation and immobilisation of P mineralisation respectively under acidic soil pH. These things altogether reduced available P content during high saline phase which we have seen earlier in the first experiment, characterisation of *Pokkali* soil. The direct and high positive effect of Al-P to available pool might be due to the availability of freshly precipitated P with various Al hydrous oxide, though over time they become increasingly unavailable.

Fig.31. Temporal variation of phosphorus fractions

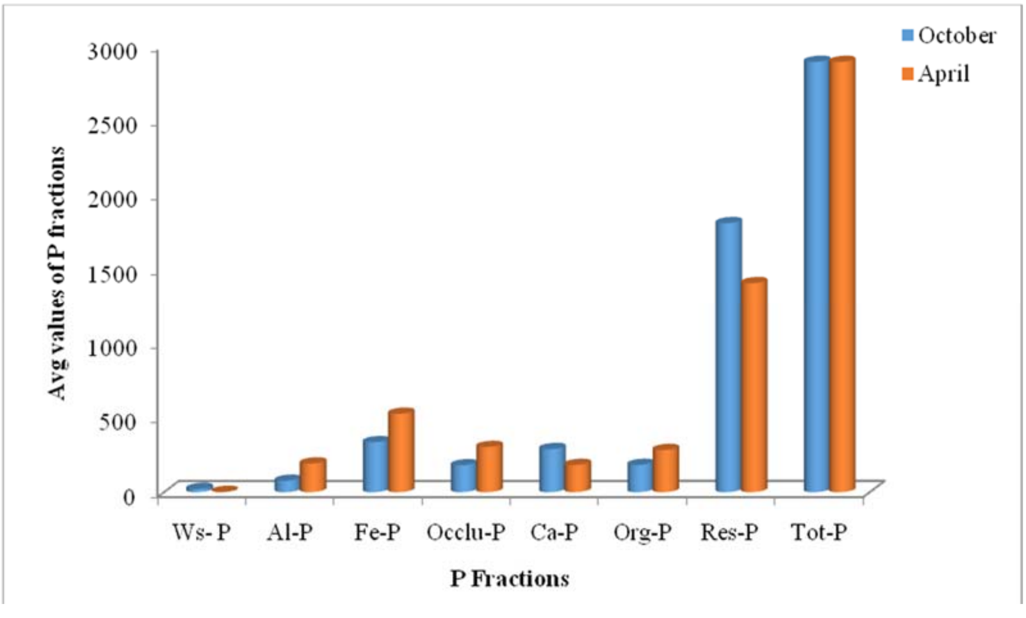


Fig.32. Spatial distribution of phosphorus fractions (%) in October

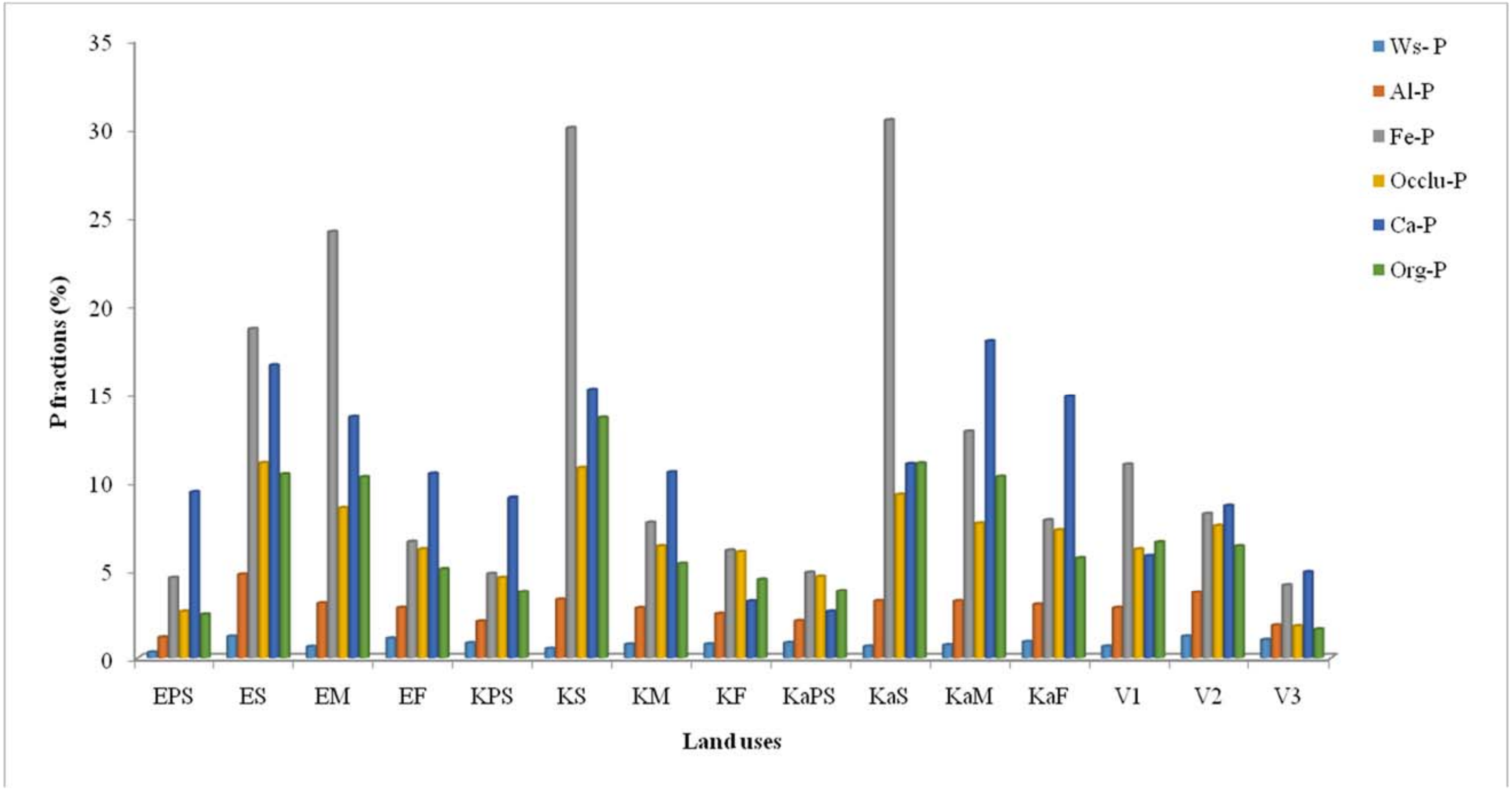
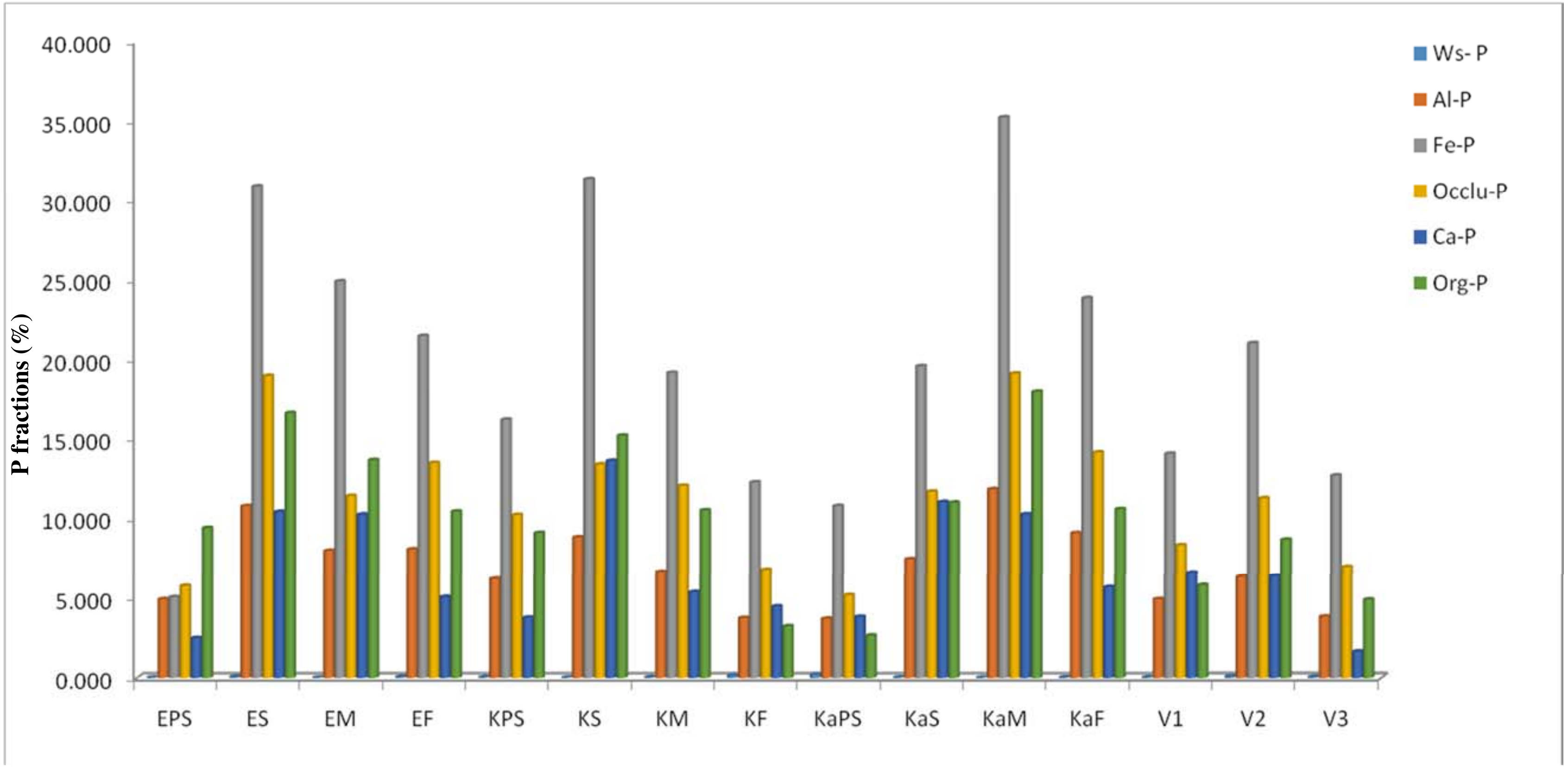


Fig.33. Spatial distribution of phosphorus fractions (%) in April



Land uses

5.2.2. Fractionation of copper

Spatial and temporal variations of copper fractions were clearly manifested in this investigation. Temporal variation of copper fractions represented in figure 34. Percentage distribution of various copper fractions in different land uses under various locations in *Pokkali* soil are presented in figures 35 and 36.

Water soluble Cu fraction is the most bio available and mobile form of copper in soils (Kuo *et al.,* 1983). Water soluble and exchangeable copper in April was found higher than that in October and it could be due to the acidic pH that prevailed during the high saline phase in April. Water soluble copper accounted for 0.67-9.47 % of total Cu in October and 4.41 to 34.8 % of the total Cu in April whereas, the corresponding values for exchangeable copper was 0.07 to 0.49 % in October and 1.84 to 8.83% in April.

Specifically adsorbed lead displaceable copper found to be high during October where neutral soil pH was observed. Specifically adsorbed lead displaceable copper comprised 5.08 to 9.32 % of total Cu in October and 0.52 to 1.68 % of total Cu in April.

The acid soluble fraction (Ac-s) is the measure of the potentially available/ non exchangeable forms present in soil (Mokwunye and Melsted, 1972). Acid soluble copper registered higher value in October and represented 4.57-12.80 % of total copper. Less amount of acid soluble copper in April could be due to high acidity of *Pokkali* soil during that period and the percentage value of acid soluble copper in April ranged from 0.90-3.84% of total Cu.

Manganese oxide bound Cu, amorphous FeO bound Cu and crystalline FeO bound Cu were recorded highest value during October when the soil pH moving towards neutral range favouring the precipitation of copper with oxides of manganese and, the amorphous and crystalline forms of iron. Manganese oxide copper made up 8.08-4 24.30% of total Cu in October and 0.44-1.29 % of total Cu in April. Amorphous and crystalline iron oxide Cu recorded 8.12-16.71% and 7.05-14.91% of total Cu in October and 0.59-1.54% and 0.59-1.91 % of total Cu in April respectively.

Residual copper was found to be highest during October and it contributed to 0.67-22.69 % of total copper in October and 22.40-79.73% of total Cu in April. Significant variation in total Cu was not observed between October and April. The mean per cent contribution of different fractions to total Cu in October and April followed as per the order

October

Org-Cu> Mn Oxide Cu > Residual> Amo-FeO-Cu > Cry.FeO-Cu > Aci-sol-Cu > Spe.ads.Pb-Cu > Ws-Cu > Ex.-Cu.

April

Residual >Ws-Cu> Org-Cu > Ex.-Cu. > Aci-sol- Cu > Cry.FeO-Cu > Spe.ads.Pb-Cu > Amo.FeO-Cu > Mn Oxide Cu

Pokkali soils are rich in organic matter content which was already reported in experiment 1. Organic matter in soil have high affinity towards copper which reflected in the copper fractions series reported in October. believed the high affinity of organic matter to copper is due to its high sorption capacity, as well its ability to chelation. Copper has a tendency to form stronger inner-sphere complex with soil organic matter (Alain and Anthoni, 2010). Next to organic matter, manganese oxide, residual, amorphous and crystalline oxides fractions dominated in October. Kabata-Pendias (2011) opined that the greatest amounts of adsorbed Cu have always been found in Fe and Mn oxides (hematite, goethite, birnessite) and amorphous Fe and Al hydroxides.

During high saline phase, acidic soil pH leads to dissolution of manganese oxide copper and, amorphous and crystalline iron oxides which resulted in very high water soluble copper in April. But most of the fractions were converted into residual form than water soluble forms during the high saline phase which resulted in highest peak of residual form during April.

Land uses did not show any direct effect on distribution of copper fractions. All the land uses showed same trend in copper fractions across the seasons. Organic matter bound phosphorus was the highest P fraction in all the land uses except Ezhikkara in October. Whereas Ezhikkara reported with the highest content of manganese oxide copper fraction followed by organic matter bound copper fraction. This might be due to the very high content of manganese oxide content in soils of Ezhikkara.

5.2.2.1. Correlation between copper fractions and correlation with soil properties

Correlation between copper fractions aredetailed in table 81 and correlation of copper fractions with soil properties are given in table 82. Significant and negative correlation of water soluble and exchangeable Cu with MnOx-Cu, Amo.FeO-Cu and Cry.FeO-Cu indicated less availability of copper owing to it getting precipitated with MnO and FeO in neutral soil pH. This result could further reaffirmed by the positive correlation of soil pH with MnOx-Cu and FeOx-Cu. The availability of copper was relatively low at pH 6.5 to 7 (Kabata–Pendias, 2011). The mobility of the majority of heavy metals becomes limited as pH increases, due to the precipitation of insoluble forms as hydroxides, carbonates and organic complexes. During high saline phase, acidity caused dissolution of iron bound copper, manganese bound copper and also acid soluble copper.

Negative correlation coefficient of water soluble and exchangeable fraction with soil pH confirmed the availability of copper in acidic soil pH. Significant and negative correlation of org-Cu with soil pH might be due to mineralisation of organic matter in neutral soil pH. Positive correlation of Aci.sol-Cu with soil pH could be due to increased solubility of acid soluble Cu in acidic soil pH.

Positive and significant correlation of water soluble and exchangeable Cu with electrical conductivity ensured the oceanic influence in *Pokkali* soil. Significant and positive correlation of water soluble Cu, exchangeable Cu and org-Cu with available Cu disclosed the role of these fractions into available pool of Cu.

5.2.2.2. Contribution of fractions to available pool of copper

The available pool of copper was significantly correlated to their respective fractions and the path analysis showing the direct and indirect effect of different fractions on available pool through path coefficients represents a better picture.

Path analysis of different fractions of copper in October (table 83a) revealed that exchangeable copper was the major fraction which contributes positively towards the available pool. Higher availability of exchangeable sites during October (neutral soil pH) than April (acidic soil pH) might have increased exchangeable fraction of copper in October and then positively contributed to available form. Next to exchangeable copper, specifically adsorbed Pb displaceable copper fraction, amorphous iron oxide fraction and acid soluble copper fractions showed direct and positive effect on available pool of copper. The negative effect of water soluble fraction to available pool indicated that water soluble copper always adsorbed onto other fractions. Except exchangeable copper fractions, all other fractions indirectly contributed to available pool through water soluble fraction which might be in immediate equilibrium with exchangeable copper in soil.

Table 83b explains contribution of various copper fractions towards available pool during April. Organic matter followed by water soluble fractions was the dominant copper fractions contribute toward available copper during April. McLaren and Crawford (1973) concluded that organic matter is the main reservoir of Cu availability for plants. Acidic soil pH prevailing in April might favour mineralisation of organic matter for copper. Sea water might have increased water soluble copper during April resulting high and positive effect to available copper. Acidity in *Pokkali* soil might have helped to dissolve crystalline iron oxide copper and acid soluble copper enabling copper into soil solution which caused high and positive direct effect of crystalline iron oxide copper and acid soluble copper to available pool.

Fig.34. Temporal variation of copper fractions

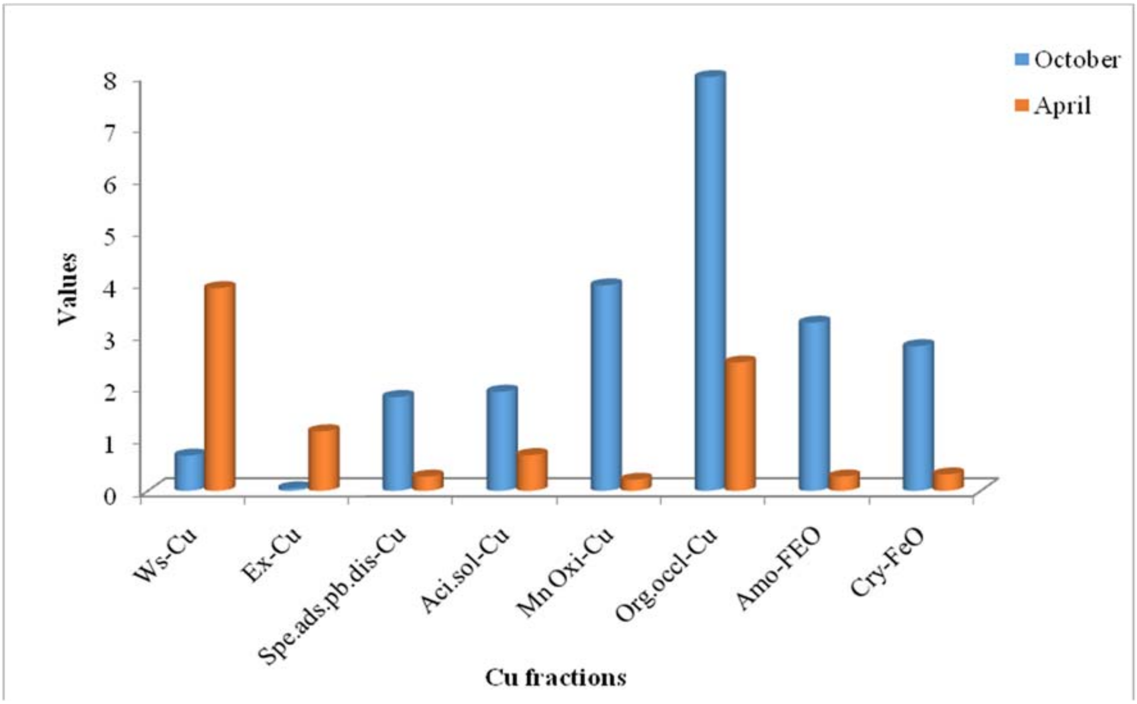


Fig.35. Spatial distribution of copper fractionsin (%) in October

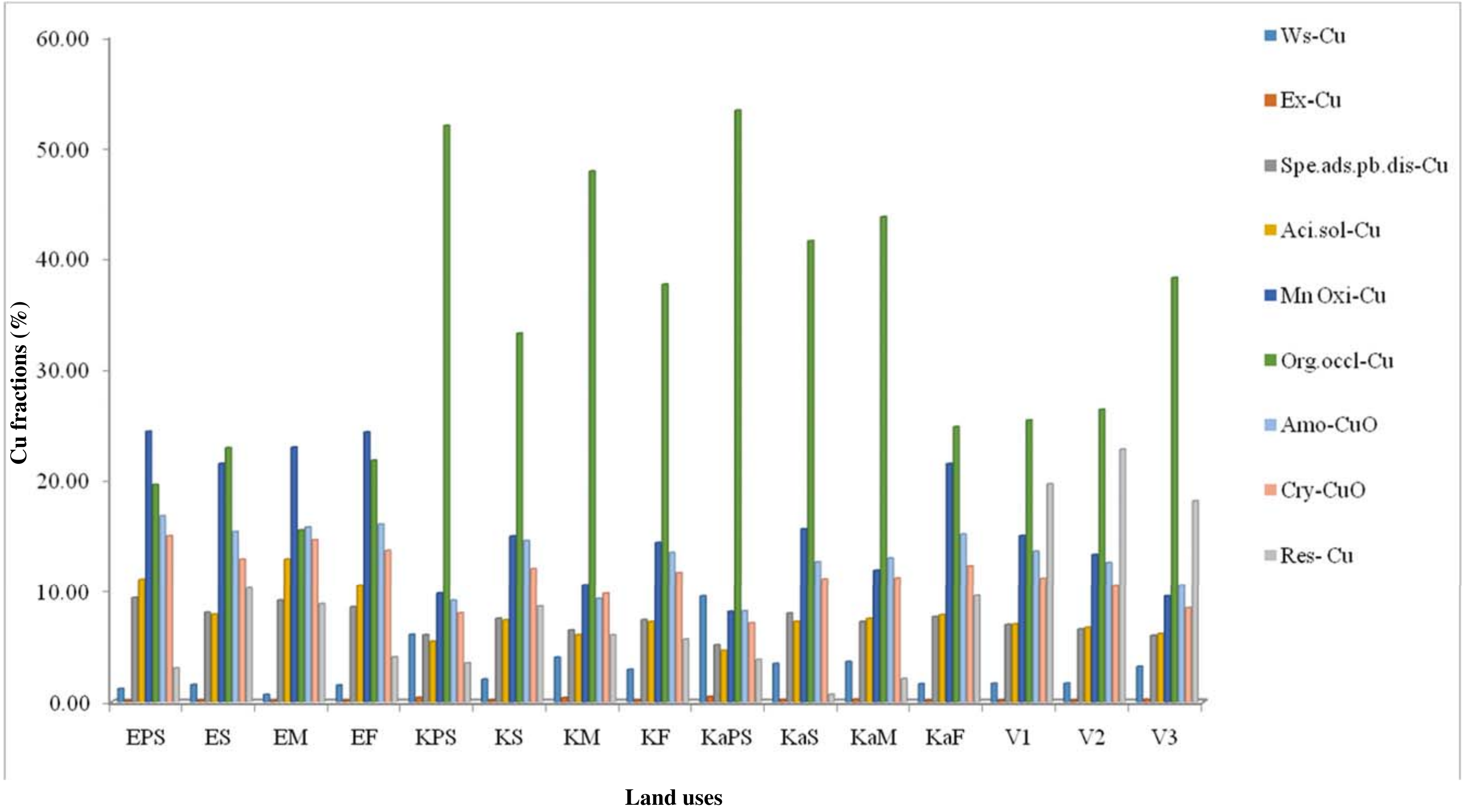
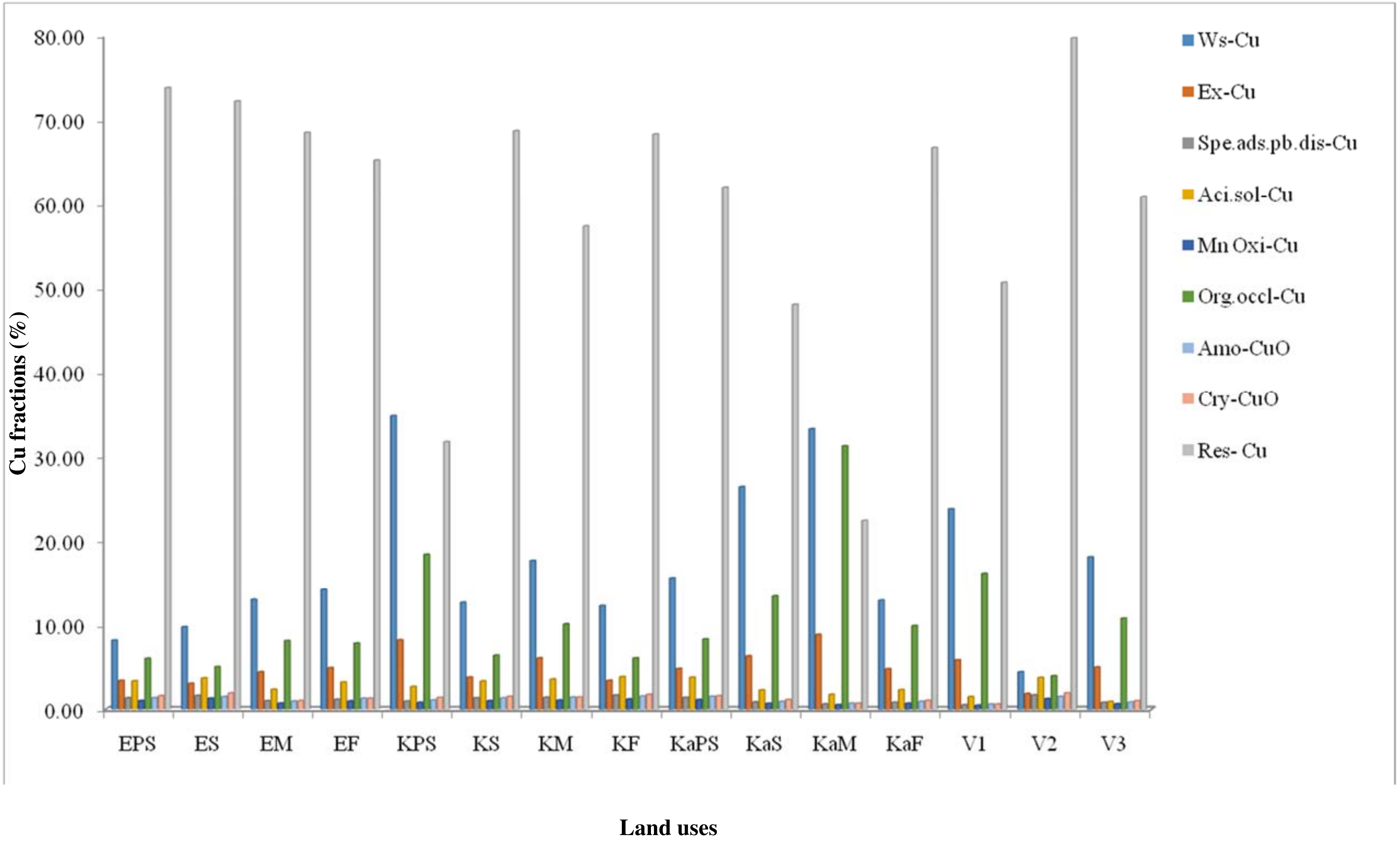


Fig.36. Spatial distribution of copper fractions (%) in April



3.1. Adsorption study

Adsorption study with respect to phosphorus and copper was carried out to unravel the chemistry behind the nutrient dynamics in *Pokkali* soil. The nutrients phosphorus and copper were selected to conduct adsorption study in *Pokkali* soil. Five soil samples having different textural classes namely clay, clay loam, sandy clay loam, loam and silt were opted for adsorption study to know the adsorption pattern of copper and phosphorus with varying texture of soil. Soil samples collectedin October (low saline phase) and April (high saline phase) were selected to understand the adsorption pattern of copper and phosphorus with seasonal change.

3.1.1. Adsorption study of phosphorus

3.1.1.1. Quantity intensity relationship

Soil samples were equilibrated with different concentrations of P as detailed in section 3.7. Measurement of phosphate potential (White and Beckett, 1964) is widely used to study the quantity-intensity relation of phosphorous in soil. This method can be used in soils where phosphate adsorption follows Schofields ratio law. This method cannot be used in Kerala soil because of specific adsorption nature of P with kaolinite and oxides and hydroxides of Fe and Al. Concentration of phosphorus in equilibrium solution after equilibration period was considered as intensity factor and the amount adsorbed per unit weight of the soil was considered as quantity factor like the way it was used in case of copper also in the present study. The Q-I curves were fitted with this data by plotting concentration of phosphorus in equilibrium solution in X axis and quantity adsorbed per unit weight of the soil in Y axis. The intercept and slope were computed from the best fit curve using regression analysis. The slope of the curve explains the buffer power.

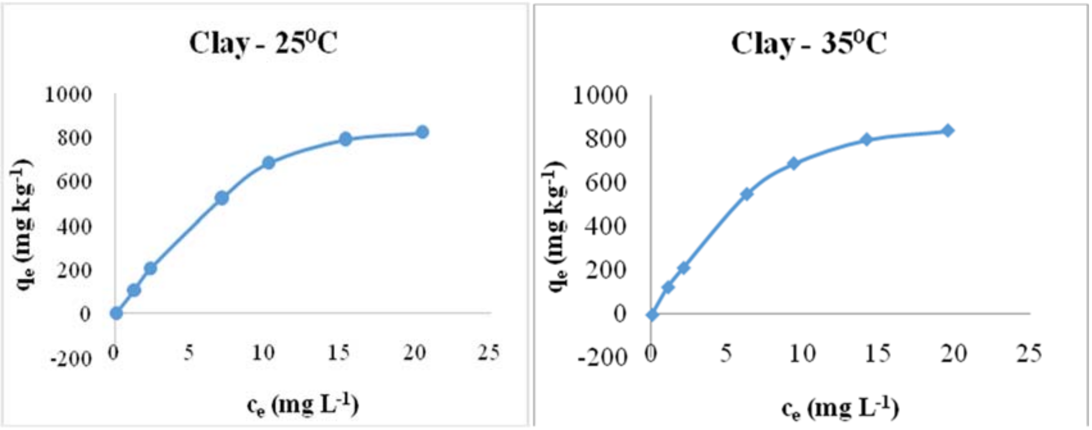
Buffer power is the change in quantity factor with respect to unit change in intensity factor ($\Delta Q/\Delta I$). Greater values of buffer power would mean that greater will be the ability of a given soil to release P from the exchange phase to the solution phase when P is depleted in solution phase and vice versa for P gain by the soil solution. The highest buffer power and maximum quantity adsorbed indicated by clay soil clearly indicated that these soils have got a greater power to retain phosphorus on solid phase and replenish its level in solution as and when it is depleted by the plant uptake or leaching losses.

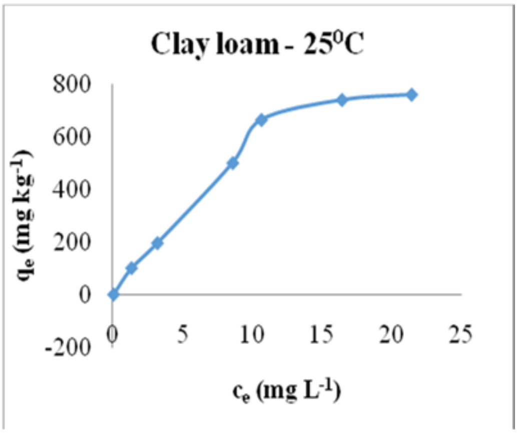
Q-I curve of representative soil samples are given in figure 37 and 38. L-shaped curve was obtained for low land soils of *Pokkali.* Such adsorption behavior could be explained by the high affinity of the adsorbent for the adsorbate at low concentrations, which then decreases as concentration increases (Sparks, 2003)

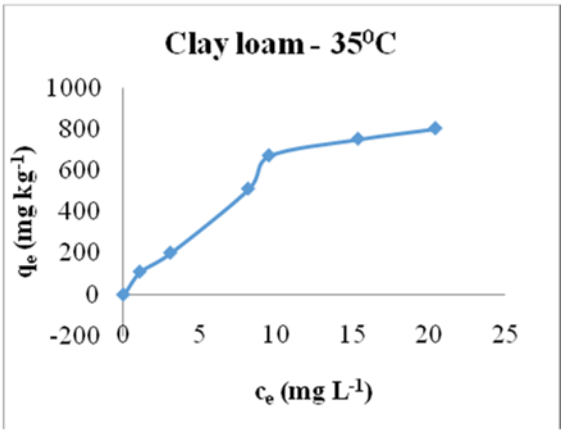
Positive intercepts of Q-I curves at 25^0C and 35^0C, indicate the requirement of a minimum amount of phosphorus at the solid phase below which there will not be any desorption. At 35^0C, the buffer power increased in *Pokkali* soil comapared to buffer power at 25^0C which indicated that the sites of adsorption are mainly inorganic *ie.* oxide and oxy hydroxide surfaces whose specificity might have enhanced at higher temperatures.

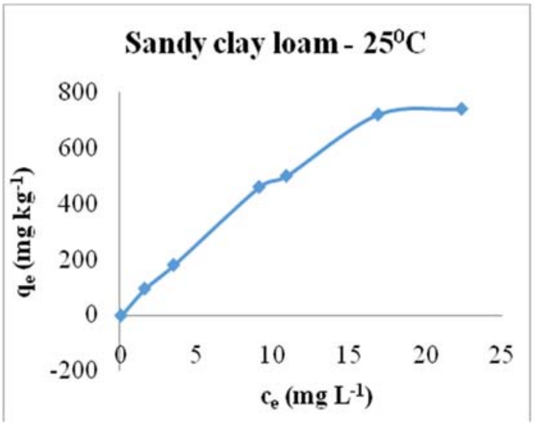
Maximum quantity adsorbed at 25^0C and 35^0C, buffer power at 25^0C and 35^0C had a very high positive correlation with Fe-P and Occlu-P which again ensured that phosphorus in *Pokkali* soil is mainly adsorbed onto inorganic surphase.

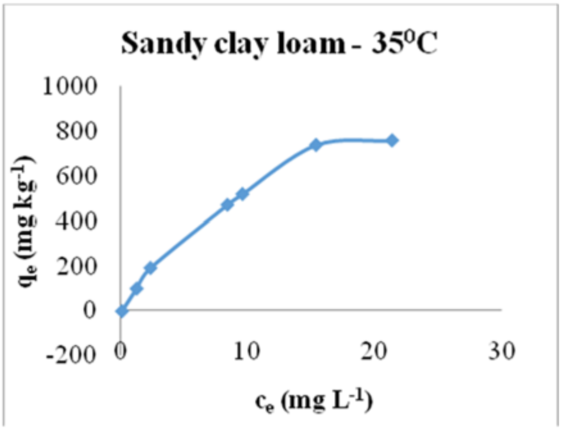
Fig.37. Quantity intensity curve for phosphorus adsorption at 25^0C and 35^0C in October

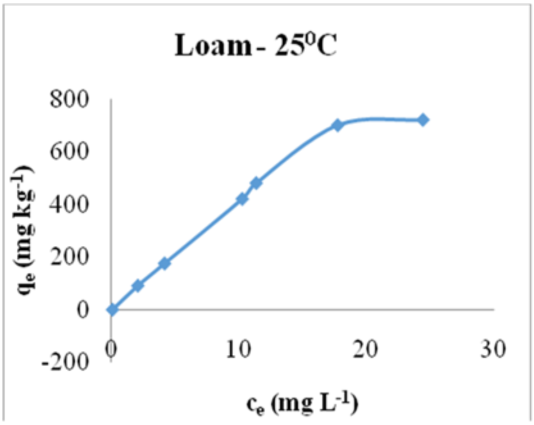


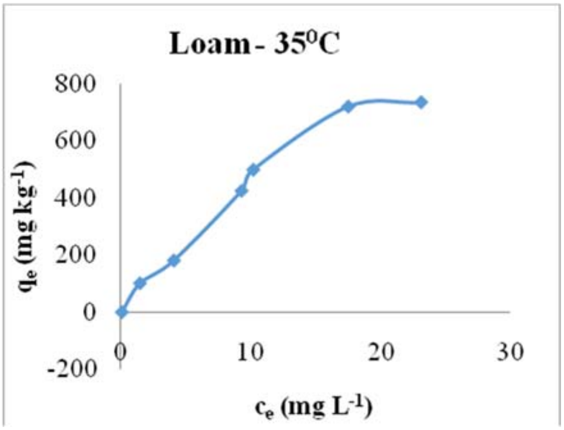

Clay loam - 25^{0}C
q_e (mg kg^{-1})
800
600
400
200
0
-200
0
5
10
15
20
25
c_e (mg L^{-1})

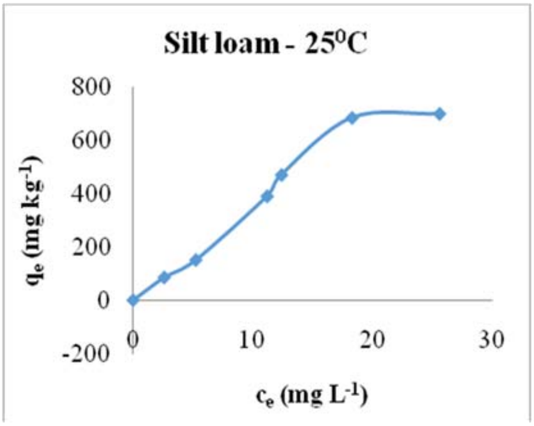

Clay loam - 35^{0}C
q_e (mg kg^{-1})
1000
800
600
400
200
0
-200
0
5
10
15
20
25
c_e (mg L^{-1})


Sandy clay loam - 25^{0}C
q_e (mg kg^{-1})
800
600
400
200
0
-200
0
5
10
15
20
25
c_e (mg L^{-1})


Sandy clay loam - 35^{0}C
q_e (mg kg^{-1})
1000
800
600
400
200
0
-200
0
10
20
30
c_e (mg L^{-1})


Loam - 25^{0}C
q_e (mg kg^{-1})
800
600
400
200
0
-200
0
10
20
30
c_e (mg L^{-1})


Loam - 35^{0}C
q_e (mg kg^{-1})
800
600
400
200
0
-200
0
10
20
30
c_e (mg L^{-1})


Silt loam - 25^{0}C
q_e (mg kg^{-1})
800
600
400
200
0
-200
0
10
20
30
c_e (mg L^{-1})

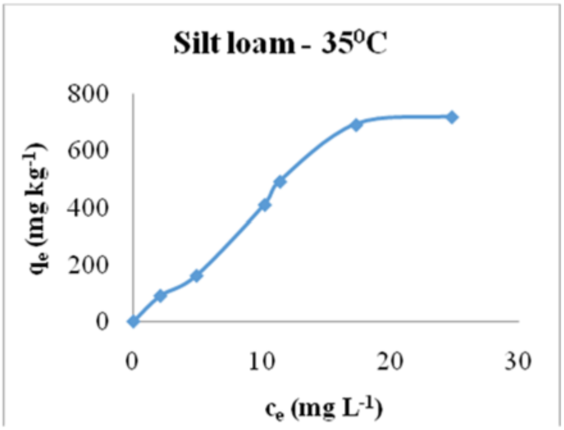
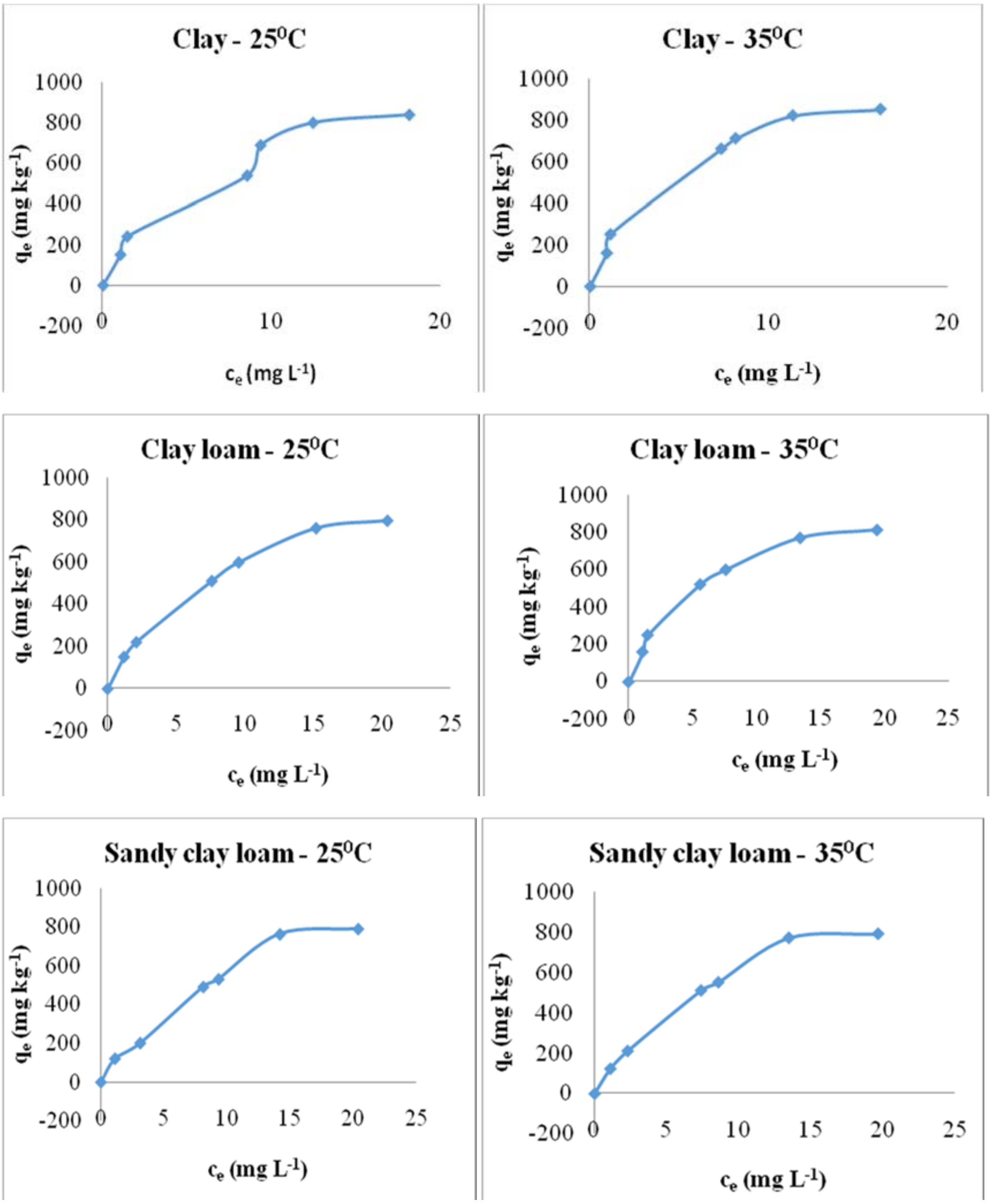
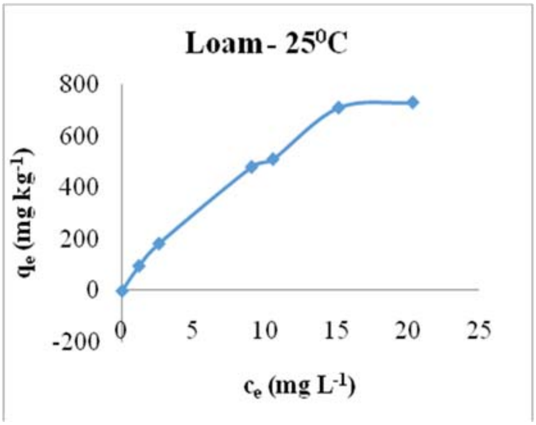
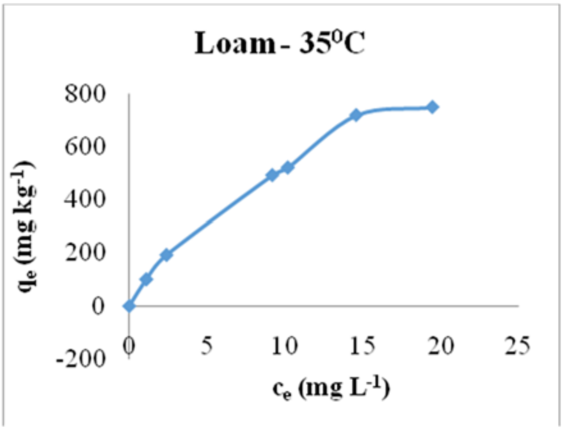

Silt loam - 35^{0}C
q_e (mg kg^{-1})
800
600
400
200
0
0
10
20
30
c_e (mg L^{-1})

Fig.38. Quantity intensity curve for phosphorus adsorption at25^0C and 35^0C in April

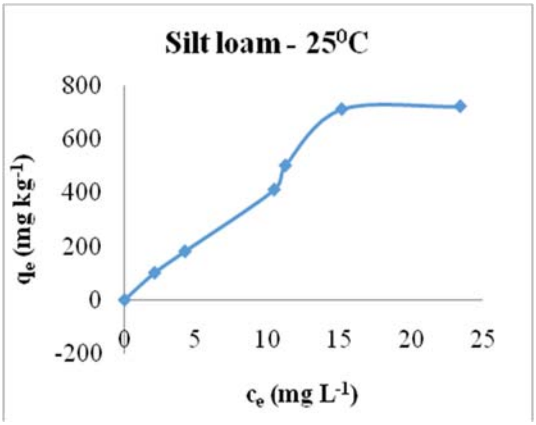




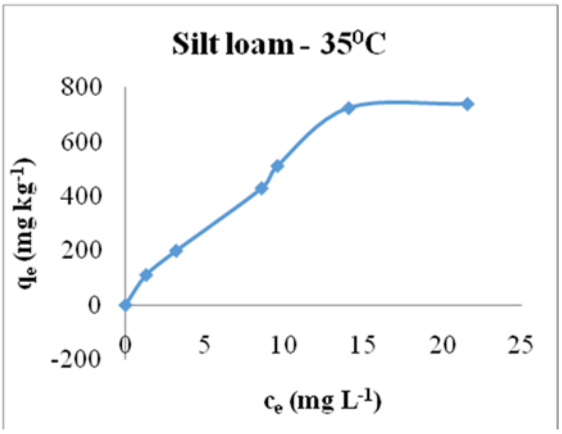
Loam - 25^0C



Loam - 35^0C



Silt loam - 25^0C



Silt loam - 35^0C

3.1.1.2. Adsorption isotherms and thermodynamics of adsorption

Adsorption of P in all soils were observed with added concentration of P. Freundlich adsorption isotherm was found best to explain P adsorption followed by Tempkin and Langmuir adsorption isotherm.

Langmuir adsorption isotherms of *Pokkali* soil samples are depicted in figure 39 and 40. Adsorption of P in silt loam soil during October was not fitted into Langmuir adsorption isotherm whereas the same was fitted into Langmuir adsorption isotherm during April which disclosed that phosphorus adsorption increased during April compared to October. At 25^0C, the failure of Langmuir equation in silt loam soils indicates the development of different sites of adsorption with different binding energies. Very high value of adsorption maxima (qm) was recorded in clay soil at the temperature of 35^0C irrespective of the seasons. Adsorption maxima were recorded low in silt loam soils of. K_L indicates the binding energy or strength of binding. Comparatively high K_L was recorded during the month of April for all the soil samples.

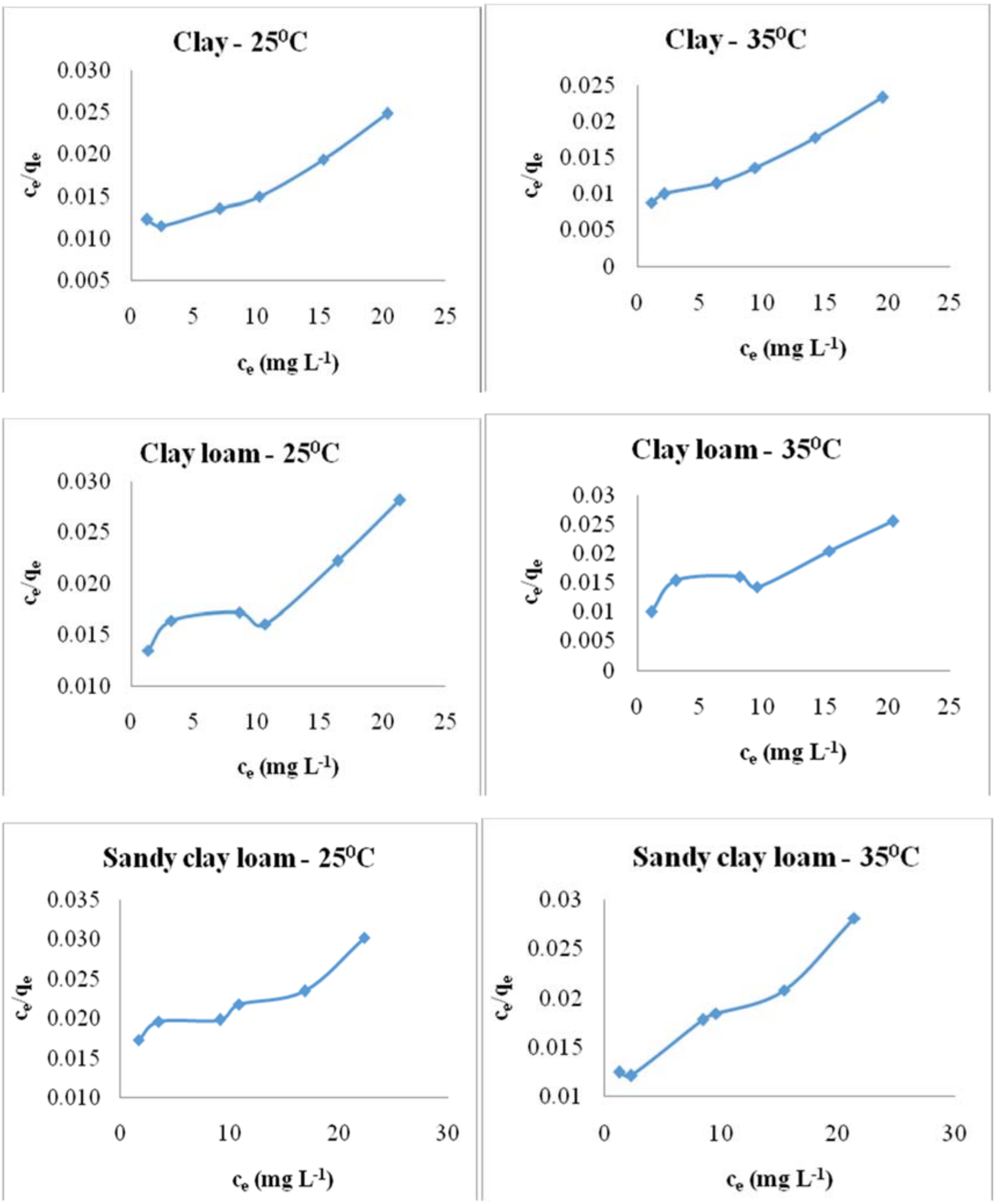
Freundlich adsorption isotherms of *Pokkali* soils are given in figure 41 and 42. All the soils were recorded with 1/n value less than 1 except fot silt loam soil at 25^0C during October. The 1/n value less than 1 indicates the increase in bonding energy with surface density (Salahi and Ghorbani, 2014). It is a measure of adsorption intensity also. The 1/n value for silt loam during April at 25 ^{0}C was less than 1 which showed that adsorption in silt loam soil increased in April. High K_F (constant related to strength of adsorption) was recorded in *Pokkali* soils during April and at temperature of 35 ^{0}C irrespective of the seasons. This very high KF indicating the adsorption capacity and strength of adsorption is high during April (high saline phase) and 35 ^{0}C irrespective of the seasons.

P adsorption in all textured soils at both temperatures was fitted into Tempkin adsorption isotherm. Tempkin adsorption isotherms of soil samples are given in figure 43 and 44. Highest value of constant related to bonding strength (K_T) was recorded in clay soil followed by clay loam soil which is an indication of strength of binding. *Pokkali* soil showed an increase in K_T with increase in temperature which is indication of chemical nature of bonding.

q_m at 25^0C, q_m at 35^0C, K_L at 25^0C,K_L at 35^0C and K_F at 35^0C made very high positive correlation with Fe-P and Occlu-P which revealed that maximum adsorption of P in *Pokkali* soil takes place with iron hydroxides/oxides. A very high negative correlation of K_F at 25^0C with soil pH and water soluble phosphorus indicated that phosphorus adsorption was favourd by low soil pH and leads to decrease in water soluble phosphorus. High positive correlation of K_T at 35^0C with EC and Cu disclosed that salinity during high saline phase increased P adsorption and also precipitation of phosphorus with copper also cannot be avoided.

Increase in thermodynamic equilibrium constant with increase in temperature was observed in all soil samples. Change in free energy (ΔG^0) was negative and change in entropy (ΔS^0) was positive for P adsorption in all soil indicating the spontaneous nature of P adsorption. Change in enthalpy was positive in all the soils which mean adsorption was endothermic in nature. Wang *et al.* (2017) also reported the spontaneous nature of P adsorption in soil.

Fig.39. Lagumuir adsorption isotherm for phosphorus at 25^0C and 35^0C in October



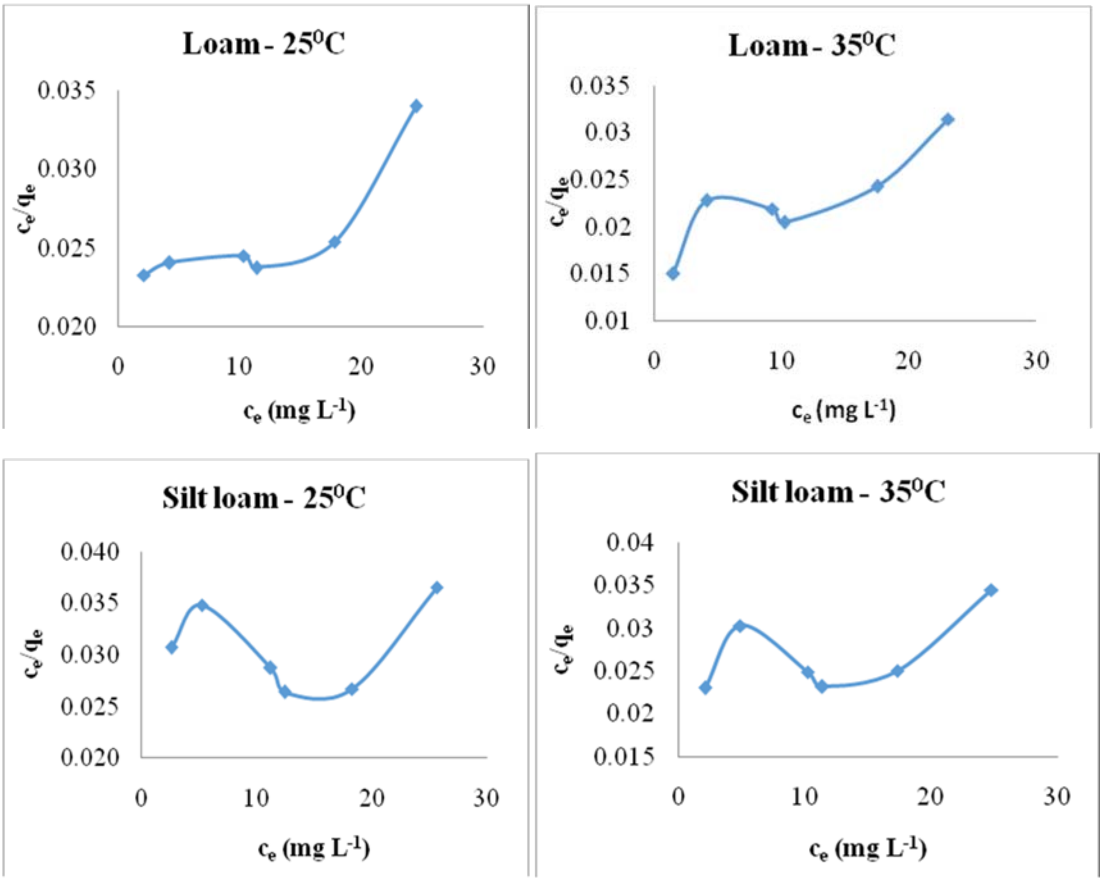
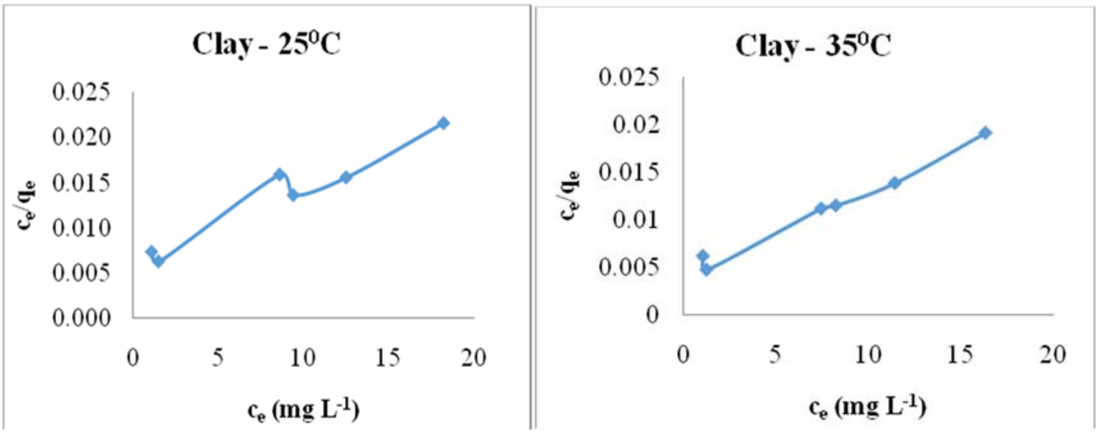
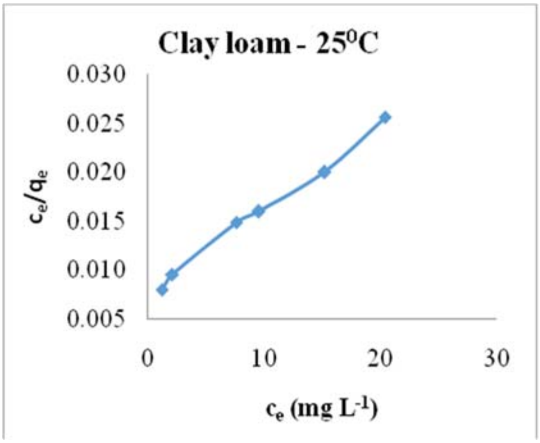
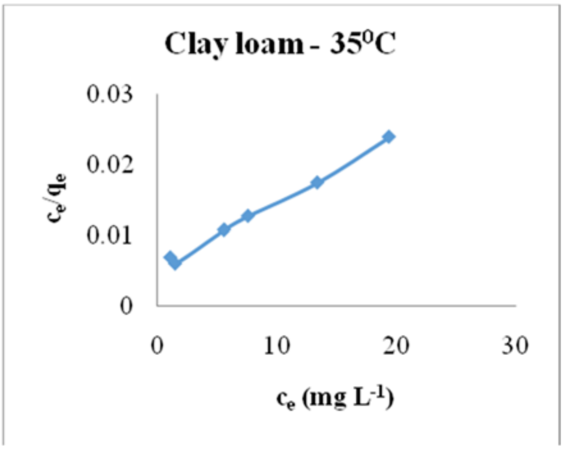
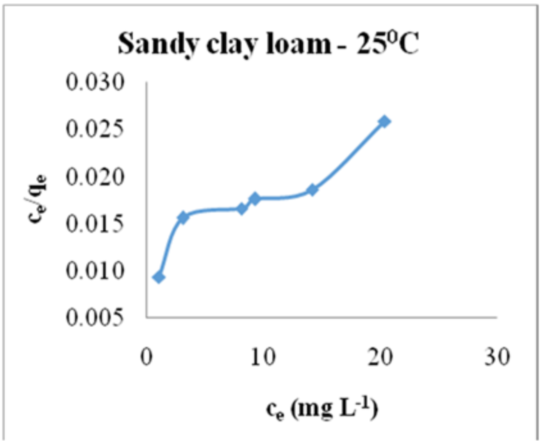


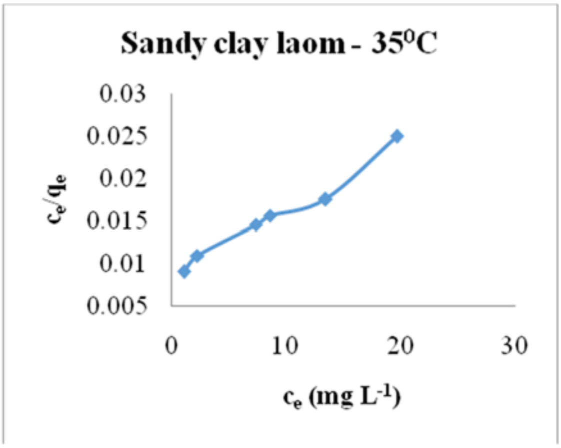
Fig.40. Langumuir adsorption isotherm for phosphorus at 25^{0}C and 35^{0}C in April

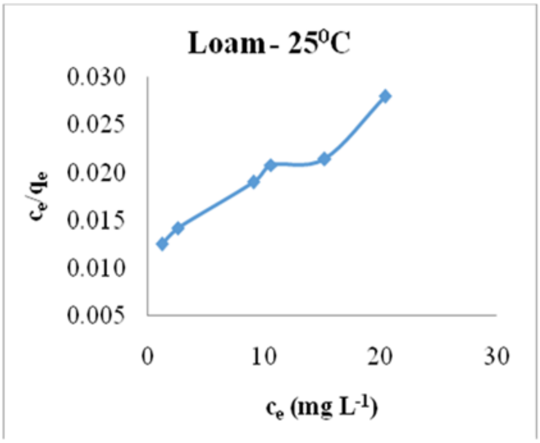


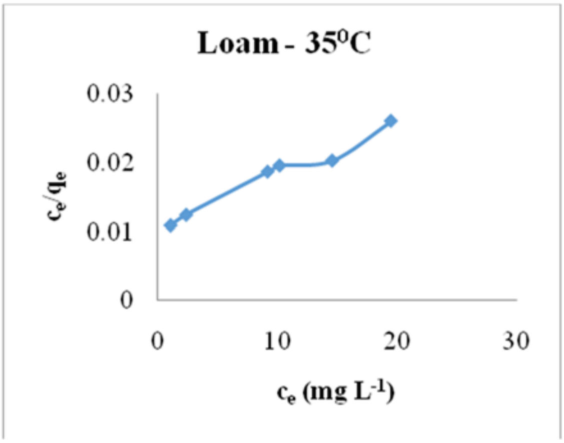

Clay loam - 25⁰C
0.030
0.025
0.020
0.015
0.010
0.005
c_e/q_e
0
10
20
30
c_e (mg L-1)


Clay loam - 35⁰C
0.03
0.02
0.01
0
c_e/q_e
0
10
20
30
c_e (mg L-1)


Sandy clay loam - 25⁰C
0.030
0.025
0.020
0.015
0.010
0.005
c_e/q_e
0
10
20
30
c_e (mg L-1)


Sandy clay laom - 35⁰C
0.03
0.025
0.02
0.015
0.01
0.005
c_e/q_e
0
10
20
30
c_e (mg L-1)


Loam - 25⁰C
0.030
0.025
0.020
0.015
0.010
0.005
c_e/q_e
0
10
20
30
c_e (mg L-1)


Loam - 35⁰C
0.03
0.02
0.01
0
c_e/q_e
0
10
20
30
c_e (mg L-1)

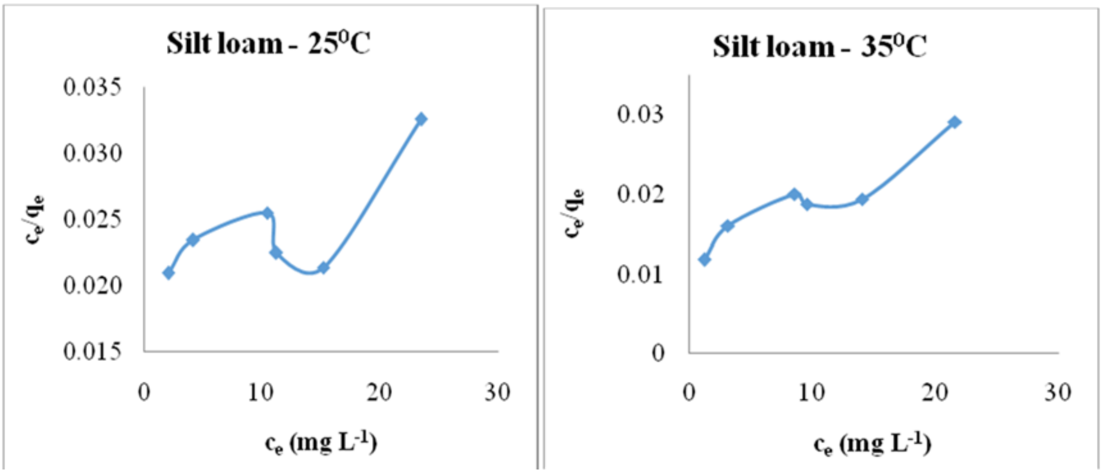
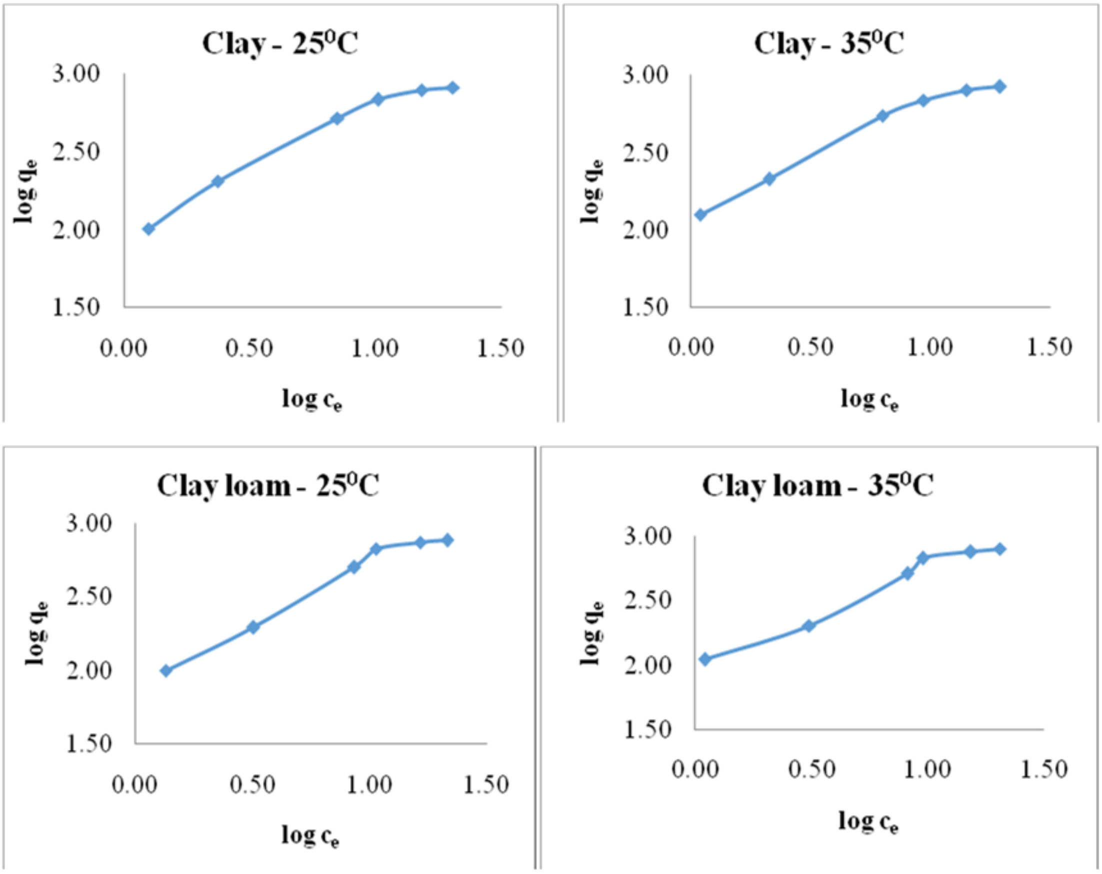
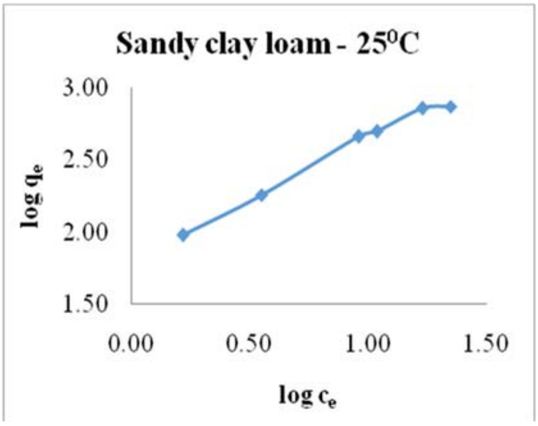
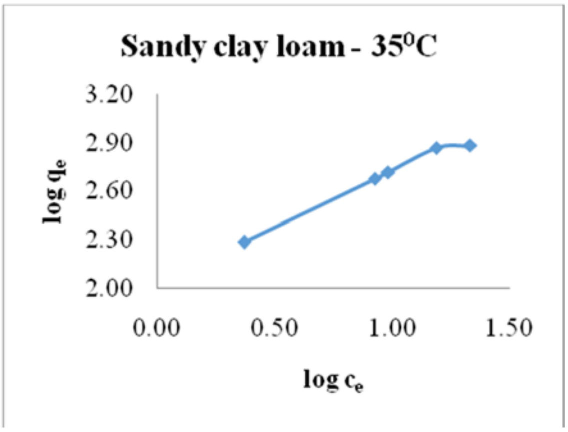
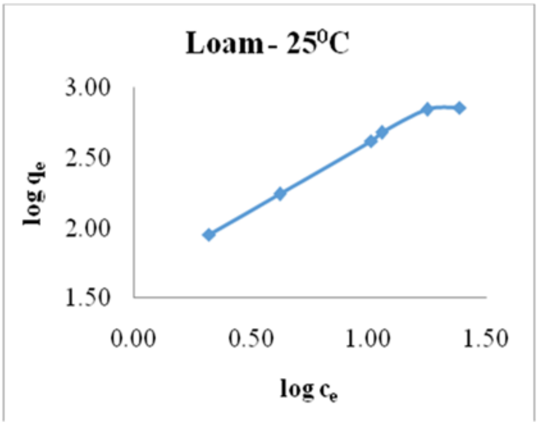


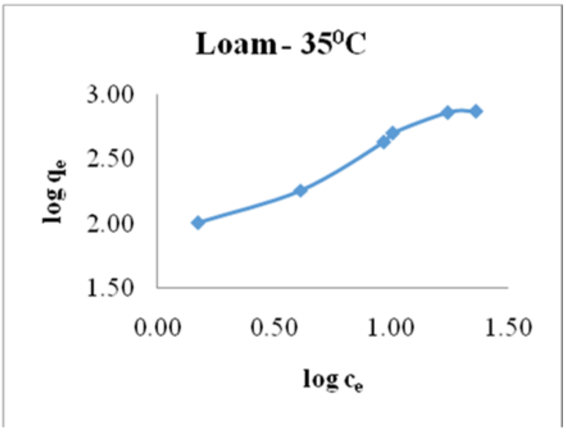
Fig.41. Freundlich adsorption isotherm for phosphorus at 25^{0}C and 35^{0}C in October

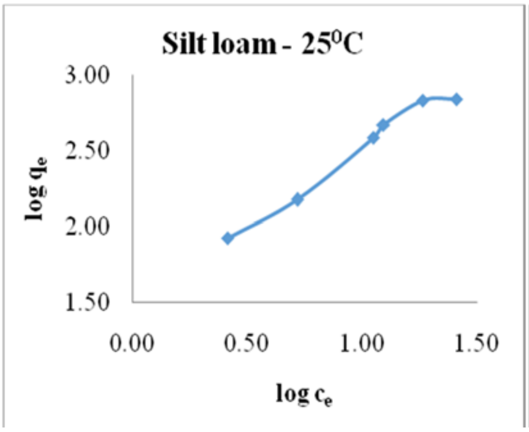



Sandy clay loam - 25⁰C
log qe
3.00
2.50
2.00
1.50
0.00
0.50
1.00
1.50
log ce


Sandy clay loam - 35⁰C
log qe
3.20
2.90
2.60
2.30
2.00
0.00
0.50
1.00
1.50
log ce


Loam - 25⁰C
log qe
3.00
2.50
2.00
1.50
0.00
0.50
1.00
1.50
log ce


Loam - 35⁰C
log qe
3.00
2.50
2.00
1.50
0.00
0.50
1.00
1.50
log ce


Silt loam - 25⁰C
log qe
3.00
2.50
2.00
1.50
0.00
0.50
1.00
1.50
log ce

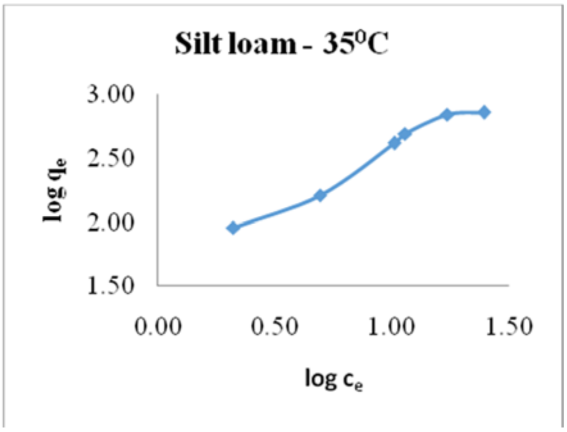
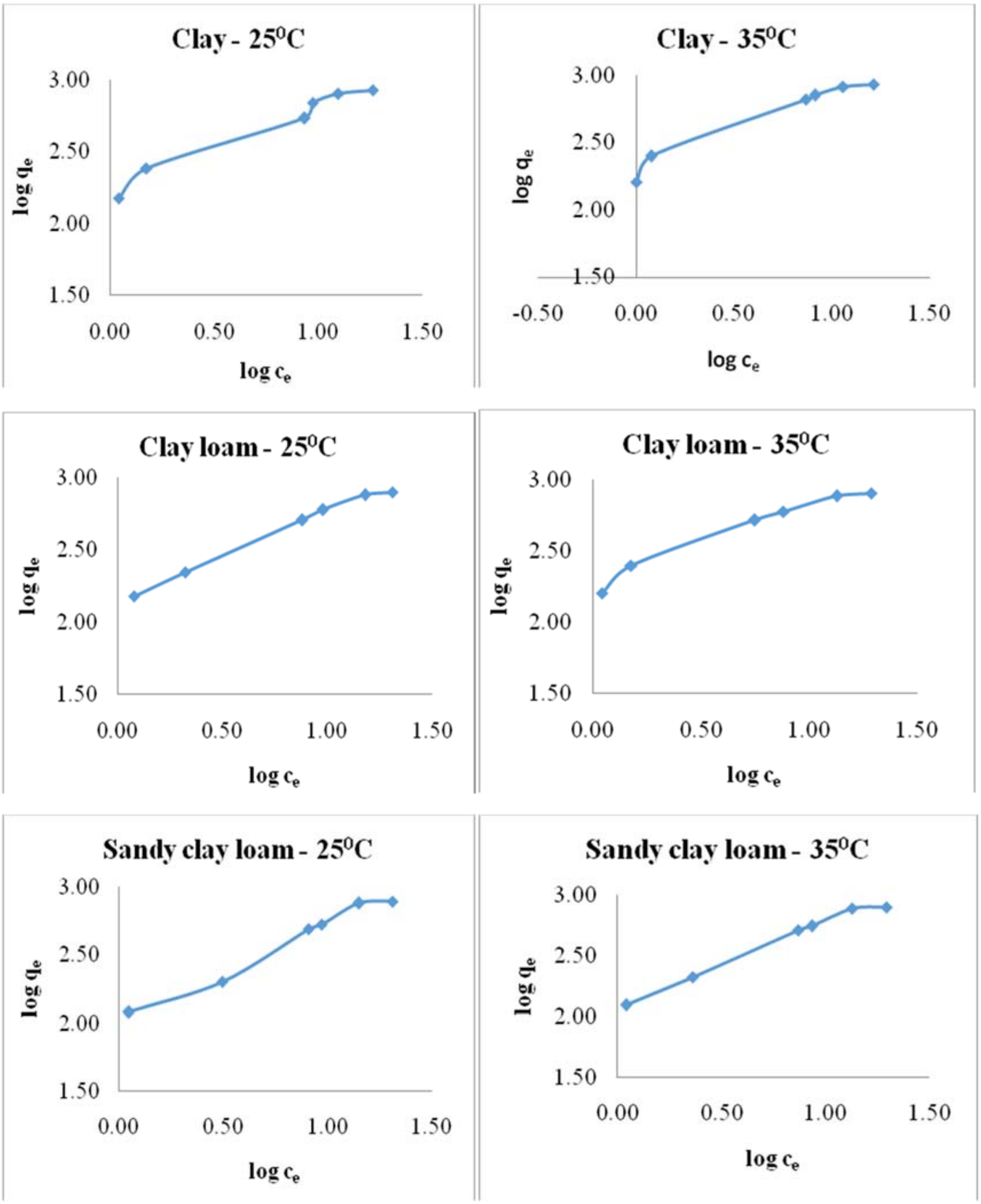

Silt loam - 35⁰C
log qe
3.00
2.50
2.00
1.50
0.00
0.50
1.00
1.50
log ce

Fig.42. Freundlich adsorption isotherm for phosphorus at 25^{0}C and 35^{0}C in April


Clay - 25^{0}C

Clay - 35^{0}C

Clay loam - 25^{0}C

Clay loam - 35^{0}C

Sandy clay loam - 25^{0}C

Sandy clay loam - 35^{0}C

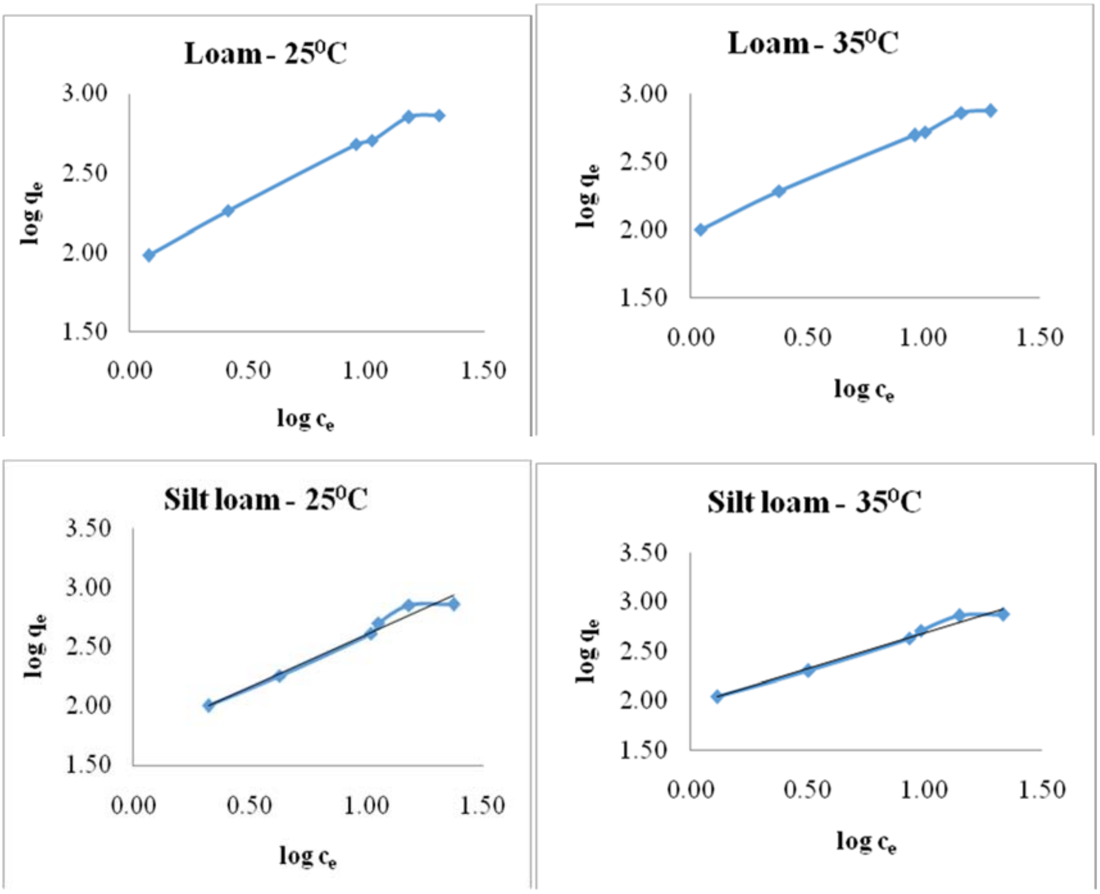
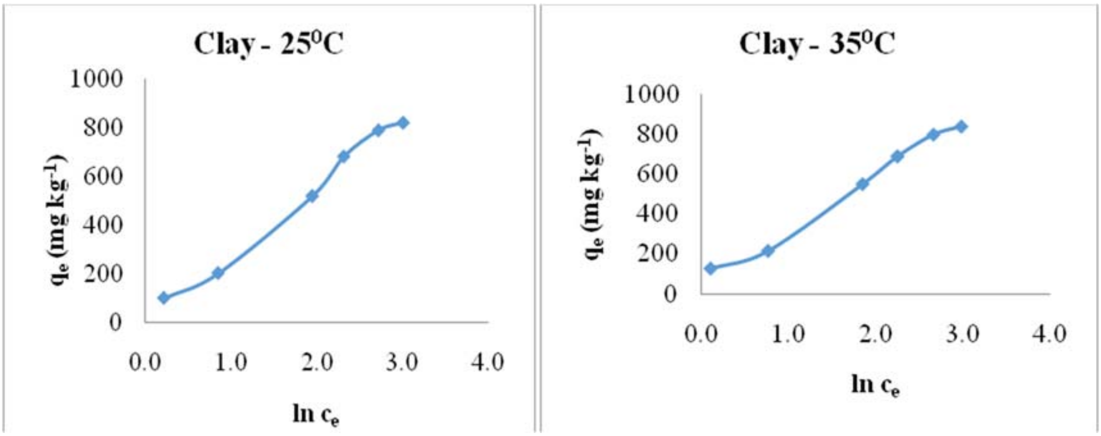
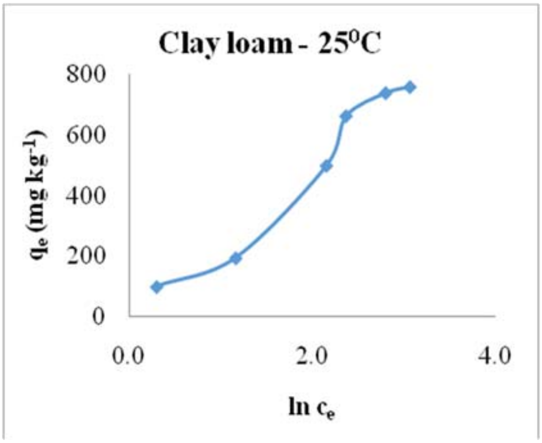
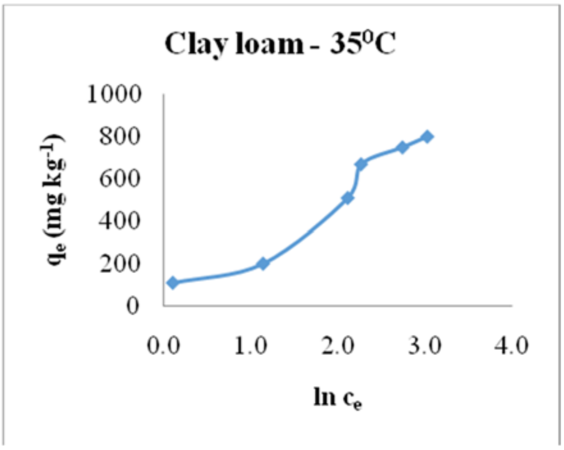
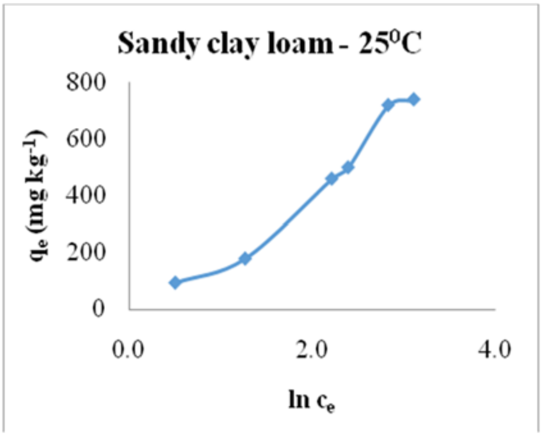


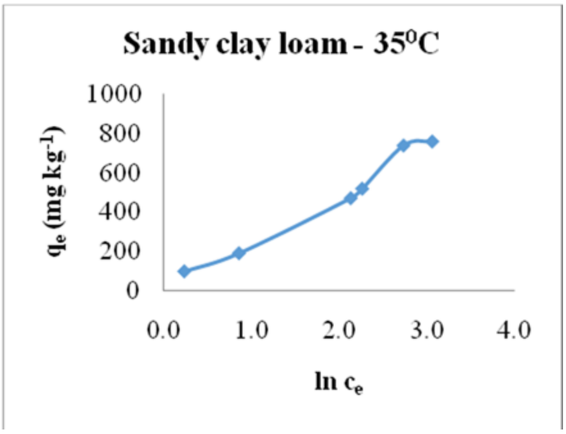
Fig.43. Tempkin adsorption isotherm for phosphorus at 25^0C and 35^0C in October

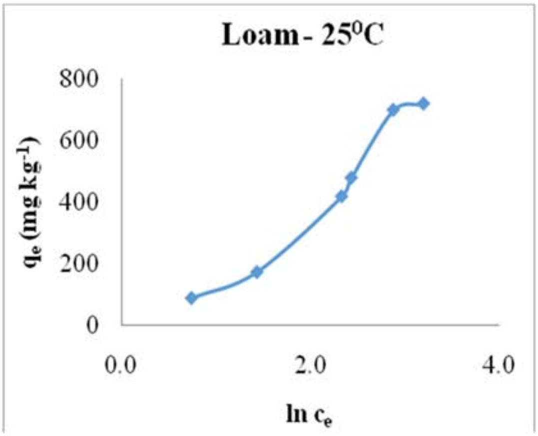


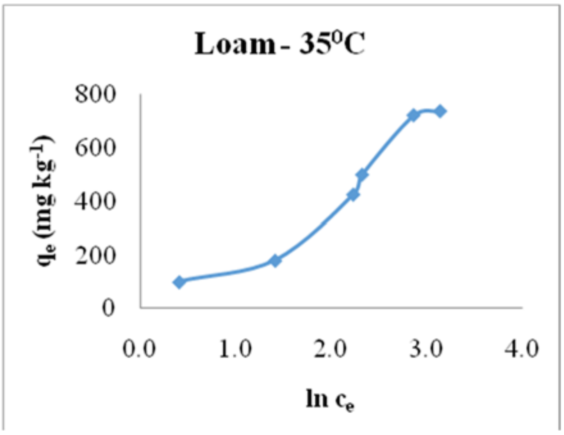

Clay loam - 25^{0}C
800
600
400
200
0
q_e (mg kg^{-1})
0.0
2.0
4.0
ln c_e


Clay loam - 35^{0}C
1000
800
600
400
200
0
q_e (mg kg^{-1})
0.0
1.0
2.0
3.0
4.0
ln c_e


Sandy clay loam - 25^{0}C
800
600
400
200
0
q_e (mg kg^{-1})
0.0
2.0
4.0
ln c_e


Sandy clay loam - 35^{0}C
1000
800
600
400
200
0
q_e (mg kg^{-1})
0.0
1.0
2.0
3.0
4.0
ln c_e


Loam - 25^{0}C
800
600
400
200
0
q_e (mg kg^{-1})
0.0
2.0
4.0
ln c_e


Loam - 35^{0}C
800
600
400
200
0
q_e (mg kg^{-1})
0.0
1.0
2.0
3.0
4.0
ln c_e

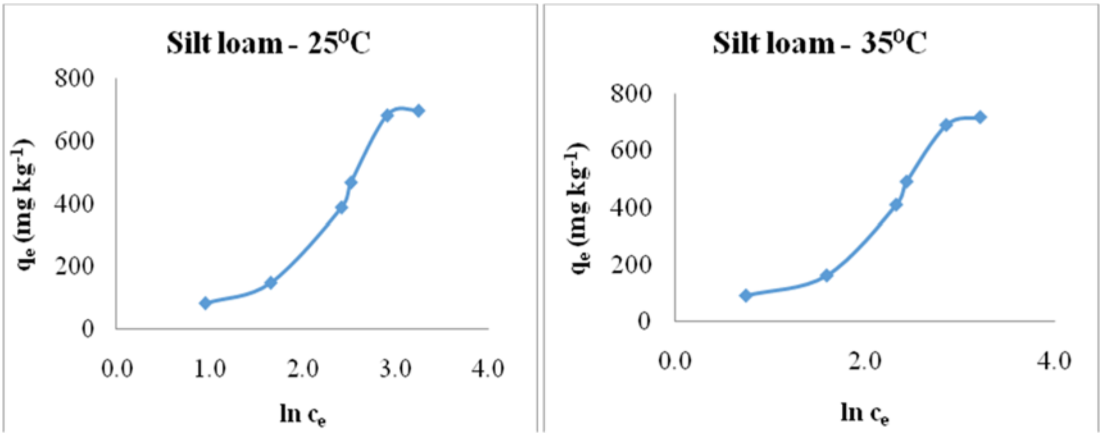
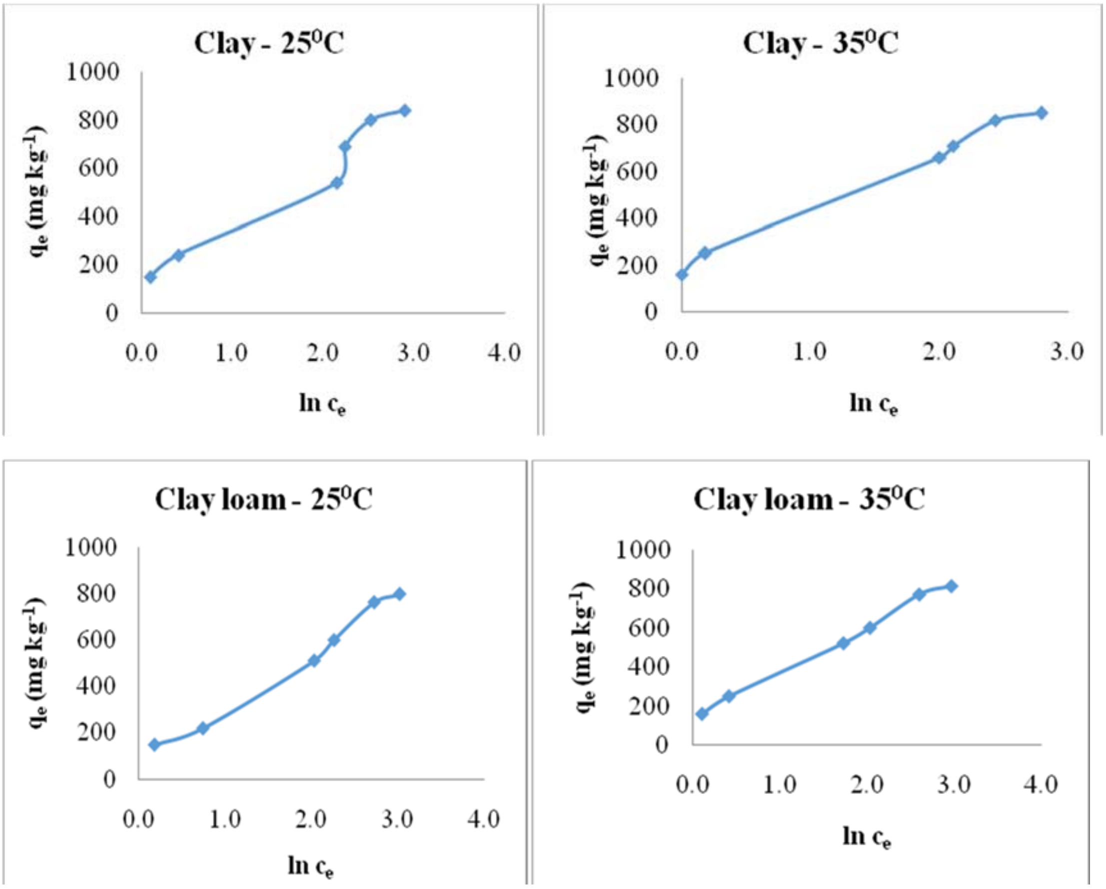
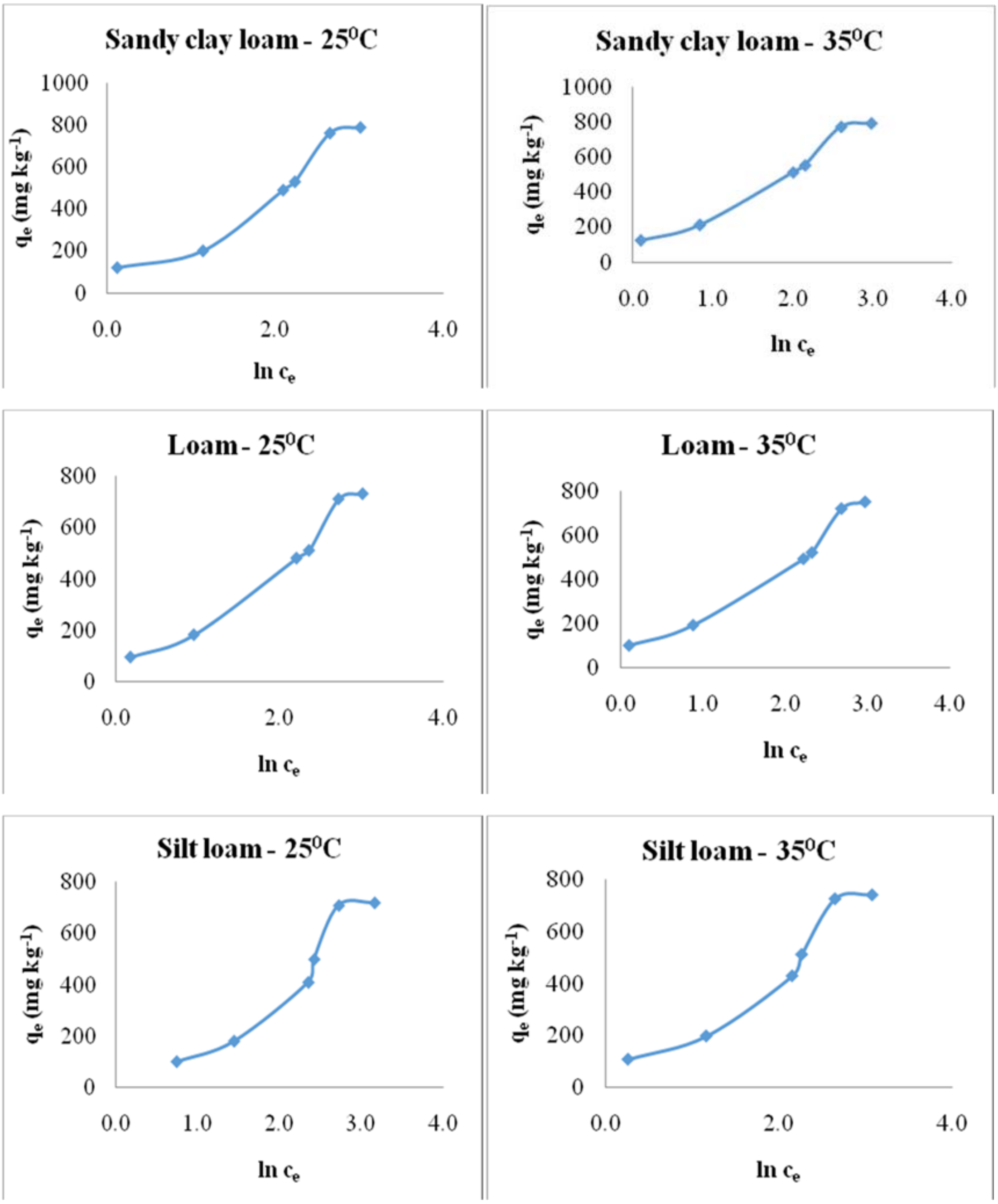


Fig.44. Tempkin adsorption isotherm for phosphorus at 25^0C and 35^0C in April





3.1.2. Adsorption of copper

3.1.2.1. Quantity –intensity relationship

Soil samples were equilibrated with different concentrations of copper nitrate as detailed in section 3.7. Quantity intensity curve for copper adsorption is presented in Figure 45 and 46. A rapid adsorption of copper was observed near to equilibrium concentration of 20 mg/L and then adsorption process increased at slow rate only. This could be due to adsorption of Cu (II) mainly occurs on surfaces of soil particles or large pores in the rapid adsorption stage. As time increased, adsorption of Cu (II) might occurred on surfaces of inner small pores. Meanwhile, a stable complex or chelate could be formed and finally the adsorption process got slow down. The S shaped adsorption isotherm was formed in the case of copper adsorption, where the slope initially increases with adsorbate concentration, but eventually decreases and becomes zero as vacant adsorbent sites are filled.

The adsorption maxima was high for claysoils and very low in silt loam soils. This is due to the fact that high amount of clay and organic matter offered sites for maximum adsorption and the abundance of these sites might have resulted in low binding energy in clay soils.

Positive buffer power was observed in all the soil samples. Increase in buffer power with temperature indicates the ability of soil to adsorb element and contribute to the quantity factor. Maximum quantity adsorbed also increased with increasing temperature. This is because that the adsorption energy of Cu (II) increases as the temperature increases, which makes Cu (II) easier to contact with sites; then it will improve the adsorption efficiency of Cu (II). In addition, the rise of temperature may change the properties of soil, such as pore size, and carbon activity.

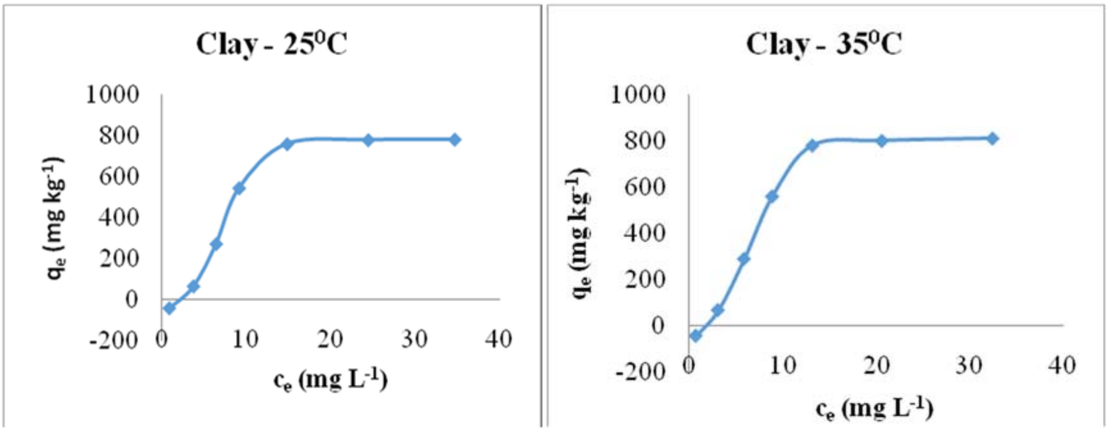
Positive intercepts of Q-I curves at 25^0C and 35^0C, indicate the requirement of a minimum amount of copper at the solid phase below which there will not be any desorption. At 35^0C, the buffer power increased in *Pokkali* soil comapared to buffer power at 25^0C which indicated that the sites of adsorption are mainly inorganic *ie.*oxide and oxy hydroxide surfaces whose specificity might have enhanced at higher temperatures.

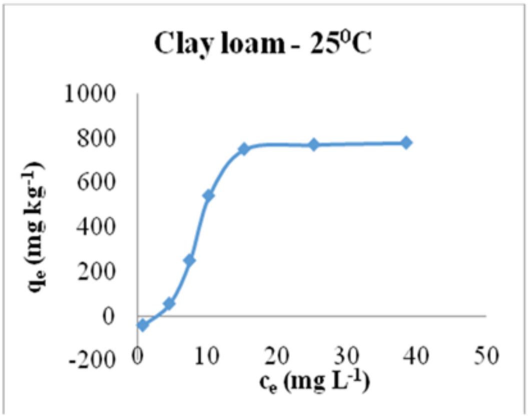
Adsorption process varied with textural change in *Pokkali* soil. Clay soil followed by clay loam showed highest adsorption and silt loam detected with least adsorption of copper. The order of textural classes of soil samples for maximum copper adsorbed can be arranged as Clay> clay loam>sandy clay loam>loam>silt for *Pokkali* soil.

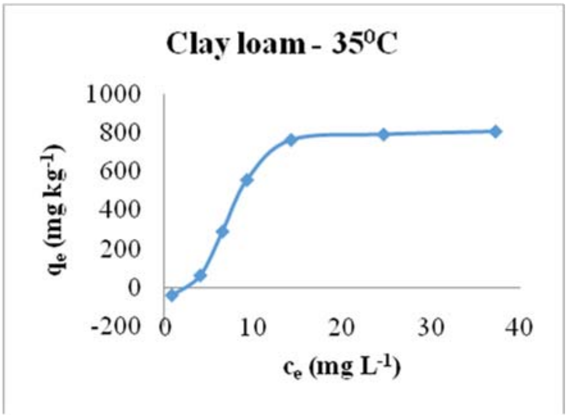
Seasonal variation in copper availability in *Pokkali* soil reflected in adsorption study of copper also. Adsorption of copper was higher in October where neutral soil pH recorded than April where acidic soil pH detected.Generaly it could be concluded that the sorption of Cu (II) increased as the pH increases. This feature can be justified with few aspects. Firstly, at low soil pH, the high content of H^+ lead to soil mineral dissolution and released ions such as Fe(II) and Al (III) in soil (Ozdemir and Yapar, 2009). These ions compete with Cu (II) for adsorption sites. Secondly, if the pH is low, the surface groups are protonated. Consequently, it will produce a positive surface charge which may weaken the ability to form complexes with Cu (II) (Agbenin and Tiessen, 1994). Thirdly, with elevated pH, the ionic state of copper may change, and the hydroxylation of Cu (II) makes Cu (II) more adsorbed to the soil. Adsorption rate is not only related to the soil charge but also influenced by the composition and properties of soil. High affinity of *Pokkali* soil towards copper adsorption could be related to very high content of organic matter and iron and aluminium content.

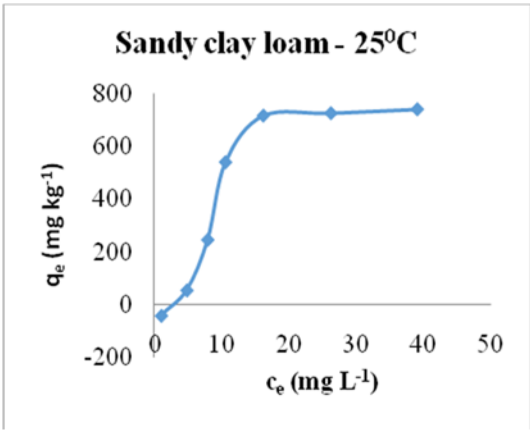
Buffer power was significantly and positively correlated with maximum quantity adsorbed for both the soil temperatures. When the amount adsorbed per unit weight of soil increases, the capacity of soil to supply the nutrient into soil solution upon depletion also increases.

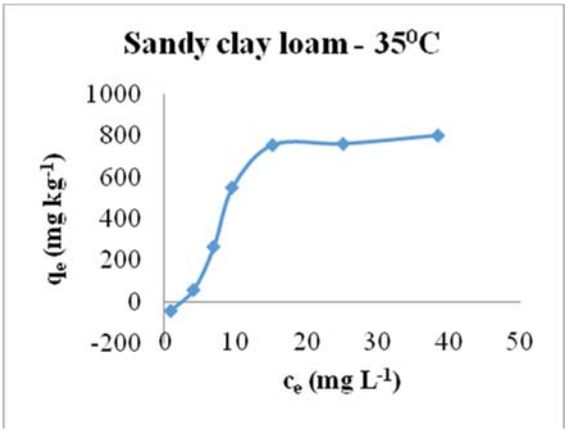
Fig.45. Quantity intensity curve for copper adsorption at 25^{0}C and 35^{0}C in October

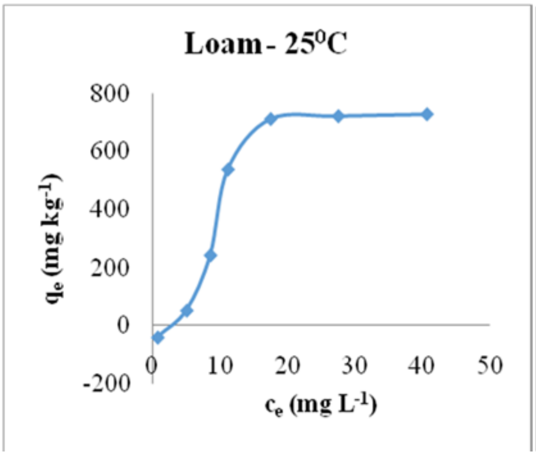


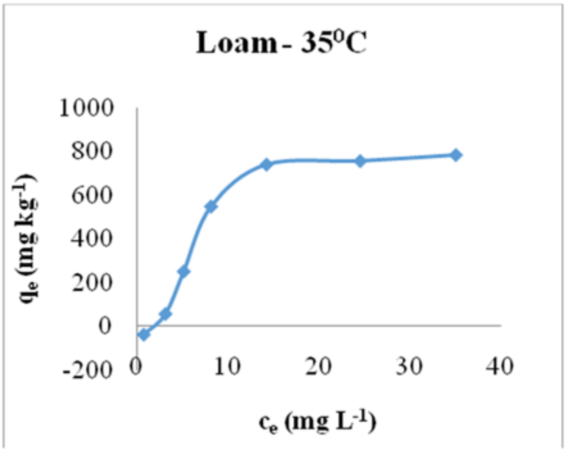

Clay loam - 25^0C

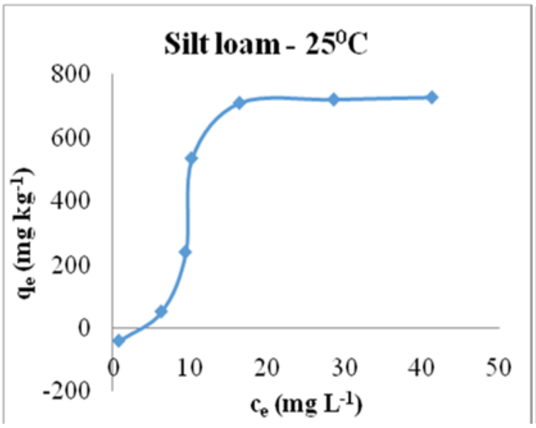

Clay loam - 35^0C


Sandy clay loam - 25^0C


Sandy clay loam - 35^0C


Loam - 25^0C


Loam - 35^0C


Silt loam - 25^0C

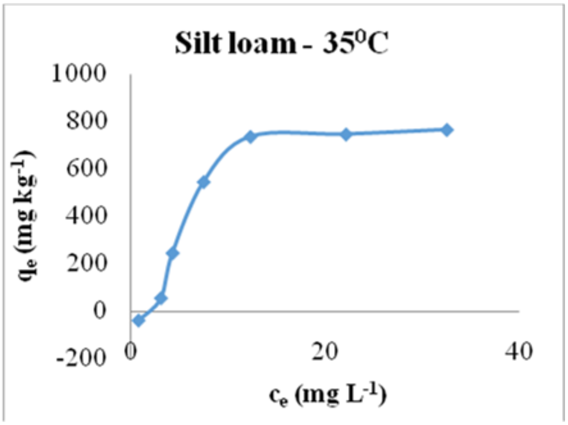
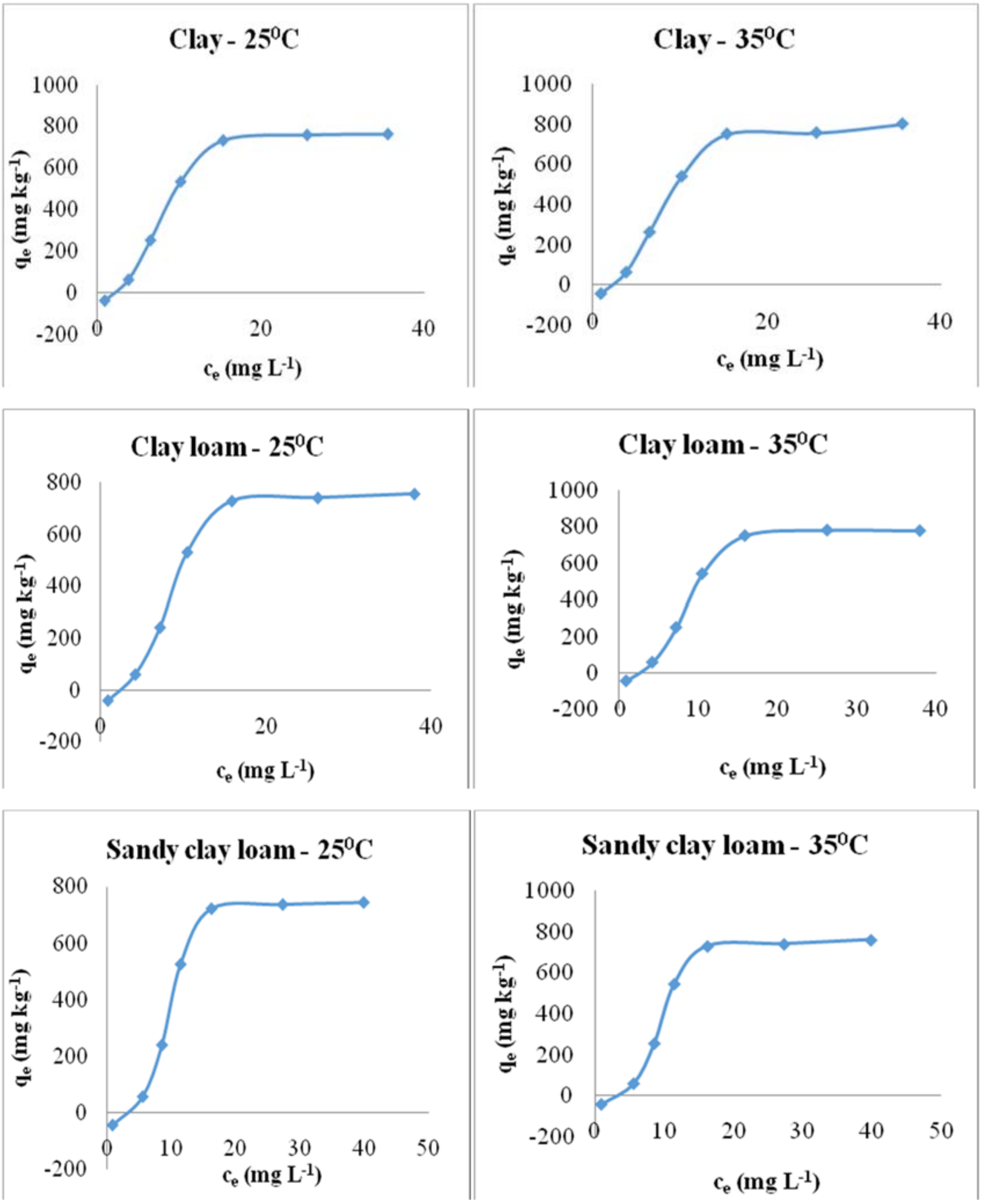
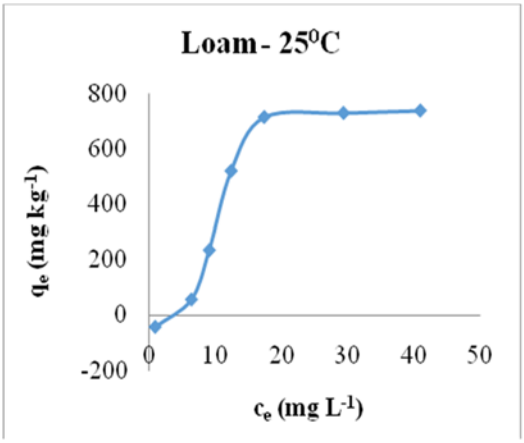
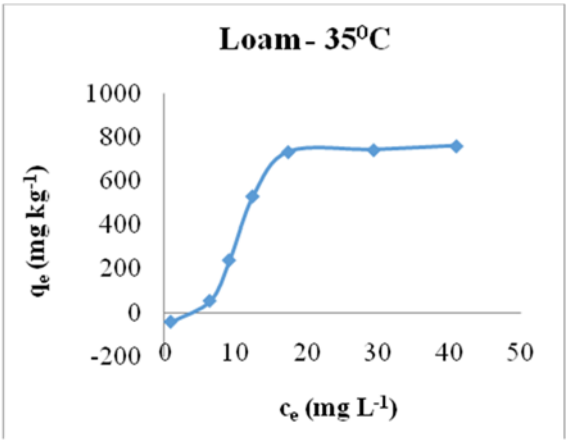
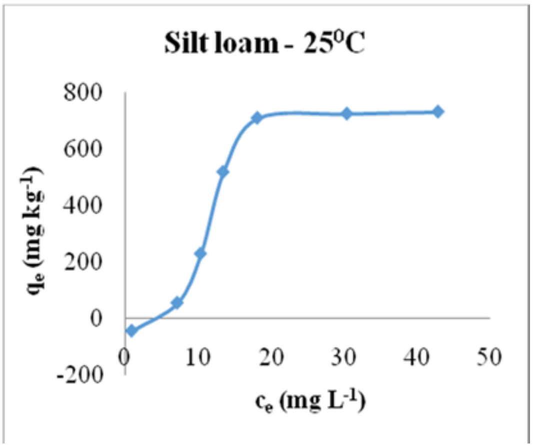

Silt loam - 35^0C

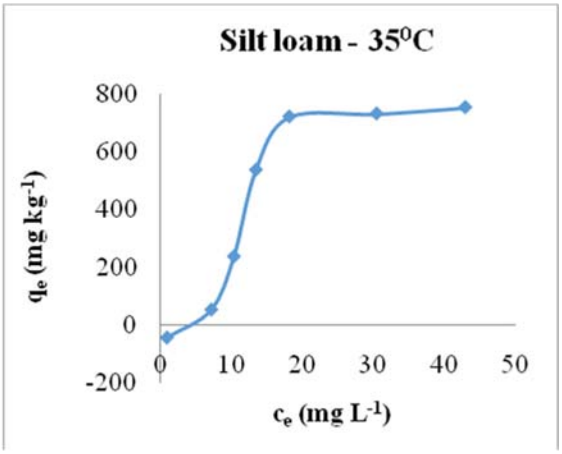
Fig.46. Quantity intensity curve for copper adsorption at 25^{0}C and 35^{0}C in April




Loam - 25°C


Loam - 35°C


Silt loam - 25°C


Silt loam - 35°C

3.1.2.2. Adsoption isotherms and thermodynamic parameters

Adsorption isotherms were fitted for soils with minimum four points with positive slopes in Q-I curve. The obtained data from quantity intensity curve were well fitted to linear Freundlich adsorption isotherm followed by Tempkin adsorption isotherm with R^2 value greater than 0.5. Where as the obtained data was not fiited to Langmuir adsorption isotherm ($R^2 < 0.5$). The failure of Langmuir isotherm to explain the adsorption pattern of soils could be attributed to the involvement of more than one type of sites with different binding energies at the concentration range studied.

The best fit of data to Freundlich adsorption (figure 47 and 48) assumes that the affinity for adsorption decreases exponentially with the increase in surface coverage which is more logical in real situation. The Freundlich isotherm parameter 1/n and K_F measures the adsorption intensity and adsorption capacity of Cu ions on soils (Sureshkumar, 1993). Significant difference was not observed in the values of 1/n and

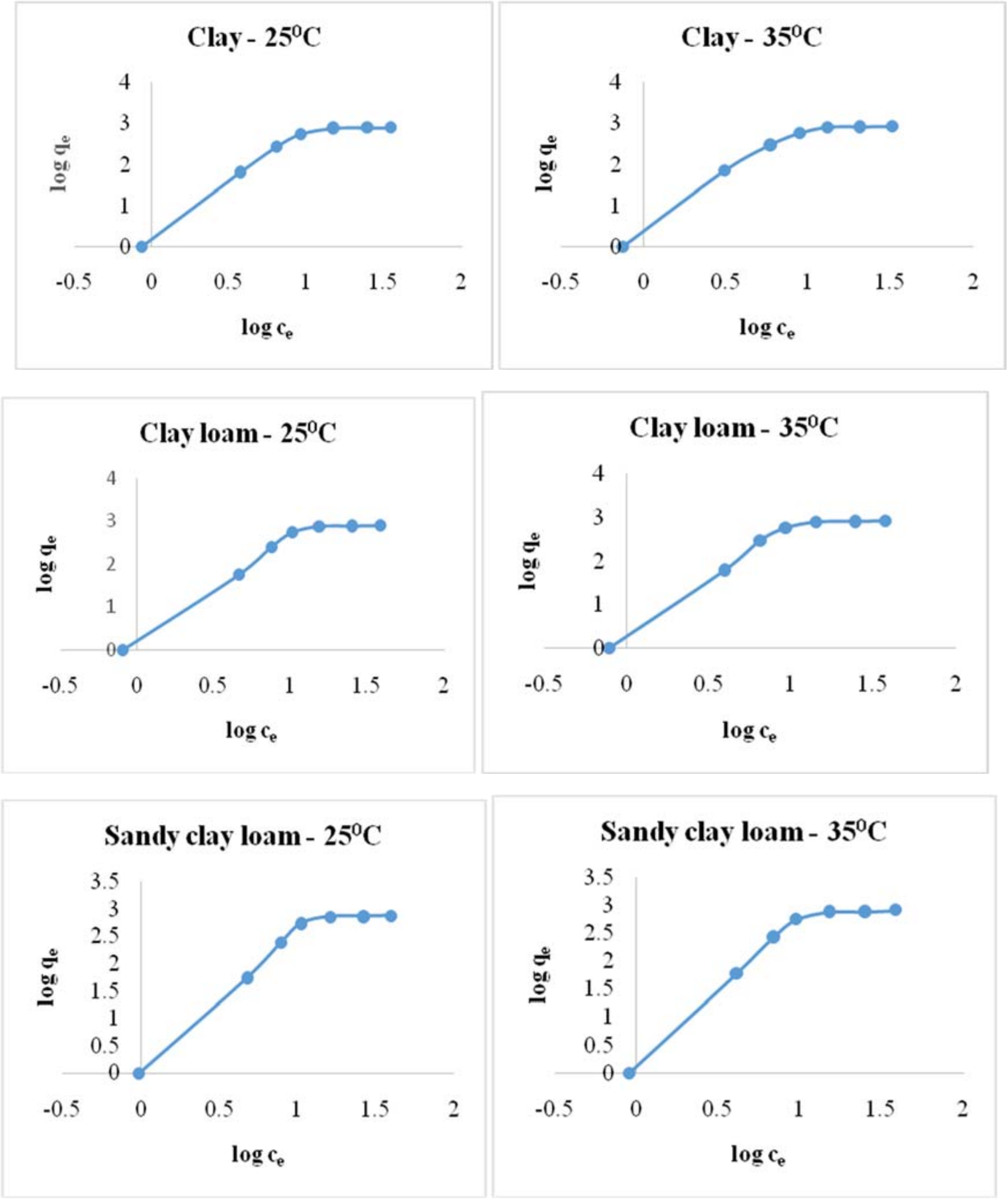
K_F with respect to soil temperature and seasons. All the soils were recorded with 1/n value greater than 1, indicating the adsorption intensity was high in *Pokkali* soil. The highest adsorption intensity recorded in sandy clay loam followed by clay loam might be due to high content of iron and aluminium sesqui oxide and organic matter content in these soil samples.Surface functional groups of Fe, Al and Mn oxides are very selective for Cu adsorption, making highly stable inner-sphere complexes (Casagrande *et al.,* 2004). Copper has a tendency to form stronger inner-sphere complex with soil organic matter (Boudesocque *et al*., 2007).

The Tempkin isotherm model (figure 49 and 50) assumes that the heat of adsorption of all molecules decreases linearly with the increase in coverage of the adsorbent surface, and that adsorption is characterized by a uniform distribution of binding energies, up to a maximum binding energy. Tempkin adsorption of representative soil samples are given in figure 29. K_T is the constant related to strength of binding, indicating the adsorbate-adsorbent interaction. b is the constant related to heat of adsorption. The values of K_T and b were highest during October compared to April which confirmed again the higher copper adsorption in October.Value of K_T was increased with increase in temperature in all the soils. That means the strength of bonding increases with increase in temperature in *Pokkali* soils indicating the chemical nature of bonding. Clay loam soil showed highest value of K_T and b which might be due to the higher organic matter or sesqui oxides presence in this soil.

Positive correlation of K_T at 35^0C with organic matter occluded copper, available copper, water soluble and exchangeable copper ensured the availability of copper in *Pokkali* soil throughout the season.

Negative value of change in Gibbs free energy and positive value of change in entropy indicated that adsorption process of copper in *Pokkali* soil was spontaneous in nature. Change in free energy for all the *Pokkali* samples showed positive values which ensured endothermic nature of adsorption.

Fig.47. Freundlich adsorption isotherm for copper at 25^{0}C and 35^{0}C in October



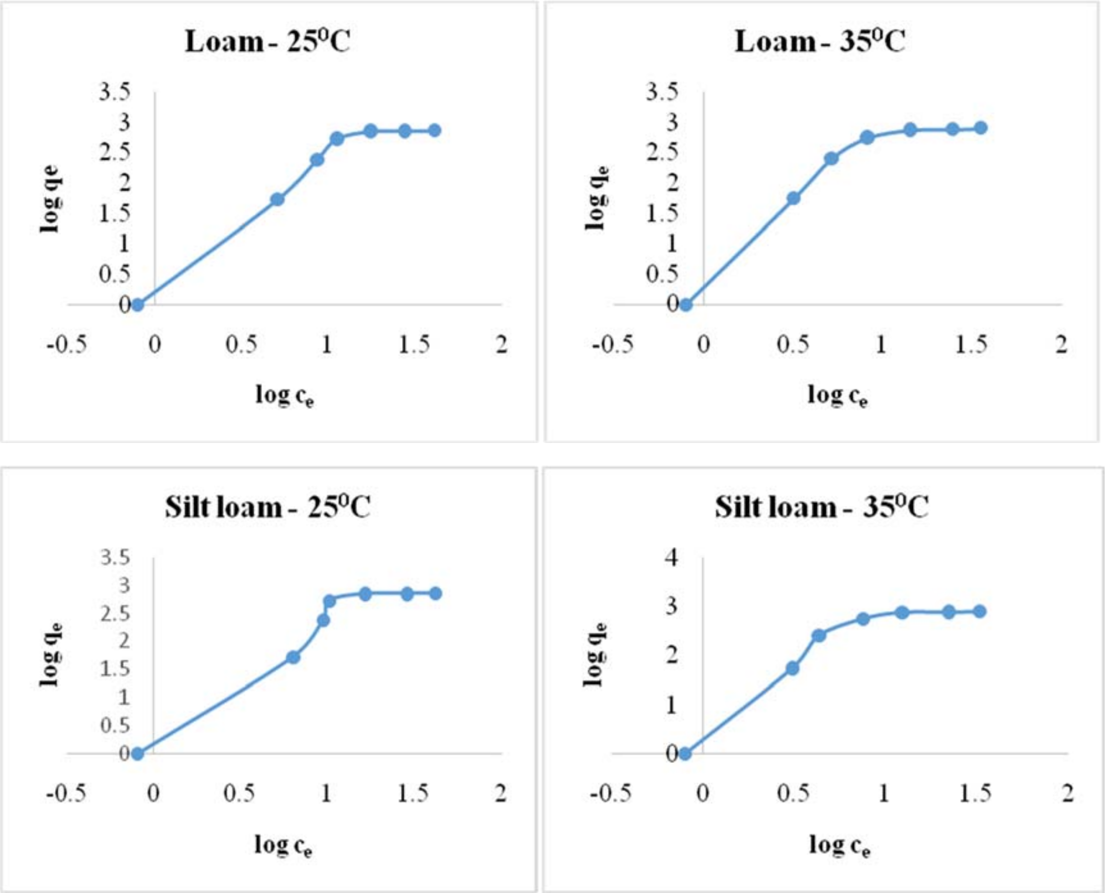
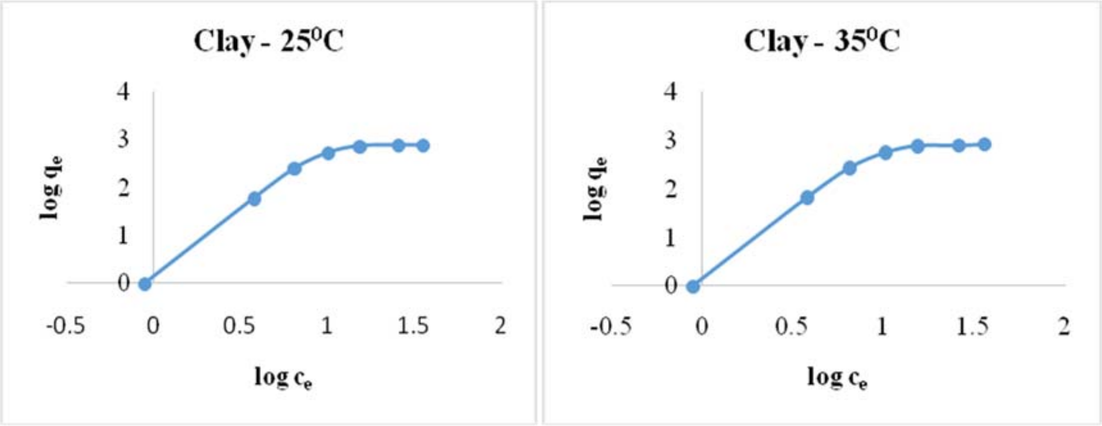
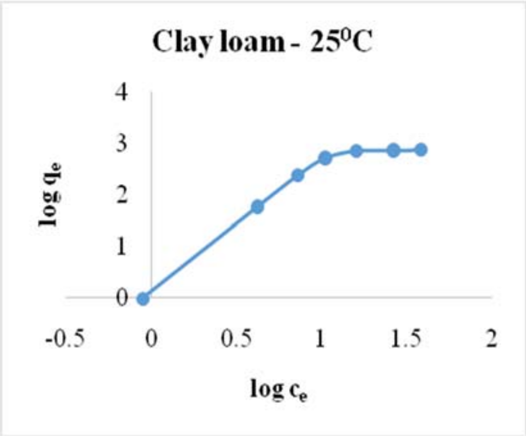
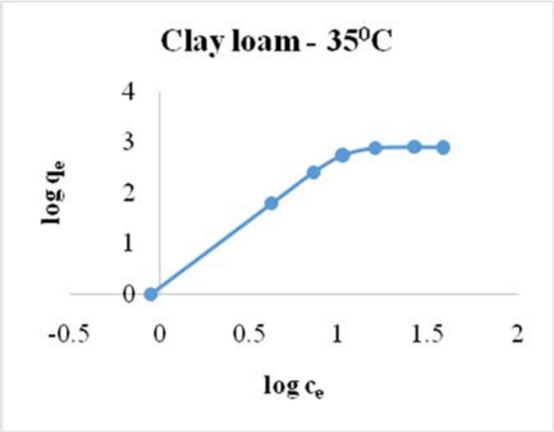
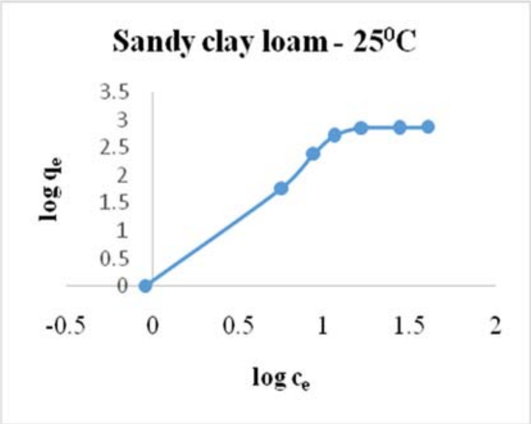


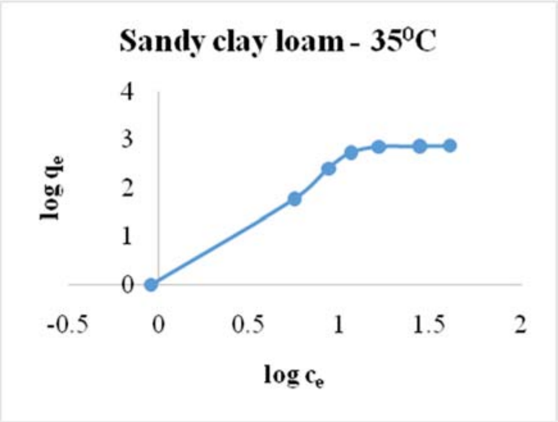
Fig.48. Freundlich adsorption isotherm for copper at 25^0C and 35^0C in April

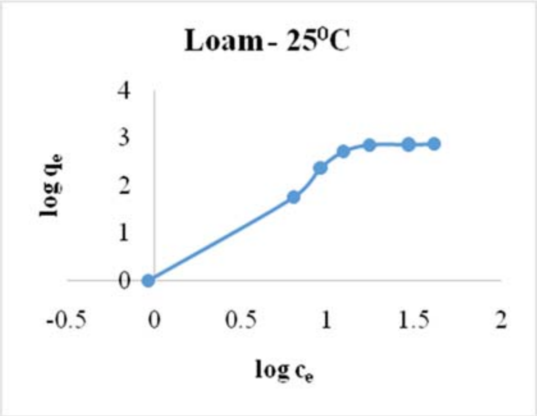


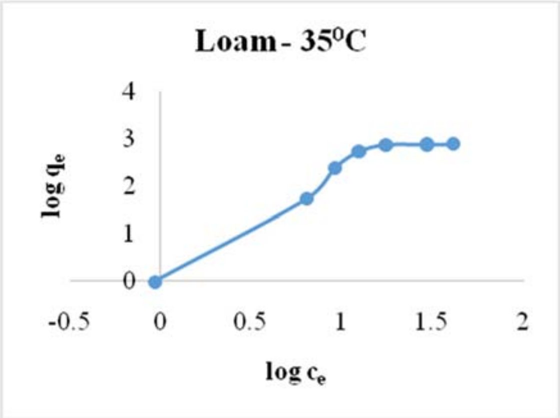

Clay loam - 25^0C


Clay loam - 35^0C


Sandy clay loam - 25^0C


Sandy clay loam - 35^0C


Loam - 25^0C


Loam - 35^0C

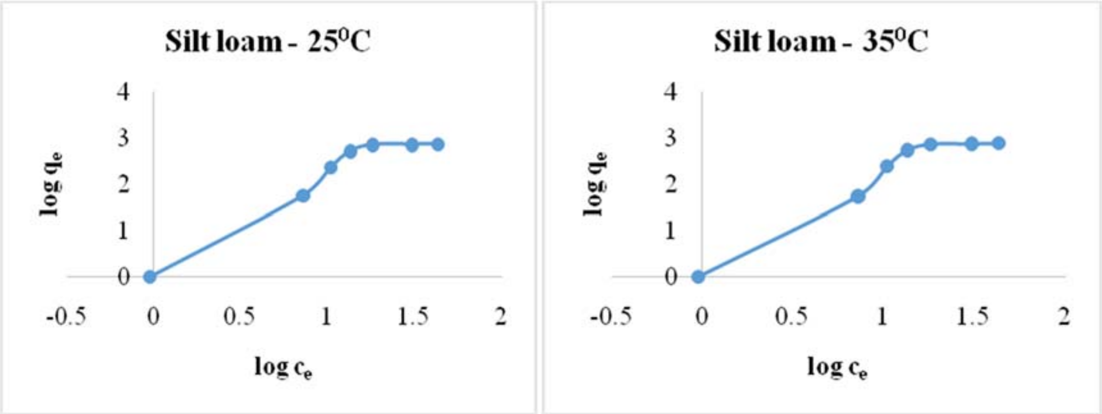
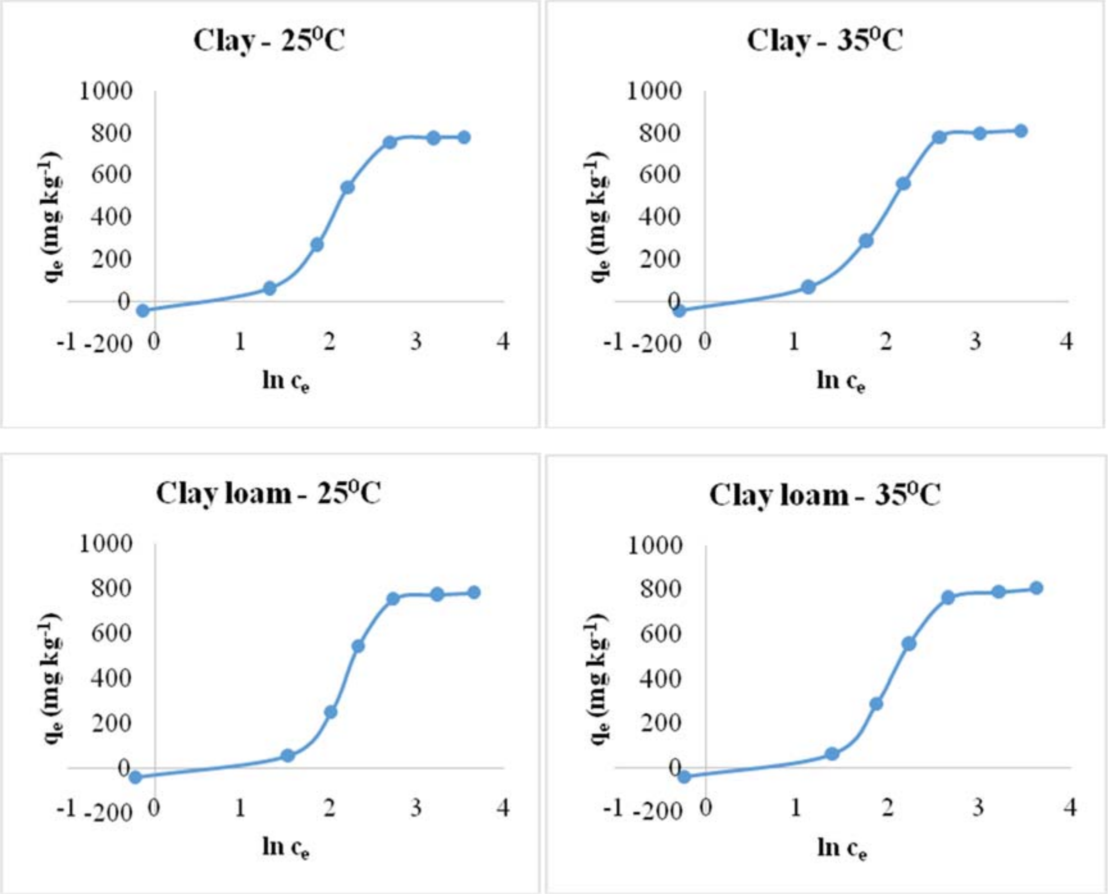
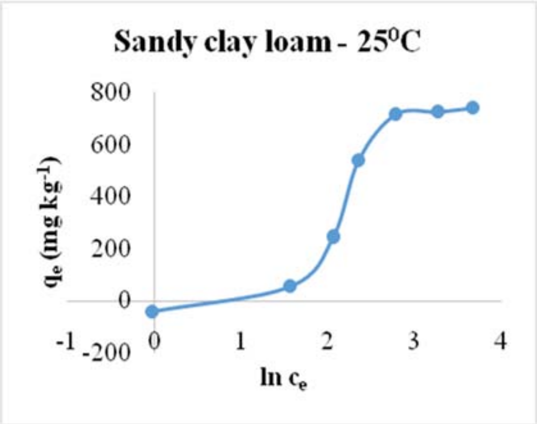
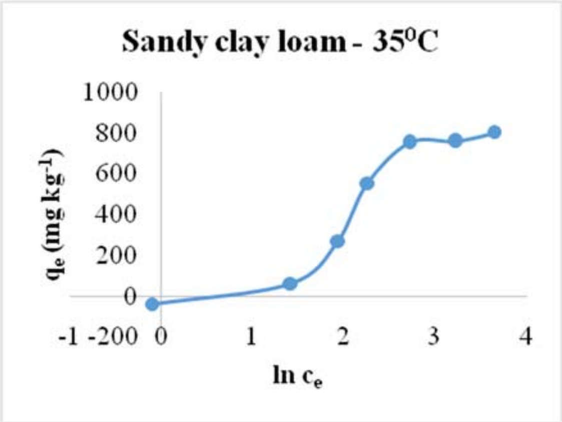
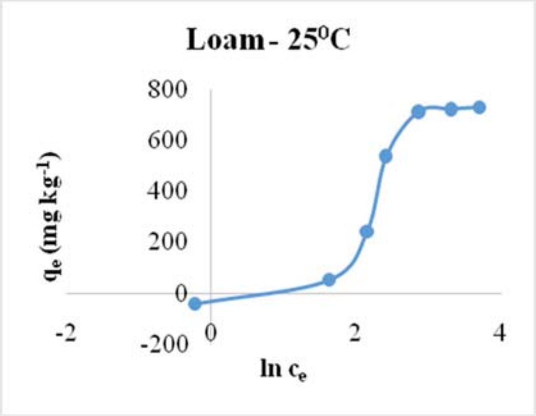


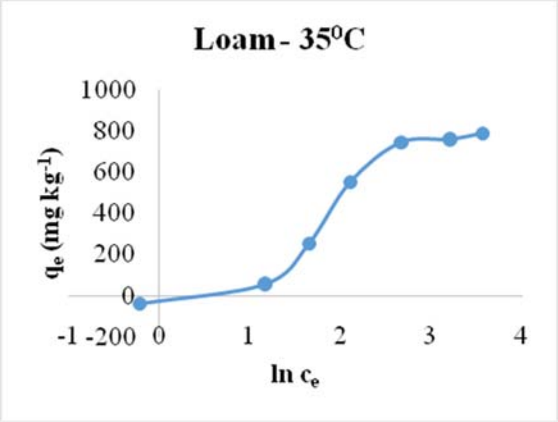
Fig.49. Tempkin adsorption isotherm for copper at 25^{0}C and 35^{0}C in October

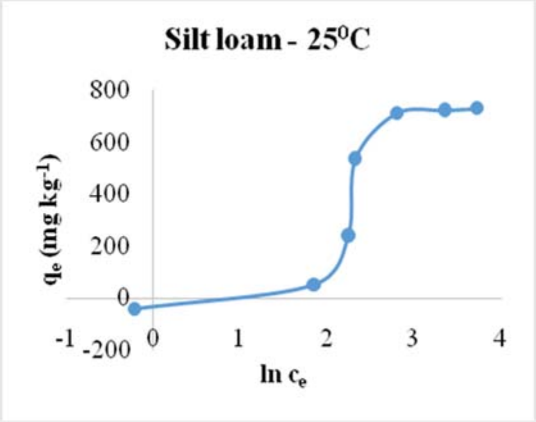


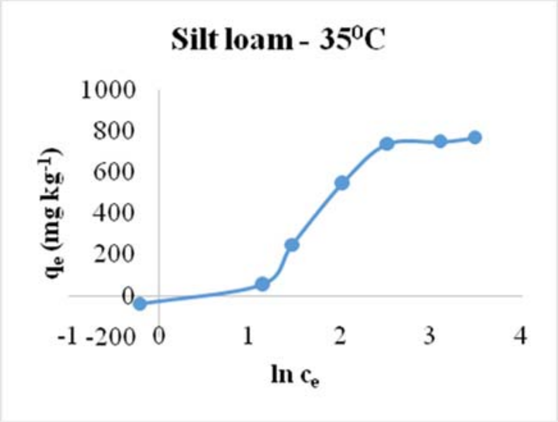

Sandy clay loam - 25⁰C
800
600
400
200
0
-200
qe (mg kg-1)
-1
0
1
2
3
4
ln ce


Sandy clay loam - 35⁰C
1000
800
600
400
200
0
-200
qe (mg kg-1)
-1
0
1
2
3
4
ln ce

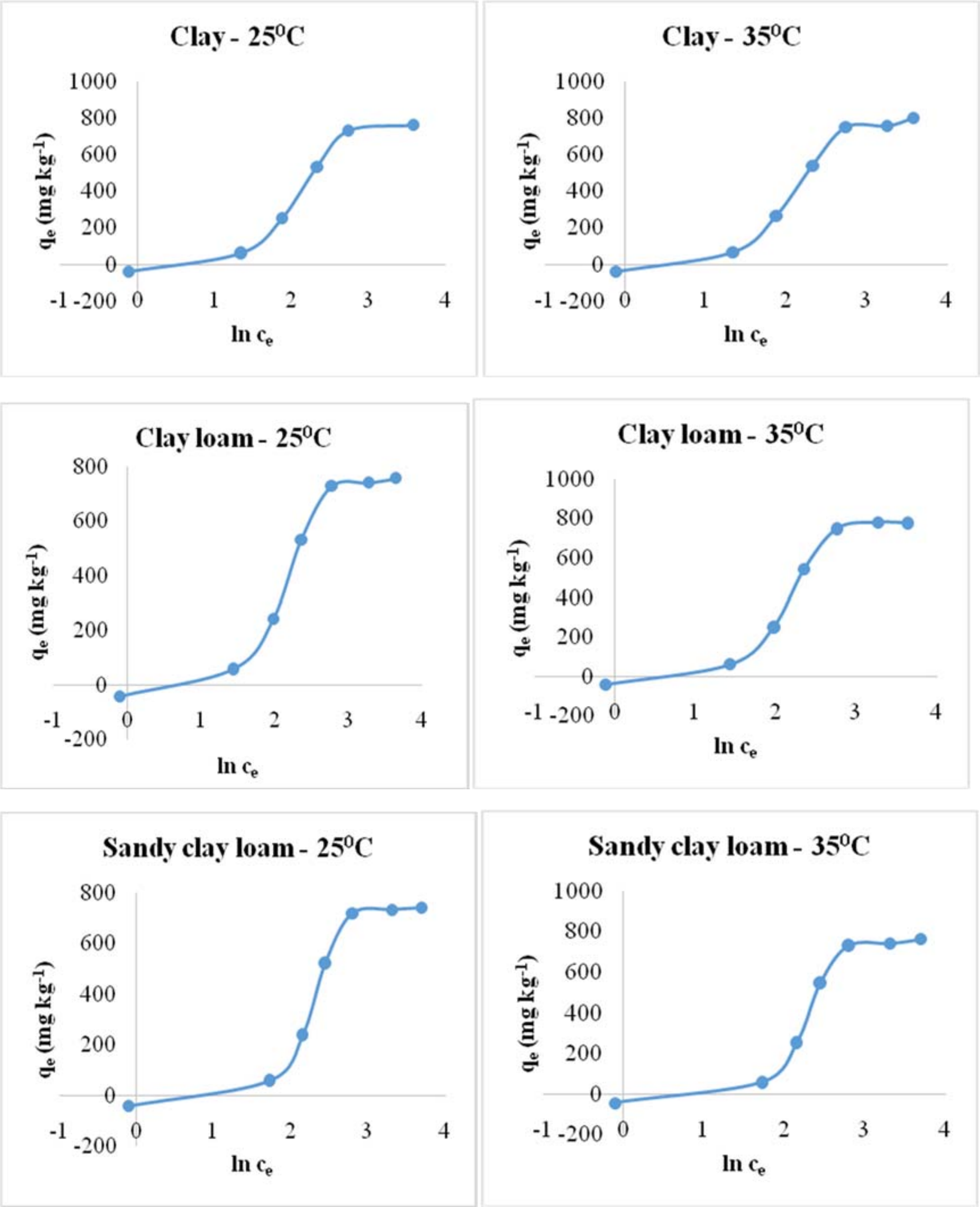

Loam - 25⁰C
800
600
400
200
0
-200
qe (mg kg-1)
-2
0
2
4
ln ce

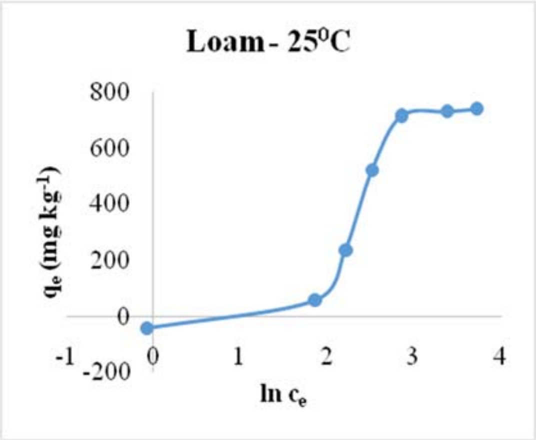

Loam - 35⁰C
1000
800
600
400
200
0
-200
qe (mg kg-1)
-1
0
1
2
3
4
ln ce

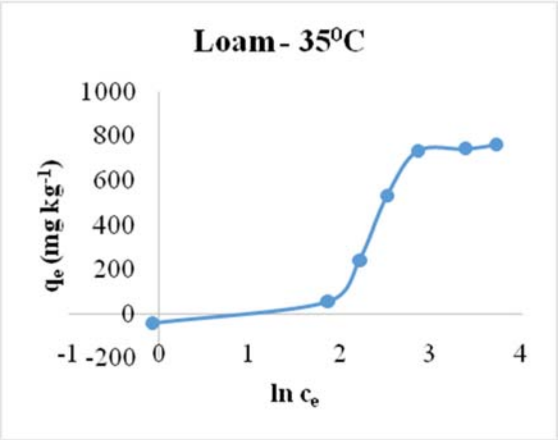

Silt loam - 25⁰C
800
600
400
200
0
-200
qe (mg kg-1)
-1
0
1
2
3
4
ln ce

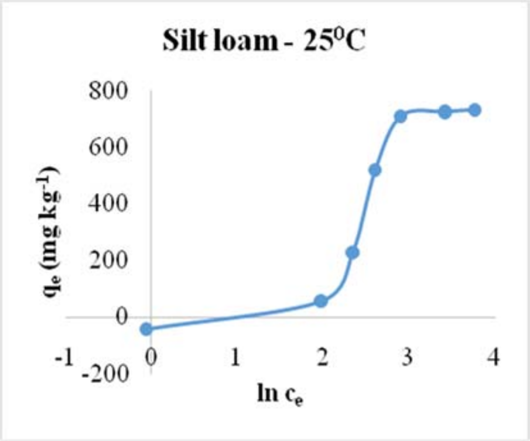

Silt loam - 35⁰C
1000
800
600
400
200
0
-200
qe (mg kg-1)
-1
0
1
2
3
4
ln ce

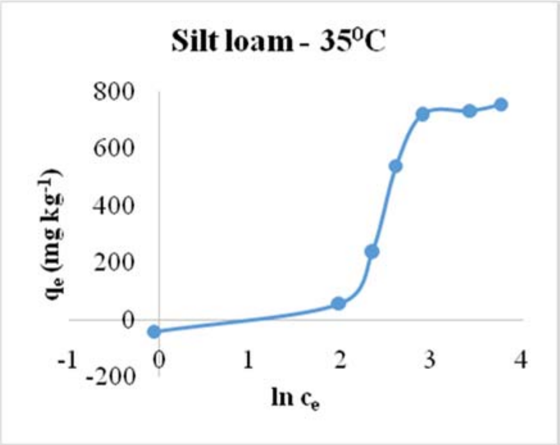
Fig,50. Tempkin adsorption isotherm for copper at 25^{0}C and 35^{0}C in April




Loam - 25⁰C


Loam - 35⁰C


Silt loam - 25⁰C


Silt loam - 35⁰C

Summary

VI. Summary

Representative soil samples were collected 0-20 cm depth from five different land uses (paddy alone, paddy-shrimp, shrimp alone, fallow and mangrove) spread across four different locations (Ezhikkara, Kottuvally, Kadamakudy and Vyttila) of *Pokkali* tract of Ernamkulam district during 2016-17. Soil samples typical of different land uses, standing water, nearby brackish water (that inundates the *Pokkali* tract) and nearby upland soils were collected at bimonthly intervals in a way to coincide with high tide and low tide phases and also the rainy and summer seasons. Thesoil samples (*Pokkali* soil and neighbouring upland soil) were characterised with respect to physical (texture, soil temperature and bulk density) and chemical (pH, EC, OC, CEC, AEC, total N, available P, K, Ca, Mg, S, Zn, Cu, Fe, B and Mn, and heavy metals like Pb, Cd, Ni, Cr, Hg, As and Co) parameters. Biological parameters (population of nitrogen fixing bacteria, dehydrogenase enzyme activity and microbial biomass carbon) were also estimated. Relative humidity, rainfall, soil temperature and redox potential were recorded during soil sample collection. Water samples (both standing water and nearby brackish water were analyzed for pH, EC, TSS total cations (potassium, sodium, calcium, magnesium), anions (sulphate, nitrate, chloride, borate, phosphate, carbonate and bicarbonate) and heavy metals (Pb, Cd, Ni, Cr, Hg, As and Co).

The result showed that temporal variation of soil pH, EC and available nutrient were more prominent during October (low saline phase) and April (high saline phase) months. Based on this two elements *Viz;* phosphorus and copper were selected for carrying out fractionation studies as their availabilitywas mostly pH dependent besides showing wide variations in accordance with seasons. Fractionation study was conducted to identify dominant form in which these nutrients existed and to understand the kinetics of transformations, including solid phase - solution phase equilibria. Sequential fractionation was carried out for P and Cu. Different fractions of P studied included were water soluble P, aluminium bound P, iron bound P, calcium bound P, organic P and residual P. The various copper fractions considered were Water soluble Cu, exchangeable Cu, specifically adsorbed (Pb displaceable) Cu, acid soluble Cu, Manganese oxide bound Cu, Organic matter bound Cu, Amorphous iron oxide bound Cu, Crystalline iron oxide bound Cu and residual Cu.

The nutrients identified for fractionation study *ie,* phosphorus and copper were subjected to adsorption studies to work out the pattern and kinetics of adsorption of these nutrients. Adsorption studies were conducted at two temperatures ie, 25ºC and 35 ºC (lowest and highest soil temperatures during soil sample collections). The quantity-intensity (Q/I) relationship was worked out and the data fitted to various adsorption isotherms *viz;* Langumuir, Freundlich and Tempkin adsorption isotherms to identify the best fit. Thermodynamic of adsorption with respect to the change in enthalpy (ΔH), entropy (ΔS) and free energy (ΔG) were also studied to identify the randomness and spontaneity of adsorption.

The salient results of the study are summarised below:

- Soil texture varied from sandy clay loam to clay in lowlands and sandy clay loam to clay loam in uplands.
- Upland soils showed the dominance of sand compared to lowland soils. Lowland soils dominated in terms of clay content.
- *Pokkali* soils generally showed lower bulk density. Spatial and temporal variation of bulk density was absent in lowlands.
- Maximum soil temperature observed was 35.53°C during April in lowlands and 32.33°C in uplands whereas the minimum soil temperature was 25°C (lowland) and 25°C (upland) in the month of December**.**
- The mean value of soil pH of lowland soil varied from 4.49 to 7.42 (very strongly acidic to neutral pH) whereas acidic pH was observed in April and neutral pH in October
- Upland soils of *Pokkali* tract showed lower pH than lowland soil with values ranging from 4.39 to 4.82 (very strongly acidic) across the seasons and 3.16 to 6.36 (ultra acidic to slightly acidic) among the land uses
- Electrical conductivity ranged from 1.80 (October) to 6.25 dSm^{-1} (April)over the seasons and 2.02 to 6.38 Ds m^{-1} among the land uses. Upland soil also exhibited same trend for electrical conductivity as lowland soil.
- The gradual decrease in the redox potential of lowland soil from June (-177 mV) to October (-300mV) and increase in the redox potential in February (-240mV) and April (-97mV) was another important feature observed.

- Organic carbon was very high in lowlands and uplands (>0.75%). Lowland soil showed higher organic carbon content than upland soil. In case of organic carbon content, spatial and temporal variation was seen in low lands whereas in uplands only spatial variation prevailed.
- Total nitrogen followed same trend as organic carbon in both lowland and uplands.
- Available phosphorus was high (>24 kg ha^{-1}) in all the soil samples irrespective of land uses in lowland and upland soils. In lowland soil, gradual increase in available P from June (75.55 kg ha^{-1}) to October (134.33 kg ha^{-1}) and a sudden decrease in available phosphorus during high saline phase when the soil pH turned to acidic could be noticed. Upland soil showed non-significant variation in available phosphorus among the months. Paddy alone land use in RRS, Vyttila recorded highest phosphorus status (137.87 kg ha^{-1}) among the land uses.
- Available status of potassium was high (>275 kg ha^{-1}) in all soil samples collected from lowlands and uplands. Available potassium decreased from June (955.91kg ha^{-1}) to October (636.51kg ha^{-1}) and increased from December to April (high saline phase). The direct effect of land uses on available potassium was absent.

- Sufficient amount of calcium (>300mgkg^{-1}) and magnesium (>120mgkg^{-1}) were recorded in both lowland and upland *Pokkali* soils. These nutrients were very high during high saline phase compared to low saline phase in both lowland and upland soils. However in respect of calcium and magnesium, some land uses in uplands showed deficiency.
- Available sulphur was reported as sufficient (>10mgkg^{-1}) throughout the months in both lowland and upland soils. Saline water intrusion into the field during high saline phase resulted in very high values of available sulphur in February and April. The intensive leaching losses of soluble sulphates from upland soil caused a reduction in the content of available sulphur compared to lowland soil.
- Available micro nutrients, Fe (>5mgkg^{-1}), Mn (>1mgkg^{-1}), Zn (>1mgkg^{-1}), Cu (>1mgkg^{-1}), and B (>0.5 mgkg^{-1}) were present in sufficient quantity in lowlands. Only B showed deficiency (<0.5 mgkg^{-1}) in uplands of some land uses. All the micro nutrients were higher during high saline phase in lowlands. Temporal

variation of micro nutrients in lowlands was highly significant compared to uplands.

- Available status of heavy metals *viz.*, nickel (<50 mgkg^{-1}), lead (<50 mgkg^{-1}), cobalt (<24 mgkg^{-1}), arsenic (<20 mgkg^{-1}) and mercury (<2 mg kg^{-1}) was very much negligible whereas toxicity due to cadmium (>3 mgkg^{-1}) and chromium (>3 mgkg^{-1}) could be detected in few of the land uses. Temporal variation of available chromium and lead was not seen in lowlands.
- All other heavy metals showed higher quantity during high saline phase. However, the variation was less significant.
- Higher CEC during October (neutral pH) and lower CEC during April (acidic pH) was a prominent feature regarding CEC in lowlands.
- Except exchangeable Ca and Mg, all other exchangeable cations were higher during high saline phase in lowlands.
- Temporal variation of AEC followed the opposite trend of CEC. Uplands showed non-significant variation in CEC and AEC across the seasons.
- Population of nitrogen fixing bacteria, microbial biomass carbon and dehydrogenase enzyme activity were very high in lowland soils compared to uplands. All the three biological properties dominated during low saline phase. Acidity and salinity together made impact on these parameters during high saline phase.
- Spatial and temporal variation in lowlands was prominent for all the soil parameters except BD, OC and TN.
- Land uses showed direct influence in case of available P only. On comparing the effect of land uses and location on nutrient dynamics, the effect of locations was found to be significant.
- Drastic variation in pH was not detected in both field and source water whereas electrical conductivity changed significantly across the seasons. Electrical conductivity values ranged from 2.78 (October) to 29.33 dSm^{-1}(February) in field water and 2.04 (October) to 26.69 dSm^{-1} (February) in source water.
- The mean concentration of water soluble calcium, magnesium, sodium and potassium were found to be higher during high saline phase (December to April) than low saline phase (June to October) in both field and source water.

- The highest value recorded for water soluble calcium, sodium, potassium and magnesium were 222.91, 7157.2, 279.47 and 782.8 mg L^{-1} respectively.
- The concentration of bicarbonate, nitrate, Phosphate and borate did not show much variation between low saline and high saline phases. Whereas concentration of chloride and sulphate in field (1171 to 12878 mg $L^{-1}$for chloride and 74.61 to 435.54 mg $L^{-1}$for sulphate) and source water (106 to 12094 mg $L^{-1}$for chloride and 71.70 to 499.62 mg $L^{-1}$for sulphate) showed the marked effect of temporal variation.
- All the heavy metals nickel, chromium, lead, cobalt, arsenic and mercury were below the detectable limit. Cadmium was detected below the recommended maximum concentration (0.010mgL^{-1}) as per FAO/WHO (2001) in field and source water.
- The average rainfall received in various months during 2017-18 can be represented in the order August> June> October> April> February> December for Ezhikkara and Kottuvally. In Kadamakudy and Vyttila this order can be rearranged as October>August>June> February> April> December. The highest value of rainfall received was 9.76 mm day^{-1} (Ezhikkara and Kottuvally) and 12.23 mm day^{-1} (Kadamakudy and Vyttila).
- S-W monsoon exerted a significant role in varying physico-chemical properties and nutrient dynamics in *Pokkali* soil.
- The highest relative humidity was recorded in June (89.96 % in Ezhikkara and Kottuvally and 90.52 % in Kadamakudy and Vyttila) and the lowest in February (55.26 % in Ezhikkara and Kottuvally and 90.52 % in Kadamakudy and Vyttila) in all the locations. Relative humidity maintained a positive relationship with rainfall.
- Soil pH was negatively and significantly correlated with redox potential, electrical conductivity and available nutrients except available phosphorus in lowland soil.
- Except available phosphorus, all nutrients were positively correlated with electrical conductivity. Saline water intrusion into the fields during high saline phase (December to April) brought about high nutrient status during this period.

- The decrease in available phosphorus from low saline phase to high saline phase might be due to the precipitation of available phosphorus with iron and aluminium in acidic condition (high saline phase).
- Soil pH and anion exchange capacity were significantly and negatively correlated in lowlands.
- Positive correlation of exchangeable sodium with electrical conductivity revealed the contribution of sodium salt towards increasing electrical conductivity in lowlands.
- In lowlands, negative correlation of exchangeable aluminium with soil pH revealed the role of exchangeable aluminium in decreasing soil pH.
- Negative correlation of exchangeable aluminium and available phosphorus disclosed the reason behind the lower availability of phosphorus during high saline phase (lower soil pH) in lowlands.
- In uplands, positive and significant correlation of soil pH with available potassium, calcium and magnesium clearly showed the less availability of these nutrients in acidic soil pH. Negative correlation of soil pH with available iron specified the less solubility of iron in neutral pH.
- Positive correlation of organic carbon with total nitrogen was suggestive of the high fertility status of upland soil.
- Available phosphorus was negatively correlated with available zinc and iron which explained the precipitation of available phosphorus with available zinc and iron in acidic pH of uplands.
- Upland showed positive correlation of electrical conductivity with available potassium, magnesium, sulphur, copper and boron which supported the contribution of salt of these nutrients towards the soil salinity.
- The significant and negative correlation of exchangeable zinc with available phosphorus signified the association of phosphorus with zinc in uplands.The precipitation of Phosphorous with zinc would have been aggravated by the acidic condition of soil prevailing in *Pokkali* tracts.
- Positive relation of soil (upland) pH with biological properties reflected the promotional effect of higher pH on biological activity, especially while shifting towards neutral range.

- Negative correlation of electrical conductivity with biological properties implied that salt content adversely affected the biological properties of upland soil.
- All the cations and anions except nitrate significantly and positively correlated with EC and TSS values thereby ensuring the contribution of cations and anions in the field and source water towards the salinity build up.
- All the cations and anions in the water samples positively and significantly correlated with soil EC and negatively and significantly correlated with soil pH. Also, all the cation and anions in the water samples significantly and positively correlated to all the available nutrients except available phosphorus which emphasised that marine influence elevated the content of all the nutrients except available phosphorus during high saline phase in *Pokkali* soil.
- All fractions of P were very high in *Pokkali* soil
- Temporal variation of all the P fractions was clearly evident in *Pokkali* soil.
- Ws-P, Ca-P and residual-P were very high during October. All other fractions were high during April.
- P fractions investigated in the month of October and April could be arranged in the order Fe-P > Ca-P > Org-P > Occl-P > Al-P > Ws-P and Fe-P > Occl-P > Org-P > Al-P > Ca-P > Ws-P correspondingly.
- High content of organic P was observed in shrimp land use in all the locations. This might be due to the high organic matter content in soil and the highly organic nature of the feed materials.
- The highest calcium P detected in shrimp alone land use in Ezhikkara, Kotuvally and Kadamakudy could be due to the deposition of shrimp shell in the field. But in the case of other P fractions like Fe-P, Al-P, Occlu-P and water soluble P, land uses didn't have any direct effect.
- Water soluble P positively correlated with soil pH and negatively correlated with Al-P.
- Org- P and Al-P were the dominant fractions present in *Pokkali* soil during October and April respectively.
- During October, water soluble P was not identified as such but in immediate equilibrium with Al-P, Org-P, and Occl-P. At neutral pH, availability of P in

Pokkali soil was found to be dependent highly on the fractions like Fe-P, Al-P, Org-P, and Occl-P.

- During April month, when soil pH remained acidic the direct and negative effect of Fe-P, Occl-P and Org-P to available P indicated precipitation of P with iron, occlusion of P during sesquioxide formation and immobilisation of P mineralisation respectively.
- Org-P was the dominant fraction that contributed positively towards available P in October whereas in April it was Al-P followed by water soluble P.
- The direct and high positive effect of Al-P to available pool during April might be due to the availability of freshly precipitated P with various Al hydrous oxide, which over time would become increasingly unavailable.
- Temporal variation of all the Cu fractions was clearly evident in *Pokkali* soil.
- Ws-Cu, Ex-Cu and residual Cu were high during high saline phase (April). All other fractions were high during low saline phase (October).
- The mean per cent contribution of different fractions to total Cu in October and April followed the order Org-Cu> Mn Oxide Cu > Residual Cu> Amo-FeO-Cu > Cry.FeO-Cu > Aci-sol- Cu > Spe.ads.Pb-Cu > Ws-Cu > Ex.-Cu and Residual>Ws-Cu> Org-Cu > Ex.-Cu. > Aci-sol- Cu > Cry.FeO-Cu > Spe.ads.Pb-Cu > Amo.FeO-Cu > Mn Oxide Cu.
- Land uses did not show any direct effect on distribution of copper fractions. All the land uses showed same trend in copper fractions across the seasons.
- Significant and negative correlation of water soluble and exchangeable Cu with MnOx-Cu, Amo.FeO-Cu and Cry.FeO-Cu was detected.
- Negative correlation values of water soluble and exchangeable fraction with soil pH confirmed the availability of copper in acidic soil pH.
- Exchangeable copper was the major fraction which contributed positively towards the available pool duringOctober.
- Organic matter followed by water soluble fractions constituted the dominant copper fractions contributing positively towards available copper during April.
- L and S-shaped curves were obtained for P and Cu adsorption respectively in *Pokkali* soils.
- Adsorption of P and Cu increased with increase in soil temperature.

- P adsorption was high during high saline phase (April) whereas Cu adsorption was high during low saline phase (October).
- Maximum quantity of P and Cu adsorbed wsas characteristic of clay soil.
- Adsorption of P and Cu among various soil textures obeyed the order clay>clay loam>sandy clay loam>loam>silt loam.
- Adsorption of P was mainly on inorganic. oxide and hydroxide surface whereas adsorption of Cu was mainly on organic.
- Maximum quantity adsorbed at 25^0C as well as 35^0C and buffer power at 25^0C as well as 35^0C made very high positive correlation with Fe-P and Occlu-P which mentioned that phosphorus in *Pokkali* soil is mainly adsorbed onto inorganic surface.
- Freundlich adsorption isotherm was found best to explain P adsorption followed by Tempkin and Langmuir adsorption isotherm.
- Adsorption data of Cu could not be fitted into Langmuir adsorption isotherm whereas it found best to fit in Freundlich adsorption isotherm followed by Languimuir adsorption isotherm.
- Adsorption of both P and Cu was spontaneous and endothermic in nature.

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SPATIAL AND TEMPORAL VARIATIONS IN NUTRIENT DYNAMICS IN *POKKALI* SOILS OF KERALA

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ABSTRACT OF THE THESIS

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ABSTRACT

The *Pokkali* soils *(Typic Sulfaquents)* are low land soils situated below the mean sea level, located along the coastal tracts of Alappuzha, Ernamkulam and Thrissur districts. These soils are acid saline in nature where shrimp/prawn farming is practiced during high saline phase (December to April) coinciding with sea water entry followed by cultivating the salt tolerant *Pokkali* rice during low saline phase (June to October) when the dilution of salts occurs after South West monsoon. Only very few studies have been undertaken so far on nutrient status in *Pokkali* soils. Wide variations in nutrient content ranging from deficient to toxic level were reported in these studies. A comprehensive study is very much essential to unravel the seasonal and temporal variations of nutrient dynamics in *Pokkali* soils.

The soil samples (lowland soils and neighbouring upland soils) from different land use systems and the water samples (both standing water and nearby brackish water inundating the *Pokkali* tract) were collected at bimonthly intervals starting from June 2017 to April 2018 to understand the nutrient dynamics in these soils with respect to spatial and temporal variation and to find out the influence of source water on them. Physico-chemical properties and biological properties of the collected soils were analysed. Salt water intrusion during high saline phase into *Pokkali* fields caused drastic increase in electrical conductivity, decrease in soil pH and associated changes in available plant nutrients. A gradual decrease in redox potential from June to October and increase from December to April were also observed as an influence of sea water intrusion. The south west monsoon received during the low saline phase played a significant role in diluting soil salinity and loss of H^+ ions from top soil, thus affecting the soil nutrient dynamics in total.

High content of available plant nutrients and the change in nutrient content with respect to spatial and temporal variations were observed in low land soils compared to the nearby upland soils. Spatial variation of all available nutrients except phosphorus was highly influenced by the nearness of brackish water rather than the type of land use system. Highest available phosphorus recorded in paddy alone land use might be due to the phosphorus mineralisation from left out crop stubbles in paddy field. Some land uses in uplands showed deficiency of available Ca, Mg and B also. In terms of temporal variation, all nutrients except available phosphorus remained very

high during high saline phase as influenced by marine water whereas availability of phosphorus was highly influenced by soil pH. High acidity and salinity during high saline phase adversely affected the soil biological properties.

Fractionation of phosphorus and copper was carried out to study their major fractions and to ascertain their contribution to the available pool. All the P fractions were high in *Pokkali* soil. Temporal variation of all the P fractions was also prominent in *Pokkali* soil. Ws-P, Ca-P and residual-P were very high in October (low saline phase) whereas other fractions were high in April (high saline phase). Effect of land uses on P fractions was absent except for Org-P and Ca-P. Temporal variation of all the Cu fractions was clearly evident in *Pokkali* soil. Ws-Cu, Ex-Cu and residual Cu were high in April (high saline phase). All other fractions were high in October (low saline phase). Land uses did not show any direct effect on distribution of copper fractions. All the land uses showed same trend in copper fractions across the seasons.

Phosphorus adsorption was high in April (high saline phase) whereas Cu adsorption was high in October (low saline phase). L and S-shaped curves were obtained for P and Cu adsorption respectively. Adsorption of P and Cu increased with increase in soil temperature. Adsorption of P and Cu among various soil textural classes followed the order clay>clay loam>sandy clay loam>loam>silt loam. Adsorption of P was mainly in inorganic forms *ie.* oxide and oxy hydroxides of Fe and Al surface whereas that of Cu was mainly in organic form. Freundlich adsorption isotherm was found as the best to explain the adsorption of P and Cu in *Pokkali* soils. Adsorption of both P and Cu was spontaneous and endothermic in nature.

Low and high saline phases attributed to variations in physico-chemical and biological properties of *Pokkali* soils. South West monsoon caused leaching losses of nutrients particularly potassium, sulphur, magnesium and boron during low saline phase. The presence of brackish water source nearer to field had more effect on nutrient dynamics in *Pokkali* soils, rather the type of land use system. The influence of temperature on nutrient was visible in the quantity –intensity relations of P and Cu. The present study has clearly shown that the nutrient dynamics in *Pokkali* soils is influenced more by temporal variations than the spatial variations.

സംഗ്രഹം

കേരളത്തിലെ പൊക്കാളി മണ്ണിലെ പോഷക മൂലക പരിവർത്തനങ്ങളുടെ സ്ഥല-സമയ സംബദ്ധമായ വ്യത്യാസങ്ങൾ

പൊക്കാളി മണ്ണ് ആലപ്പുഴ, എർണാകുളം, തൃശ്ശൂർ ജില്ലകളിലെ തീരപ്രദേശത്ത് സമുദ്ര നിരപ്പിനു താഴെയായി സ്ഥിതി ചെയ്യുന്നു. അമ്ല-ലവണാംശ ഗുണമുള്ള ഈ മണ്ണിൽ വേലിയേറ്റ സമയത്ത് (ഡിസംബർ-ഏപ്രിൽ) ചെമ്മീൻ കൃഷിയും വേലിയിറക്ക സമയത്ത് (ജൂൺ -ഡിസംബർ) ഉപ്പു ഉപ്പ് രസത്തിന് പ്രധിരോധ ശക്തിയുള്ള പൊക്കാളി നെല്ലും കൃഷി ചെയ്ത് വരുന്നു. വിരളമായ പഠനങ്ങളാണ് പൊക്കാളി മണ്ണിലെ മൂലകങ്ങളെ അടിസ്ഥാനമാക്കി നടന്നിട്ടുള്ളത്. മൂലകങ്ങളുടെ ആധിക്യത്തെയും അപര്യാപ്തതയും പറ്റിയുള്ള പഠനം പൊക്കാളി മണ്ണിൽ നടത്തിയിട്ടുള്ളതാണ്. പൊക്കാളി മണ്ണിലെ പോഷക മൂലകങ്ങളുടെ സ്ഥല-സമയ ബന്ധമായ പരിവർത്തനങ്ങൾ മനസിലാകുന്നതിന് വേണ്ടി സമഗ്രമായ പഠനം അത്യന്താപേഷിതമാണ്.

പൊക്കാളി മണ്ണിലെ പോഷക മൂലകങ്ങളുടെ സ്ഥല-സമയ ബന്ധമായ പരിവർത്തനങ്ങൾ പഠിക്കുന്നതിനു വേണ്ടിയും ഉപ്പ് വെള്ളം പൊക്കാളി മണ്ണിനെ എങ്ങനെ സ്വാധീനിക്കുന്നു എന്ന് മനസിലാകുന്നതിന് വേണ്ടിയും വിവിധ ഭൂ വിനിയോഗ വ്യവസ്ഥകളിൽ നിന്ന് മണ്ണ് സാമ്പിളുകളും ജല സാമ്പിളുകളും രണ്ടു മാസത്തെ ഇടവേളകളിൽ 2017 ജൂൺ മാസം മുതൽ 2018 ഏപ്രിൽ മാസം വരെ ശേഖരിക്കുകയും പൊക്കാളി മണ്ണിലെ ഭൗധിക- രാസ -ജീവശാസ്ത്രപരമായ സവിശേഷതകൾ വിശകലനം ചെയ്യുകയും ചെയ്തു. ഉപ്പു വെള്ളം പൊക്കാളി മണ്ണിലേക്ക് പ്രവേശിക്കുന്നത് വൈദ്യുത ചാലകത കൂടുന്നതിനും മണ്ണിലെ പി എച് മൂല്യം കുറയുന്നതിനും പോഷക മൂലകങ്ങളിലെ അളവിലുള്ള വ്യത്യാസങ്ങൾക്കും കാരണമാകുന്നു. ഓക്സികരണ നിരോക്സികരണ പ്രവർത്തനങ്ങളുടെ തോത് ജൂൺ മുതൽ ഒക്ടോബർ വരെ കുറയുന്നതായും ഡിസംബർ മുതൽ ഏപ്രിൽ വരെ കൂടുന്നതായും കാണപ്പെട്ടു. തെക്ക്-പടിഞ്ഞാറൻ കാലവർഷം പൊക്കാളി മണ്ണിലെ ഉപ്പ് കുറക്കുന്നതായും, H^+ അയോൺ പൊക്കാളി മണ്ണിൽ നിന്നും നഷ്ടപെടുന്നതായും, ഇത് പൊക്കാളി മണ്ണിലെ മൂലകങ്ങളുടെ പരിവർത്തനത്തെ ബാധിക്കുന്നതായും കണ്ടു. ഉയർന്ന പ്രദേശത്തേക്കാൾ വിളകൾക്ക് ലഭ്യമാകുന്ന പോഷക മൂലകങ്ങളുടെ ആധിക്യവും, പോഷക മൂലകങ്ങളുടെ സ്ഥല -സമയ സംബദ്ധമായ പരിവർത്തനവും കൂടുതലായി കാണപ്പെട്ടത് പൊക്കാളി പാടത്താണ്. ഭാവഹം ഒഴിച്ച് ബാക്കി എല്ലാ മൂലകങ്ങളുടെയും സ്ഥല സംബന്ധമായ വ്യത്യാസം ഭൂ വിനിയോഗ വ്യവസ്ഥകളെക്കാളും ആ സ്ഥലം കായലിനോട് എത്രത്തോളം അടുത്ത് സ്ഥിതി ചെയ്യുന്നു എന്നതിനെ ആശ്രയിച്ചിട്ടാണിരിക്കുന്നത്. പൊക്കാളി കൃഷി ചെയ്യുന്ന സ്ഥലത്ത് വിളകൾക്ക് ലഭ്യമാകുന്ന ഭാവഹം അധികമായി കണ്ടത് ധാന്യം കൊയ്തശേഷം അവശേഷിക്കുന്ന കുറ്റിയിൽ നിന്നും ഭാവഹം ലഭ്യമായത് കൊണ്ടാകാം.

ഉയർന്ന പ്രദേശത്തുള്ള ചില ഭൂ വിനിയോഗ വ്യവസ്ഥകളിൽ കാൽസ്യം, ബോറോൺ, മഗ്നീഷ്യം എന്നീ പോഷക മൂലകങ്ങളുടെ അപര്യാപ്തത കാണപ്പെട്ടു. ഭാവഹം ഒഴിച്ച് ഭാക്കി എല്ലാ പോഷക മൂലകങ്ങളും പൊക്കാളി മണ്ണിൽ വേലിയേറ്റ സമയത്ത് വളരെയധികം കൂടുന്നതായും, എന്നാൽ ഭാവഹത്തിന്റെ ലഭ്യത വേലിയിറക്ക സമയത്തു കൂടുന്നതായും കാണപ്പെട്ടു. പൊക്കാളി മണ്ണിലെ അമ്ലത്വവും ഉപ്പുരസവും ജീവശാസ്ത്രപരമായ ഗുണങ്ങളെ വിപരീതമായി ബാധിച്ചു.

പൊക്കാളി മണ്ണിലെ ഭാവഹം, കോപ്പർ എന്നീ മൂലകങ്ങളുടെ മണ്ണിലെ വിവിധ ഘടകങ്ങൾ അറിയുന്നതിനും, ഈ ഘടകങ്ങൾക്ക് സസ്യ ലഭ്യതയിലേക്കുള്ള പങ്ക് അറിയുന്നതിന് വേണ്ടിയും ഭാവഹം, കോപ്പർ എന്നീ മൂലകങ്ങളുടെ ഘടകങ്ങളെ വേർതിരിക്കുന്നതിനുള്ള പരീക്ഷണം നടത്തുകയുണ്ടായി. ഭാവഹത്തിന്റെ എല്ലാ ഘടകങ്ങളും പൊക്കാളി മണ്ണിൽ കൂടുതലാണ്. ഭാവഹത്തിന്റെ എല്ലാ ഘടകങ്ങളുടെയും സമയബന്ധിതമായ വ്യത്യാസം പൊക്കാളി മണ്ണിൽ വ്യക്തമായി കാണപ്പെട്ടു. വേഗത്തിൽ ലയിക്കുന്ന ഭാവഹം, കാൽസ്യവുമായി ബന്ധപ്പെട്ട ഭാവഹം, അവശേഷിക്കുന്ന ഭാവഹം എന്നിവ പൊക്കാളി മണ്ണിൽ വേലിയിറക്ക സമയത്ത് കൂടുന്നതായും ഭാക്കി എല്ലാ ഘടകങ്ങളും വേലിയേറ്റ സമയത്ത് കൂടുന്നതായും കാണപ്പെട്ടു. ഭൂ വിനിയോഗ വ്യവസ്ഥകളുടെ സ്വാധീനം ജൈവ കാർബണുമായി ബന്ധപ്പെട്ട ഭാവഹം, കാൽസ്യവുമായി ബന്ധപ്പെട്ട ഭാവഹം എന്നീ ഘടകങ്ങളിൽ മാത്രമേ കാണപ്പെട്ടൊള്ളു. കോപ്പറിന്റെ ഘടകങ്ങളുടെ സമയബന്ധിതമായ വ്യത്യാസങ്ങൾ പൊക്കാളി മണ്ണിൽ വളരെയധികം പ്രകടമായിരുന്നു. വേഗത്തിൽ ലയിക്കുന്ന കോപ്പർ, അവശേഷിക്കുന്ന കോപ്പർ എന്നിവ പൊക്കാളി മണ്ണിൽ വേലിയേറ്റ സമയത്ത് കൂടുതലായി കാണപ്പെട്ടു. കോപ്പേരിന്റെ മറ്റു അംശങ്ങളെല്ലാം പൊക്കാളി മണ്ണിൽ വേലിയിറക്ക സമയത്ത് കൂടുതലായി കാണപ്പെട്ടു. ഭൂ വിനിയോഗ വ്യവസ്ഥകൾക്ക് കോപ്പേരിന്റെ ഘടകങ്ങളുടെ മേൽ യാതൊരു സ്വാധീനവും ഇല്ല. കോപ്പറിന്റെ എല്ലാ ഘടകങ്ങളും എല്ലാ ഭൂ വിനിയോഗ വ്യവസ്ഥകളിലും എല്ലാ സമയത്തും ഒരേ പ്രവണത കാണിച്ചു.

ഭാവഹത്തിന്റെ ശോഷണം ഏപ്രിൽ മാസത്തിലും കോപറിന്റെ ശോഷണം ഒക്ടോബർ മാസത്തിലും കൂടുതലായി കാണപ്പെട്ടു. ഭാവഹത്തിന്റെ ശോഷണ വളവ് എസ് രൂപത്തിലും, കോപ്പറിന്റെ ശോഷണ വളവ് എൽ രൂപത്തിലും ആണ്. പൊക്കാളി മണ്ണിലെ താപനില ഉയരുന്നതിനനുസരിച്ച് ഭാവഹത്തിന്റെയും കോപ്പേറിന്റെയും ശോഷണം പൊക്കാളി മണ്ണിൽ കൂടുന്നതായി കാണപ്പെട്ടു. ഭാവഹത്തിന്ടെയും കോപ്പേറിന്ടെയും ശോഷണം വിവിധ രചനകളിലുള്ള മണ്ണിൽ താഴെ പറയുന്ന പ്രകാരം ആകുന്നു കളി മണ്ണ് >ക്ലേ ലോം >സാൻഡി ക്ലേ ലോം >ലോം >സിൽട് ലോം. ഭാവഹത്തിന്റെ ശോഷണം പ്രധാനമായും ജഡികമായ രൂപത്തിലാണ്. എന്നാൽ കോപറിന്റെ ശോഷണം പ്രധാനമായും ജൈവികമായ രൂപത്തിലാണ്. ഫ്രണ്ട്ലിച് മോഡലിന് കൂടുതൽ കൃത്യതയോടും വ്യക്തതയോടും കൂടി അധിശോഷണ പ്രക്രിയ അവതരിപ്പിക്കാൻ കഴിഞ്ഞു. പൊക്കാളി മണ്ണിൽ ഭാവഹതിന്റെയും കോപ്പേറിന്റെയും അധിശോഷണ പ്രക്രിയ യാദൃശ്ചികവും ഉള്ളിൽ നിന്നും താപം വര്ജിക്കുന്നതുമായതാണ്.

വേലിയേറ്റവും വേലിയിറക്കവുമാണ് പൊക്കാളി മണ്ണിലെ ഭൗതികവും, രസതന്ത്രവും, ജീവശാസ്ത്രപരവുമായ ഗുണങ്ങളെ നിയന്ത്രികുന്നത്. തെക്കു പടിഞ്ഞാറൻ കാലവർഷം വേലിയിറക്ക സമയത്ത് പൊക്കാളി മണ്ണിൽ നിന്ന് പോഷക മൂലകങ്ങൾ പ്രത്യേകിച്ച് ക്ഷാരം, സൾഫർ, മഗ്നീഷ്യം, ബോറോൺ എന്നിവ ഒലിച്ചുപോകാൻ കാരണമാകുന്നു. ഭൂവിനിയോഗ വ്യവസ്ഥകളെക്കാളും പൊക്കാളി മണ്ണിനടുത്തുള്ള കായലിലെ വെള്ളമാണു പൊക്കാളി മണ്ണിലെ പോഷക മൂലകങ്ങളുടെ പരിവർത്തനത്തിന് കാരണമാകുന്നത്. മണ്ണിലെ താപനിലക്ക് പോഷക മൂലകങ്ങളുടെ മേലുള്ള സ്വാധീനം ശോഷണ പ്രക്രിയയിൽ വ്യക്തമായിട്ടുണ്ട്.

സമയ സംബന്ധമായ വ്യത്യാസങ്ങൾ ആണ് സ്ഥല സംബന്ധമായ വ്യത്യാസങ്ങളെക്കാളും പൊക്കാളി മണ്ണിലെ മൂലകങ്ങളുടെ പരിവർത്തനത്തിന് കാരണമാകുന്നതെന്ന് ഈ പഠനത്തിലൂടെ വ്യക്തമായി.