Management of soil salinity with calcium salts in rice–prawn farming system in *Pokkali* lands

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DECLARATION

I, hereby declare that this thesis entitled **"MANAGEMENT OF SOIL SALINITY WITH CALCIUM SALTS IN RICE–PRAWN FARMING SYSTEM IN *POKKALI* LANDS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis of award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Certified that this thesis **entitled "MANAGEMENT OF SOIL SALINITY WITH CALCIUM SALTS IN RICE–PRAWN FARMING SYSTEM IN *POKKALI* LANDS"** is a record of research work done independently by Ms. Diya P.V.. under my guidance and supervision and that it is not previously formed the basis for award of any degree, diploma, fellowship or associateship to her.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

APH	After Prawn Harvest
ARH	After Rice Harvest
BC ratio	Benefit-Cost ratio
@	at the rate of
CD	Critical Difference
cm	centimetre
c mol (+)kg^{-1}	centimol proton per kilogram
RBD	Randomized Block Design
^{o}C	degree Celsius
dS m^{-1}	deci Siemen per metre
EC	Electrical Conductivity
et al	and coworkers
Fig	Figure
g	gram
KAU	Kerala Agricultural University
kg	kilogram
kg ha^{-1}	kilogram per hectare
Mg m^{-3}	Megagram per meter cube
M	metre
m^2	metre square
meq	milliequivalent
MBC	microbial biomass carbon
$\mu g\ g^{-1}$	microgram per gram
mg kg^{-1}	milligram per kilogram
mm	millimetre
M	Molar

Mm	Millimolar
N	normal
NH4OAc	Neutral normal ammonium acetate
No.	Number
%	Per cent
pH	Soil reaction
ppm	parts per million
SAR	Sodium absorption ratio

Introduction

INTRODUCTION

The coastal wetlands of Kerala, occupying 13 per cent of the total geographical area of the state plays important roles in ecology, economy and social well-being of the people. Wet land ecosystems of Kerala include low lying marshy and water logged areas. Because of the unique and specific ecological conditions, no other type of agriculture would be possible other than cultivation of rice. People grow saline tolerant rice varieties in the low lying marshes and swamps situated near the estuaries of streams and rivers not far from the sea along with traditional capture based aquaculture in many places over many centuries. This characteristic type of cultivation is traditionally known as *Pokkali* cultivation. The term *Pokkali* refers to a salt tolerant rice cultivar. The areas of *Pokkali* cultivation are famous as *Pokkali* land and the rice produced in this tract is famous as *Pokkali* rice. *Pokkali* tracts are distributed in coastal belts of Ernakulam, Alappuzha and Thrissur districts. Specifically Kochi, Kanayannur, Paravur, Thrissur and Kodungallor taluks.

The rice cultivation starts with south west monsoon, in the low saline phase till October. During monsoon fresh water from the rivers enter the field, salinity is diluted and partially washed off. From November onwards salinity builds up and the field is unsuitable for paddy cultivation. Fish farming or prawn cultivation is followed in these high saline phase. Tidal flows make the field fertile. There should not be any hindrance for natural tidal flow of water for a sustainable paddy production. This helps pond sediments to fertilize the rice crops resulting in avoiding chemical fertilizer use for rice production making a natural organic rice production system having less production cost. It is an integrated system in which one season of rice farming is alternated with another season of prawn culture. Absence of *Pokkali* farming may lead to flooding of entire area, increased acidity, salinity and ionic toxicity, less oxygen and there will be more hydrogen sulphide accumulation in the soils. All this can be effectively removed by various farming operations.

17

Pokkali soils are the major salt affected soils in Kerala. Salinity, acidity and waterlogging are three major challenges of *Pokkali* cultivation apart from other environmental issues. The soil is highly acidic, with pH 3.0-4.5. The range of electrical conductivity values of *Pokkali* soils varied from 0.1 to 4.0 dS m^{-1} in low saline phase. Toxic salt accumulation is maximum in summer months when electrical conductivity rises to the range of 10 to 15 dS m^{-1}. Salinization is a major growth limiting factor leading to poor crop production and crop failures. Rice crop is moderately sensitive to salinity. Plant growth is affected by salinity at all stages of development. Excess salt in the root zone causes osmotic imbalance and ionic toxicity and it is capable of modifying nutritional status in soil as well as plant. Excess sodium present in the saline environment create adverse conditions for plant growth. It promotes dispersion of soil aggregates leading to reduced infiltration and soil permeability. Plants take up more Na than Ca and K and reduces its selectivity. Lower concentration of these ions affect salt tolerance capacity of the species. Salinity can negatively affect basic functions of plants like photosynthesis. It was reported that higher salinity can reduce panicle initiation, number of tillers, grain yield, dry matter content and eventually the total yield in rice.

Hence control or management of soil salinity is essential for a better crop production as well as for its continued use for livelihood support. Calcium has been found as an ameliorant against adverse effect of salinity. Many works have been carried out to restore the fertility in *Pokkali* tracts and managing salinity and acidity. Furthermore research and trials are needed to improve the yield as well as adaptability to different environmental conditions.

Hence the present study was under taken on management of soil salinity with calcium salts in rice–prawn farming system in *Pokkali* lands, with the following objectives.

- To manage soil salinity by application of calcium salts in *pokkali* lands
- To assess the effect of calcium salts on the growth and nutrition of rice, yield of prawn and soil properties

Review of Literature

REVIEW OF LITERATURE

Pokkali is one of the unique variety of rice, cultivated in the water-logged coastal saline acid soils of Kerala. The areas of *Pokkali* cultivation are famous as *Pokkali* land and these are tidal wetlands characterized by multi stressed conditions such as acidity, salinity and waterlogging. The *Pokkali* rice-shrimp rotational farming system prevalent in traditional paddy fields is a classic example of sustainable agri- aqua integration. It is a unique ecosystem situated adjacent to Vembanad lake with rich biodiversity and capacity to produce rotational paddy and shrimp organically. Fluctuations in concentration of salts in soil solution and acidity are common because of water supply, drainage, evaporation and transpiration which makes poor crop production. The salinity in the area can be overcome by ameliorative effect of Ca by improving soil conditions and thereby crop production.

2.1. Pokkali cultivation

Pokkali fields are the tidal wetlands which are adjacent to the Vembanad Lake and having acid saline soils. They are distributed in the coastal regions of Ernakulam, Alappuzha and Thrissur districts of Kerala state. *Pokkali* rice has received Geographical Indication (GI) registration from the Geographical Indications Registry Office, Chennai, Tamil Nadu (Shylaraj *et al.,* 2013).

In *Pokkali* farming one season of rice is alternated with another season of prawn culture. Land Preparation for *Pokkali* rice cultivation starts in the month of April. The fields are allowed to dry by preventing entry of water in the fields. Sluice gates with shutter helps in proper regulation of water level to support both paddy farming and fish farming. It prevents and regulates the seepage of saline water into the field. Before the onset of south west monsoon raking is done with specialised spades and mounds are prepared. Salts and toxic elements are washed off in rain water from the mounds, and on this sprouted *Pokkali* seeds are sown (Shylaraj *et al.,* 2013). Harvesting take place in the 1st week of October. Only panicles are cut and rest of the parts are left in the field for decay which become feed for prawns (Joseph, 2014).

Second phase of *Pokkali* farming starts on November- December. After strengthening of bunds and sluices, the water is allowed to enter the fields during high tide and traditional prawn filtration is carried out. *Pokkali* fields were additionally stocked with hatchery seed of tiger prawns (*Penaeus monodon*). Harvesting coincides at the time of low tides, just before and after the full and new moon. The final harvesting is done by draining the field and resorting to cast netting and even hand pricking (Pillai, 1999).

2.2. Rice-Prawn farming system

It is an integrated farming system which combines paddy cultivation along with prawn culture in *Pokkali* lands, which is considered as sustainable organic system. It is an ecologically viable system which improves the livelihood opportunities of the local population. Rice cultivation is practised in the monsoon season followed by prawn culture in the next post-monsoon period. Rice and prawn culture is alternated in the *Pokkali* lands just like crop rotation (Shylaraj *et al.*, 2013).

Pokkali fields differ from normal paddy fields. Perennial channels present in the fields provide easy passage of fishes and prawns into the lands during low tides. These channels have depth varying from 50-75 cm and width from 100-120 cm. Sluices are the indivisible component of *Pokkali* fields. Sluices with shutter facilitate exchange and regulation of water from the river in low tides and high tides during rice and fish culture (Shylaraj *et al.*, 2013).

Prawn filtration is the traditional method followed in most of the *Pokkali* fields. After rice cultivation the field is prepared for prawn culture by removing weeds and floating vegetation and strengthening bunds (Rajendran *et al,* 1993). Entry of water into the field is controlled with the help of sluices, At night during low tides hurricane lamps are fixed on the mouth of the sluices. Juvenile prawns are attracted by light and enter in to the field. In high tides a net is fixed at the sluices which prevents the escape of prawns from the fields. Harvesting stars from middle of the December till March (Pillai, 1999).

Quality of pond soil and water highly influence the successful growth, propagation, survival and harvest of the shrimps (Krishnani *et al.,* 2011). Extensive shrimp farming system of *Pokkali* field registered a pH of 6.18 to 6.48 for water and pH of 6.1 to 6.91 in traditional paddy land use system (Krishnani *et al.,* 2011).

Selective culture of tiger/white prawn is an improvement over traditional prawn filtration. Because availability of prawn seeds varies according to different environmental factors and it is the main factor that determine the success of traditional culture. Hatchery seed of tiger prawn (*Penaeus monodon*) and white prawn (*Penaeus indicus*) are used for improved prawn cultivation. Now a days selective culture of prawn with fast growing varieties produces quality prawns which are in great demand for export and also fetch good income (Purushan, 1993).

Economic analysis of rice-prawn integrated system have a high economic peak also. Expenditure of rice farming is comparatively less with other rice grown areas since it does not use any external inputs like fertilizers, pesticides and herbicides. Traditional prawn culture required only the maintenance cost of bunds, sluices (Pillai, 1999). Waibel *et al.,* (1994) found that 2.5 times greater profit comes from rice cum fish field than that of fields in which rice alone was cultivated. In selective prawn culture, cost of fingerlings, cost of feed and harvest operations accounts for major expenditure. Economic analysis confirm the increase in net returns and benefit : cost ratio of *Pokkali* fields (Shylaraj *et al.,* 2003). According to Nair *et al.,* (2010) simultaneous rice-fish culture in modified *Pokkali* fields is a possible alternative to improve sustainability. The study suggested that growing fish and paddy together is a potentially better alternative which can yield significantly higher production compared to the traditional *Pokkali* farming alone. However sequential rice-prawn culture is more popular compared to simultaneous rice-fish culture in *Pokkali* fields.

2.3. Rice-fish integrated farming system

Li (1992) opined that integration of paddy and fish give rise to a balanced ecosystem. Pandiarajan (1995) reported that apart from increased productivity of rice-fish integration, it lowered the cost of cultivation and pest and improved the yield.

Padmakumar *et al.,* (2003) suggested a multilevel integrated farming system model suitable for Kuttanad, which involve paddy cum fish in low lands, and coconut, banana, pineapple on the dikes along with pig, poultry and cattles. Rice-fish culture with fruit crops and rice-fish-vegetable farming system is practiced in deep water rice growing region of West Bengal (Roy *et al.,* 1990). Victor *et al.*, (1994) reported that in Cauvery delta of Tamil Nadu, rice cum edible fish culture lead to reduction in the mosquito populations of surrounding area. Integrating aquaculture with agriculture was found to be judicial management and ideal utilization of farm resources and conservation of ecosystem for sustainable use in case of lowland farming and it plays a major role in reduction of environmental degradation, improving human nutrition and livelihood opportunities and increasing farmers purchasing power (Lightfoot, 1991).

2.2. Salient characteristics of Pokkali soil

Pokkali soil is stiff impervious clay, rich in organic matter with bluish black in colour and is more than one meter deep. By increasing depth the colour intensity varies. The soil is hard and creates deep fissures when dry and sticky when wet (Varghese *et al.*, 1970).

Some preliminary studies conducted by Varghese *et al.,* (1970) in *Pokkali* soils indicated that *Pokkali* soils originated from lacustrine and alluvial deposits. As per soil taxonomy it belongs to loamy mixed isohyperthermic salidic acid family sulfaquepts. According to Samikutty (1977) major clay mineral found in *Pokkali* soil is kaolinite along with fairly large amount of smectite and small amount of halloysite.

The soil is highly acidic, with pH 3.0-4.5 (Varghese *et al.*, 1970). Samikutty (1977) observed that range of EC values of *pokkali* soils varied from 0.1 to 2.0 dS m^{-1} in low saline phase. In rainy season rain water dilutes the salt concentration and reduces it to traces. Toxic salt accumulation is maximum in summer months when electrical conductivity rises to the range of 10 to 15 dS m^{-1}. Mohan (2016) reported that the inbuilt acidity of *Pokkali* soil becomes more dominant, when the salinity is washed away.

The tidal influx brought about significant changes in the chemical properties of *Pokkali* soils. For a sustainable rice production in *Pokkali* lands, there should not be any hindrance for natural tidal inflow of water. Tidal action significantly increases the soil pH and available K content. Organic matter and available phosphorus was also high under tidal situations (Sasidharan, 2004). Organic carbon content in *Pokkali* soils showed a very high status and available P, K, Ca, S, Fe, Mn, Zn, Cu, Al and B were also found to be very much higher (Mohan, 2016). High content of sulphates present in the soils of *Pokkali* lands has resulted in the high positive correlation of water soluble fraction with available sulphur, which indicate that these water soluble fractions exist as sulphates of Ca and Mg (Bhindu, 2017). The direct marine influences along with high organic matter content has resulted in the high content of available boron in organically complexed form in lowlands of *Pokkali* tract (Santhosh, 2013). According to Bhindu (2017), among the micronutrient cations in the low lands of *Pokkali* tract, Mn was dominant while the other sites were occupied by Fe, Zn and Cu on exchange. Available Ca and Mg showed significant positive correlation with pH, EC, Mg, S, exchangeable Ca and Mg, CEC and PBS in the soils of *Pokkali* land. While with exchangeable Al it showed significant negative correlation.

Potential acid sulphate soils are poorly drained soils with a high content of pyrite. Soil pH will be neutral or slightly acid in the field. Upon drainage, the soil becomes strongly acidic, which directly affects the growth of plants as a result of aluminium and iron toxicity, and indirectly decreases the availability of phosphorus and other nutrients (Attanandana and Vacharotayan, 1986). Acid sulphate soils in tidal areas are often affected by salinity. Salinity aggravates other toxicities such as iron and perhaps aluminium in solution creating unfavourable conditions for plant growth (Parischa and Ponnamperuma, 1976). Beye (1973) and Ghosh *et al.* (1973) pointed out that acid sulphate soils contained merely low amounts of exchangeable Ca and Mg. Murthy (1971) reported high content of Mg compared to Ca.

2.2.1. Soil salinity

Among abiotic stresses, high salinity is the most devastating environmental stress that impair agriculture production on at least 20 percent of irrigated land worldwide. Saline soils, due to presence of excess soluble salts, exhibit saturation extract electrical conductivity (ECe) values equal to and/or above 4 dS m^{-1} at 25°C and higher salt concentrations render them unsuitable for majority of the arable crops. Padmaja *et al.,* (1994) reported that there were three types of saline soils in Kerala. Origin, genesis and development of these soils are under peculiar climatic and environmental conditions. *Pokkali* soils are the predominant among them. These *Pokkali* lands are adjacent to Arabian sea and back waters which make the soil saline. Chlorides and sulphates of Na, K, Ca are the major salts in the soil solution.

High sodium concentration in the soil leads to dispersion of soil aggregates and fine soil particle block the soil pore space. This results in reduction of soil permeability (Allotey *et al*, 2008). Sodium is capable of creating adverse environment for plant growth in soil such as reduced hydraulic conductivity, reduced infiltration, reduced soil permeability etc (Frenkel *et al.,* 1978).

Salinity affect the ion activities in solution by changes in ionic strength, ion-pair formation, and precipitation (Cramer, 1986). Salinity also affects the plant growth in three principle ways; by ion toxicity mainly Na^+ and Cl^-, osmotic stress, and nutritional imbalance (Hadi *et al.,* 2012). Higher salt deposition in the soil creates a low water potential zone, which make difficult to acquire water as well as nutrients (Zhu, 2002) Yoshida (1981) found that under salinity stress conditions, the growth of rice is influenced by many factors such as salinity level, nature of salt, duration and exposure of salinity, pH of the substrate and stage of development of the crop. Higher salinity level condition lead to the substantial reduction in grain yield of rice with decrease in plant height, number of tillers per hill, and 1000 grain weight (Govindaraju and Balakrishnan, 2002). Salinity affects plant's fundamental processes like photosynthesis, protein synthesis, lipid metabolism and nutritional balance (Parida and Das, 2005; Grattan and Grieve, 1999). Excess sodium promotes slaking of soil aggregates that degrades the soil structure and impedes water movement and root growth.

2.4. Salt injury

Pokkali land races are world famous for their salinity tolerance gene SalTol QTL which is widely utilized in the international rice improvement programmes for salinity tolerance. They are also tolerant to soil acidity and submergence, which make them suitable for increased salinity and submerged environments (Shylaraj *et al.,* 2013).

Ali *et.al* (2004) studied the effect of salinity on chlorophyll concentration, leaf area, yield and yield components of rice genotypes grown under saline environment. Rice genotypes were grown under an artificially salinized (EC-8.5 dSm^{-1}) soil conditions. After 90 days of transplanting, the results showed that the yield per plant, chlorophyll concentrations, fertility percentage and number of productive tillers, panicle length and number of primary branches per panicle of all the genotypes were reduced by salinity. High concentration of Na ion in the root zone inhibits Ca uptake and transport resulting in lower Ca/Na ratios in salt stressed plants (Hadi *et al.,* 2008). Yeo and Flowers (1985) investigated the effect of Na/Ca ratio in the growth medium on the response of the rice to NaCl. Increased toxicity of NaCl was seen only at Na/Ca ratios of 100 and above.

Levitt (1980) found that plants with high Na uptake resulted in deficiencies of elements such as K, Zn, Cu and Mn. Paliwal *et al.*, (1975) reported

96

that increase in soil salinity negatively affect the N content in plants. Lal and Singh (1974) reported that grain yield of wheat and K, N, Ca and Mg uptake reduces by use of irrigation water containing higher EC and SAR. Plant uptake of P is drastically affected at high soil salinity conditions. This is due to competitive inhibition caused by Cl. Since PO_4 and Cl are present in absorption sites, higher content of Cl influence the uptake of P (Machanda *et al.,* 1985).

Aslam *et al.,* (1988) conducted a study on response of rice to salinity shock at various growth stage and observed that different varieties showed different response to salinity. But in general, maximum adverse effect was noticed when salinity shock was applied at panicle initiation stage followed by seedling stage. According to Akbar *et al*., (1972) rice is one of the suitable crops for saline soils although it is considered as moderately sensitive to salinity. Significant decrease in height, root length, new root emergence and dry matter content of rice was noticed at electrical conductivity 5-6 dS m^{-1} (Pearson *et al*, 1966, Akbar and Yabuno, 1974). Salinity injury symptoms at early stage manifest on the first leaf, followed by second one and finally growing tip. Higher saline content inhibit leaf elongation and formation of new leaves. Photosynthetic function is inversely proportional to salinity concentration (Ota and Yasue, 1962). Rice plant gains tolerance to salinity at reproductive stage. Plant height, root length, production of tillers and biomass are negatively affected by salinity and it create increasing sterile florets by affecting panicle initiation at reproductive stage. It also reduces panicle length, no of primary branches and spikelet per panicle, fertility and weight of panicle there by reduces the grain yield (Pearson 1966, Akbar *et al*., 1972).

Makihara *et al.,* (1999) revealed that yield components most responsible for the yield decrease under salinity varied among the varieties and ability to maintain a low sodium concentration is not a major characteristic that determine salinity tolerance.

2.2.2 Soil acidity

Soil acidity is considered to be one of the major challenges for plant production in all over the world. Hydrogen ions are the cause of acidity. In acid to moderately acid soils aluminium and hydrogen ion account for the active hydrogen. Reduction of iron and carbon dioxide concentration in submerged conditions directly influence the soil reaction in the presence of easily decomposable organic matters, reducible iron and other electron acceptors like carbon dioxide and sulphates (Ponnamperuma, 1972).

Soil chemical properties and microbiological activities are directly influenced by soil pH. The concentration of cations such as Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and Al^{3+} in soil are highly influenced by soil reaction. These alkaline elements are not available with increasing acidity. Availability of P is high in acidic soil. In case of micronutrients, generally those present in cationic form such as Fe, Mn. Cu and Zn increases with increase in acidity and those present in anions such as Mo and B decreases. In organic soil, soil pH and nutrient availability relationship is quiet different. Copper may be deficient in acid organic soils. Fe, Mn, and Al are highly soluble and exhibit toxicities at low pH. Whereas these are in unavailable form at high pH.

At pH less than 5.0 most of the Al becomes soluble and is either tightly bound by organic matter and present in the form of aluminium hydroxyl cations (Gupta *et al.,* 1990). Aluminium plays a key role in exchangeable acidity (Coleman and Thomas, 1967).

2.3. Submergence

Pokkali varieties are blessed with tolerance of three abiotic stresses in one variety. Submergence is one among them and it is considered as perennial problem apart from salinity and acidity. Since most of the *Pokkali* fields are adjacent to Arabian sea, cultivable lands experience natural floods. Nutrient rich alluvial sediment deposition is a result of flooding (Samikutty, 1977). In monsoon season, the fields will remain flooded with 45-50 cm of standing water. In order to resist the flooding plant varieties grows into a height about 1-1.5m.

Waterlogging causes changes in the properties of soils, which profoundly affect the nutrition of lowland rice. One of the main characteristic of submerged soil is absence of molecular oxygen, however it is not uniformly devoid of oxygen. In the surface layers concentration of oxygen may be high compared to subsurface layer. Oxidation–reduction potential undergo similar abrupt changes with depth (Pearsall and Mortimer, 1939). Nitrate, manganic compounds, ferric compounds, and sulfate become unstable when the oxygen supply of the soil is restricted. Nitrate nitrogen is subjected to loss through denitrification. Nitrate reduction starts only after complete absence of oxygen. Manganese dioxide follows nitrate in the reduction process and the next option is Fe^{2+} system (Ponnamperuma, 1972).

2.4. Amelioration of acid saline soil

Reclamation of saline soil involve replacement of exchangeable Na by Ca. Amendments are used in most of the saline-sodic soil for reclamation, which provide soluble calcium within the soil. The replaced Na^+ is removed either below the root zone or out of the soil profile by leaching with water.

Salinity can be effectively managed in case of saline lands and used for potential crop production by preventing the influx of saline water and leaching the salts from root zone and correcting the nutrient toxicities (Ponnamperuma, 1984). Soil amendment includes all inorganic and organic substances mixed into the soil for achieving a better soil constitution regarding plant productivity. Amelioration using different organic and inorganic amendments like pyrite, gypsum, saw dust, composted coir pith, lime etc. have been studied by Clarson *et al.,* (1984) and Tiwari *et al.,* (1984) depending upon the chemical characteristics of the soil. Application of lime was found to have beneficial effects on growing rice on acid sulphate soils (Subramoney, 1961; Kabeerathumma and Chitharanjan, 1974).

Liming should be combined with progressive and careful drainage, which might help in releasing and neutralizing the potential acidity.

Application of lime as amendment to neutralize the exchangeable Al^{3+} to a certain extent is effective. Liming improve base status, inactivates Fe, Mn, and Al in soil solution. It reduces P fixation and danger of toxicity of micronutrients.

Ameliorating effect of lime, saw dust and gypsum were tested in acid-saline soils in varying levels. Higher yield was recorded in the field with application of 1000 kg ha^{-1} lime along with 20 kg N and 40 kg P_2O_5 ha^{-1}. But reduction in the yield was reported in doses higher than 1000 kg ha^{-1}. Application of lime in two splits are usually followed. Half of the quantity applied on mounds at the time of sowing and remaining at the time of dismantling of seedlings. Application of saw dust as amendment was not beneficial in Pokkali lands (Shylaraj *et al.,* 2013).

According to Attanandana and Vacharotayan (1986) acid sulphate soils are among the major problem soils and require appropriate methods of amelioration. Since the soils are situated in lowlands and suitable for rice culture, amelioration include leaching and drainage, submergence, liming, manganese dioxide addition, nitrogen, phosphorus and potassium application including utilization of rock phosphate as phosphate source. Manganese dioxide improved the growth and yield of rice in an acid sulphate soil because it depresses the concentration of water-soluble Fe^{2+} and Al^{3+} (Nhung and Ponnamperuma, 1966).

2.5. Amelioration with Calcium

Calcium has been shown to ameliorate adverse effects of salinity on plants. Soil structure can be improved by application of Ca^{2+} because it is involved in cationic bridging with clay particle and soil organic matter (David and Dimitrios, 2002) and Ca can prevent clay dispersion and inhibit aggregate disruption by its exchangeable nature with Na and Mg. since it facilitate aggregate stability (Chan,1995; Zhang and Norton, 2002). Aslam *et al.,* (2003) studied the impact of calcium supply on the growth and yield of rice in nutrient and solution culture experiments. It showed that supply of Ca tended to decrease sodium and chloride concentration in the shoot of rice cultivars. Plant take up excessive amount of Na^+ in the saline soils at the cost of K^+ and Ca^{2+} (Wyn jones, 1981). So that lower Ca^{2+}/Na^+ and K^+/Na^+ ratios may negatively affect the selectivity of root membrane and result in passive accumulation of Na in root and shoot (Kramer *et al.,* 1977).

A study on impact of different external K/Na and Ca/Na ratios on growth, ionic composition and selectivity of rice lines varying in salt tolerance by Aslam *et al.,* (1990) showed that the effect of Ca^{2+} : Na^+ ratio on shoot or root yield was not much. But it reduces the Na concentration and increases K : Na ratio in shoot and root and improve the K^+ selectivity. It is important for increasing the plant tolerance and resistance to various environmental stress.

Butt *et al.*, (1995) conducted a study on effect of different Ca:Mg ratios of saline medium on the yield and ionic composition of rice. Sodium chloride along with varying ratios of $CaCl_2$ and $MgCl_2$ was added to create salinity levels of 50 and 75 Mm respectively. Results showed decrease in paddy and straw yield with increase in salinity but decrease was comparatively less in treatment with high calcium in the medium. Concentration of K was improved with higher Ca content. Increasing salinity leads to increase in sodium content in leaves and it decreases K concentration. Minimum sodium was reported in medium containing higher Ca.

According to the study conducted by Sasidharan (2004) the ameliorants mostly, lime in combination with other nutrients significantly increased the exchangeable K of the soil.

Lime applications results in greater availability of nitrogen due to enhanced mineralization of organic nitrogen by increasing microbial activity of mineral soils (Srivastava *et al.,* 1972; Nambiar, 1950). Lime application enhanced or accelerated organic carbon oxidation which resulted in reduced C/N ratio with increase in N mineralisation (Subramoney, 1964). Borthakur and Manzumder

(1958) showed that in case of waterlogged condition, effect of lime on N availability was not significant.

Lime increases P availability by increasing hydrolysis of phosphate minerals like strengite reduces the P fixation there by improving mineralisation of organic P in acid soils (Subramoney, 1964). In soils containing montmorillonite clay increased fixation of P was observed when P fertilizers were applied after liming (Hall and Baker, 1971).

Increase in soil pH with addition of magnesium limestone was reported by Azman *et al.*, (2014), along with increase in Ca and Mg content in the soil.

On acid sulphate clays in Thailand, Maneewon *et al.,* (1982) and Charoenchamratcheep *et al.*, (1982) have reported significant responses to optimum combinations of lime and ammonium phosphate or rock phosphate, in terms of both yield and financial benefit.

Gypsum is one of the commonly used amendment for reclamation of sodic soils in most of the agricultural fields. It reduces harmful effect of Na in irrigation waters because of soluble nature (Amezketa *et al.,* 2005). According to Keren (1996). Application of gypsum in sodic soil may increase soil permeability by increasing electrolyte concentration and by cation exchange impacts. Qadir *et al.*, (1996) found that higher rate of gypsum application remove grater amount of Na out of the soil profile resulting in the substantial reduction of soil EC and SAR. Gypsum application in saline/sodic soil has been reported to improve paddy yields in semiarid regions because of Ca can decrease the concentration of Na and improves plant tissue concentration of P, K, Zn, Cu, Mg, and K:Na ratio (Rengel, 1992). Aslam *et al.*, (2003) showed that improvement of paddy yield is due to Ca application in the form of gypsum in salt tolerant and salt sensitive rice cultivars grown in salt affected soils.

Soil acidity can be effectively corrected by application of phosphogypsum, by product of phosphoric acid plant in lateritic soil by making changes in the exchangeable acidity (Sumner, 1970). Ameliorating effect of phosphogypsum is mainly due to the presence of calcium and it moves much faster than lime. It increases the activity of calcium in the soil solution and also effective for reducing subsoil acidity (Ritchey *et al.,* 1980).

2.5.1. Role of Ca on plant's salt tolerance

Ca is an essential nutrient for higher plants and it plays a key role in plant cells. It preserve structural and functional integrity of plant cell membranes (Tuna *et al.,* 2007). It stabilizes cell wall structure of the plant. It has a major role in regulating ion transport and selectivity and control ion exchange behaviour and also the enzyme activities (Qiu *et al.,* 2003; Aslam *et al.,* 2000).

Calcium plays an important role in the elongation and the division of plant cells, the cell membrane permeability, the metabolism of nitrogen and the translocation of carbohydrate and help the plants to overcome salts stress (White and Broadley, 2003). Hussain *et al*., (2010) found that Ca is an indivisible component of plant to restrict the entry of Na into the cells of plant. High concentration of Ca^{2+} is necessary in rice roots for keeping high root and shoot uptake of Ca^{2+} and K^{+} in saline soils to decrease the salt injury (Song *et al.,* 2006). Gong *et al*., (2006) reported that Ca can reduce Na transport to shoots in rice.

2.6. Ca in prawn/shrimp culture

Gopalakrishnan *et al*., (2008) found that water quality parameters plays an important role in shrimp culture and each one differs with salinity and ionic composition. Marine shrimp culture is traditionally practised in coastal ecosystems. In those areas salinity of water resource varies from 15 to 40 ppt. Now a days shrimp farming is gaining popularity in many parts of the nation using low to medium saline water from rivers and irrigation channels. Aquatic ecosystem require supplementation of minerals to achieve desired productivity (Muralidhar *et al.,* 2016). Allen Davis *et al.,* (2004) suggested that if the salinity is adequate, calcium, potassium and magnesium are the most important ions for survival of shrimp. According to Muralidhar *et al.,* (2016) ionic ratios are quite different between seawater and different source waters. The ratio of Na to K and Mg to Ca in water are more important than pond water salinity. High variations in the ratios of these minerals in water lead to osmotic stress which has a cascading effect on growth and survival of shrimp. The Na:K and Mg:Ca ratios should be preferably 28:1 and 3.4:1 respectively. Generally under high or low saline waters with optimum mineral concentration and proper ionic ratios, there is no need of supplementation. However, throughout the culture period, major minerals are lost due to soil adsorption, shrimp harvest, draining at harvest and seepage, altering their concentration (Muralidhar *et al.,* 2016).

The more soluble minerals like calcium, phosphorus, sodium, potassium and chloride function in osmoregulation, acid base balance, and production of membrane potentials (Boonyaratpalin, 1996). Davis and Galtin (1992) evaluated the requirement of thirteen elements, Ca, P, Na, Cl, K, Mg, Mn, Fe, Zn, I, Se, Cu and Cr for the shrimp (*P. vannamei*) and reported that minerals are essential for prawn nutrition. Among the minerals, calcium and phosphorus play very important role in shrimp nutrition. The calcium requirement may be totally or partially met through absorption of calcium from the water (Deshimaru and Yone 1978) and they reported that addition of calcium in the diets improves growth (Deshimaru and Yone 1978; Ali, 1999). According to Yuvanatemiya *et al.,* (2011) lime has a better use as a disinfectant due to its explosive reaction with water.

The role of calcium in crustacean physiology and metabolism is well documented (Travis 1955a and b; Haefner, 1964; Sitaramaiah and Krishnan 1966; Sather 1967). Mills and Lake (1976) working on calcium concentration in the crayfish, suggested that exoskeleton calcium in the prawn is related to the amount of available calcium in the water in which they inhabit. According to Lovell (1989) most of the shell-building animals have to obtain calcium and it also involved in blood clotting, muscle functions and nerve transmission in other animals.

Among different culture system, marine shrimp develop best at a pH between 7 and 9 (Van wyk and Scarpa, 1999) pH influences most of the chemical reactions and different phenomena that occur in the water and it directly affect the physiological condition of the shrimp (Lemonnier *et al*, 2004).

Materials and Methods

MATERIALS AND METHODS

The present study was carried out to manage soil salinity by application of calcium salts in *pokkali* lands and thereby to assess the effect of calcium salts on the growth and nutrition of rice, yield of prawn and soil properties. The *Pokkali* field of Kottuvally Panchayath in Ernakulam district was selected for experiment. The study was conducted at College of Horticulture, Vellanikara during 2016-2018.

3.1. Location of study

The experiment was conducted in the Thathapilli padasekharam (10°12'N Latitude and 76°26' E Longitude) of Kottuvally Panchayath in Ernakulam district.

3.2. Season

The rice crop was raised from June to October 2017, followed by prawn farming in December 2017 to April 2018. Date of sowing of rice was July 4th, 2017. Harvest was carried out in 20th October, 2017. Release of prawn was in December 28th, 2017 and harvest was on April 15th, 2018.

3.3. Experiments details

The experiment was laid out in randomized block design with six treatments and four replications having plot size of 100 m^2 each. The treatments consisted of application of Ca salts such as nitrate, chloride, sulphate, dolomite and rock phosphate so as to maintain the ratio of exchangeable Na : Ca as 1: 5 in the exchange complex on soil test basis. Rice variety, Vyttila 6 was raised in the first crop season. The variety was medium duration (105-110 days), semi tall and non-lodging. The treatments were applied before the rice crop only.

Initial soil testing was carried out in order to find out the ratio of exchangeable Na : Ca in the soil. Quantity of Ca salts required to maintain the Na : Ca ratio was found out separately for each treatments.

3.3.1. Rice cultivation

The land preparation for rice cultivation started by the months of April. Bunds were strengthened and sluices repaired for regulating water level. Fields then drained during low tides and allowed to dry. Mounds were prepared along the field which facilitated washing down of salts during rains. Each treatment plots were separated by small bunds along the experimental field. With the onset of monsoon sprouted seeds were sown at the rate of 100 kg ha^{-1} on the mounds. Rice seedlings were dismantled after 30 days of sowing. Seedlings were uniformly distributed with a spacing of 20 x 15 cm. The harvest was carried out in 3^{rd} week of October.

Table 1. Exchangeable cations in soil

<table>
<tr><td>Exchangeable cations</td><td></td><td>Values</td></tr>
<tr><td>Ca</td><td rowspan="9">meq per 100 g of soil</td><td>1.093</td></tr>
<tr><td>Mg</td><td>0.089</td></tr>
<tr><td>Na</td><td>0.714</td></tr>
<tr><td>K</td><td>0.720</td></tr>
<tr><td>Fe</td><td>0.438</td></tr>
<tr><td>Mn</td><td>0.020</td></tr>
<tr><td>Zn</td><td>0.039</td></tr>
<tr><td>Cu</td><td>0.0006</td></tr>
<tr><td>Al</td><td>0.118</td></tr>
<tr><td>CEC</td><td>cmol (+) kg^{-1}</td><td>3.23</td></tr>
<tr><td>PBS</td><td>Per cent</td><td>80.99</td></tr>
</table>

Table 2. Details of treatments

Treatments		Percentage of Ca	Quantity (kg per 100 m^2)
T_1	Absolute control	-	-
T_2	Calcium nitrate	24 %	45
T_3	Calcium chloride	36 %	30
T_4	Calcium sulphate	29 %	34
T_5	Rock phosphate	40 %	27
T_6	Dolomite	22 %	25

3.3.2. Prawn culture

The field was prepared by strengthening bunds and sluices, removing weeds and floating vegetation from the area and fixing net in order to prevent the entry of non-insect pest. Stocking of tiger prawn (*Penaeus monodon*) seeds were carried out on 28th of December in the same field after two months of rice harvest. Prawn seeds at rate of 40,000 ha^{-1} were released. In the initial one month feeding was done with company feed named "Higashi". After that prawns were fed with 1 kg of wheat, twice in a day. Prawns were harvested after 107 days of culture by pumping out the water from entire field and cast netting and also by hand picking. Total catch composed of tiger prawns, other species of prawns, crabs, pearl spot and many other fishes. The yield of each species, length and breadth were recorded separately.

3.4. Layout

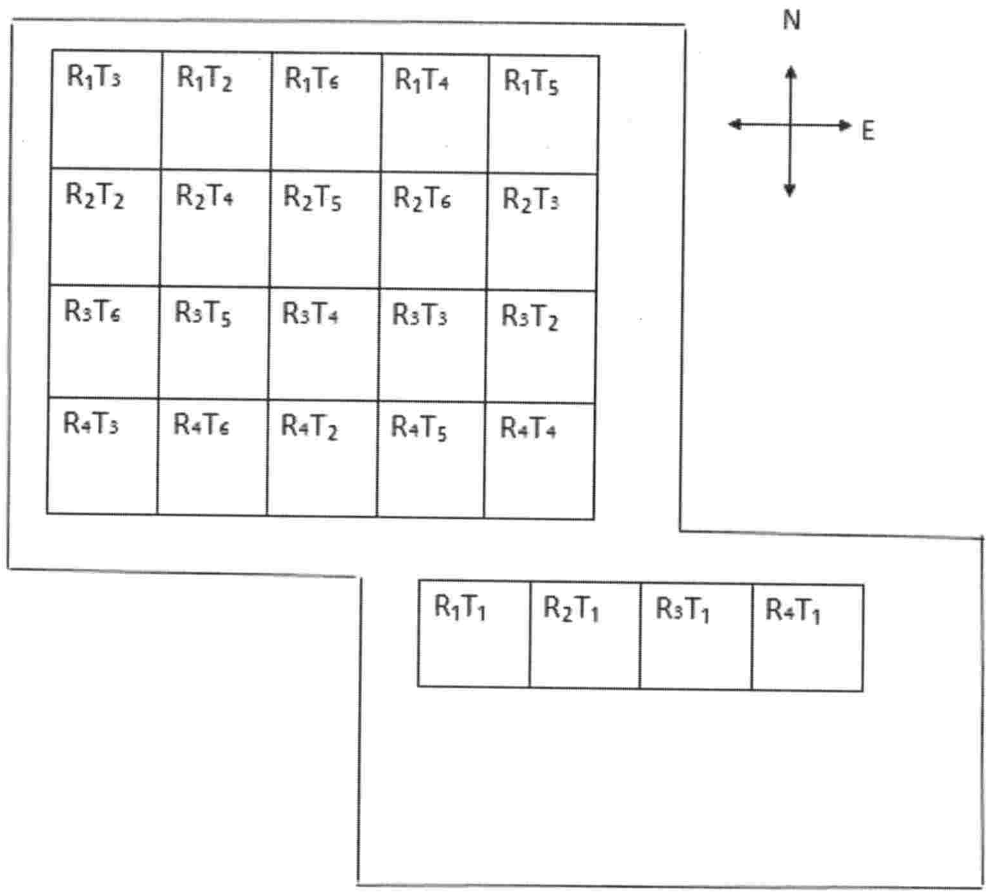

Fig 1. Allocation of treatment in experimental site

T_1 : Absolute control

T_2 : Calcium nitrate

T_3 : Calcium chloride

T_4 : Calcium sulphate

T_5 : Rock phosphate

T_6 : Dolomite

DIFFERENT STAGES OF EXPERIMENT

FIELD PREPARATTION

SOWING SEEDS

TRANSPLANTING

RECORDING OBSERVATIONS

FIELD BEFORE HARVEST

HARVESTING OF RICE

DIFFERENT STAGES OF PRAWN CULTURE

FIELD AT HIGH SALINE PHASE

RELEASE OF PRAWN SEEDS

PRAWN HARVEST USING NETS

DRAINED FIELD

TIGER PRAWNS

OTHER FISHES

3.3 Collection of soil and plant samples

Soil samples were collected from the treatment plots during three stages; first set of soil samples were collected in June 2017 during the time of mound preparation. Soil samples were collected at a depth of 0-15 cm. The next sampling was carried out in October 2017 at the time of rice harvest. Plant samples were also collected at harvest. Last set of soil sampling was completed in April 2018 at the time of harvest of prawn.

3.4. Characterisation of soil samples

Collected soil samples were analysed for physical, chemical and biological properties. Wet analysis was followed for all soil samples collected from the field.

3.4.1. Expression of result of wet analysis

Gravimetric method was used to find out the moisture content of soil samples. It was determined by taking initial weight of soil sample as W_1 then dried in hot air oven at 105°C. After drying to a constant weight, final weight W_2 was taken. Moisture content was calculated by the formula,

Percent moisture = $[(W_1 - W_2)/ W_2] * 100$

3.4.2. Physical characterisation

3.4.2.1. Texture

Soil texture was determined by means of mechanical analysis. The international pipette method was followed for the analysis of particle size distribution (Robinson, 1922).

3.4.2.2. Bulk density

Core samples were collected from 0-15 cm depth were dried to a constant weight in an oven at 105 C. The bulk density of the soil was calculated as the ratio of the mass of the dry soil to the total volume of soil (Dakshinamurti and Gupta, 1968).

3.4.3. Chemical characterisation

3.4.3.1. Soil pH

Soil pH was measured in 1:2.5 soil water suspension, using a pH meter (Jackson, 1958)

3.4.3.2. Electrical conductivity

Electrical conductivity of the soil was determined using a conductivity meter. The supernatant liquid of the 1:2.5 soil water suspension was used for measuring electrical conductivity (Jackson, 1958).

3.4.3.3. Organic carbon

Organic carbon of the soil was estimated by wet digestion method (Walkley and Black, 1934).

3.4.3.4. Available N

Available nitrogen in the soil was estimated using alkaline potassium permanganate method. Potassium permanganate oxidizes the soil organic matter and hydrolyses the liberated ammonia. It is absorbed in boric acid and titrated against standard acid (Subbiah and Asija, 1956).

3.4.3.5. Available P

Available phosphorous in the soil samples was extracted using Bray No.1 reagent (Bray and Kurtz, 1945) and determined colorimetrically by reduced ascorbic acid blue colour method proposed by Watanabe and Olsen (1965), using spectrophotometer.

3.4.3.6. Available K

Available potassium in the soil samples was extracted using neutral normal ammonium acetate and it was estimated by flame photometry (Jackson, 1958).

3.4.3.7. Available Ca and Mg

Available calcium and magnesium in the soil samples were extracted using neutral normal ammonium acetate (Jackson, 1958) and estimated using atomic absorption spectrophotometer.

3.4.3.8. Available S

Available sulphur in the soil samples was extracted using $CaCl_2$ (0.15 percent) and estimated using spectrophotometry through turbidimetry (Tabatabai, 1982).

3.4.3.9. Available micronutrients (Fe,Cu,Mn and Zn)

Available micronutrients in soil samples were extracted with 0.1M HCl. Four grams of soil was shaken with 40 ml of 0.1 M HCl for 5 minutes and filtered through Whatmann No.1 filter paper. The micronutrients Fe, Cu, Mn, and Zn content in the filtrate were analysed using atomic absorption spectrophotometer (Sims and Johnson, 1991).

3.4.3.10. Available B

Available boron in soil samples was estimated with hot water soluble method, followed by the colorimetric estimation using azomethine – H in spectrophotometer (Gupta, 1972).

3.4.3.11. Exchangeable Al

Exchangeable aluminium was estimated from soil samples using 0.1 M $BaCl_2$ as the extracting agent and analysed using atomic absorption spectrophotometer (Ciesielski *et al.,* 1997).

3.4.3.12. Exchangeable Na

Exchangeable sodium in the soil samples was extracted using neutral normal ammonium acetate and it was estimated by flame photometry (Jackson, 1958).

3.4.4. Biological characterization

3.4.4.1. Microbial biomass carbon

The chloroform fumigation and extraction method was used to estimate microbial biomass carbon in soil. A total of five sets of 10 g soil samples were taken. One set was kept in an oven at 105° C and the moisture was determined using gravimetric method. Vacuum was created inside desiccator using a vacuum pump. Two sets of soil samples and a beaker with ethanol free chloroform were kept in vacuum desiccator for 24 hrs. Then extract was taken using 0.5 M potassium sulphate from the fumigated and non-fumigated samples to determine organic carbon. Potassium dichromate (0.2 M), concentrated sulphuric acid and ortho phosphoric acid were added to 10 ml extract. It was kept in a hot plate at 100° C for half an hour under refluxing condition. Then, 250 ml water was added. It was titrated against standard ferrous ammonium sulphate (Jenkinson and Powlson, 1976).

3.5. Collection and analysis of plant samples

Plant samples were collected at the time of harvest and dry weight was recorded. Plant samples were analysed for N, P, K, Ca, Mg and Na separately for shoot and root and Ca: Mg, K: Na ratios were worked out following standard analytical procedures (Chesnin and Yein, 1951; Piper, 1966).

Table 3. Analytical methods for plant samples

Sl. No.	Element	Method
1.	Nitrogen	Microkjeldhal method (Piper, 1966)
2.	Phosphorus	Digestion of plant samples using nitric acid followed by colorimetric estimation in spectrophotometer by Vanadomolybdate yellow color method (Piper, 1966)
3.	Potassium and Sodium	Digestion of plant samples using nitric acid followed by filtration and determined by flame photometer (Piper, 1966)
4.	Calcium and Magnesium	Determination using atomic absorption spectrophotometer (Piper, 1966)

3.6. Biometric observations

3.6.1. Height of the plant

Ten plants were selected randomly from each plot and average height was measured in centimeters from ground level to the tip of the longest leaf at 90 days after sowing of the crop

3.6.2. Number of tillers

From each 100 m^2 plot ten plants were selected randomly and number of tillers were counted.

3.6.3. Yield and dry matter content

The yield of rice from each treatment plot was recorded. The dry matter content was also recorded.

3.6.4. Prawn yield

The total prawn catch was recorded from experimental field and control separately in kilograms and the yield was compared with control. Species wise catch was also recorded.

3.7. Statistical analysis

The statistical analysis was performed with statistical software OPSTAT (one factor analysis RBD).

Results

RESULTS

The results of experiment "Management of soil salinity with calcium salts in rice–prawn farming system in *Pokkali* lands" are discussed in chronology of the different facets of experiment which include analysis of various physical, chemical and biological attributes of soil as we crescent as first, second and third stage. First stage ; before sowing of crop, second stage : immediately after harvest of rice, third stage: immediately after harvest of the prawn and plant nutrient analysis at harvesting stage. Experiment data were subjected to statistical analysis and results obtained are presented below.

4.1. SOIL ANALYSIS

Soil samples were collected from the treatment plots during three stages; before the sowing of crop, after the harvest of rice and after the harvest of prawn. The soil samples are analysed for various physical (soil texture, bulk density), chemical (pH, EC, organic carbon, available N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, B and exchangeable Na and Al) and biological parameters (microbial biomass carbon).

4.1.1. Initial properties of soil

4.1.1.1. Physical attributes

Relative proportions of various soil separates namely sand, silt and clay in the soil samples were determined and soil texture observed in experimental field was sandy loam. Clay fraction constituted about 24.64 per cent, silt content 15.89 per cent and sand fraction about 59.47 per cent in the experimental field. One of the key soil physical properties used as indicator of soil compactness and soil structure is soil bulk density. As shown in table 4, the bulk density of the soil samples was 1.25 Mg m^{-3}.

4.1.1.2. Chemical attributes

The pH of the soil was 6.74 which comes under neutral range. Electrical conductivity of soil was 1.51 dSm^{-1} and the organic carbon content of the soil was 2.16% (Table 4).

The available N content recorded was 174.45 kg ha^{-1} and hence categorised as low. Available P and available K recorded high content and the values were 71.32 kg ha^{-1} and 281.11 kg ha^{-1} respectively.

Among the secondary nutrients available Ca content in soil was recorded as low (218.11 mg kg^{-1}). The available Mg content was found to be 10.69 mg kg^{-1} in soil and was below sufficiency level. Available S content was high (232.21 mg kg^{-1}). With respect to micronutrients, available Fe, Mn, Zn and B were recorded above sufficiency level and the values were 122.28 mg kg^{-1}, 5.66 mg kg^{-1}, 12.76 mg kg^{-1} and 0.604 mg kg^{-1} respectively. On contrast, available Cu content was found to be deficient (0.198 mg kg^{-1}). The exchangeable Na content in soil was 164.28 mg kg^{-1} and Al content was 10.6 mg kg^{-1}. The microbial biomass carbon was also analysed from soil sample as a biological parameter. On analysis the microbial biomass carbon content recorded was 235.7 µg g^{-1} soil. A detailed account of different soil parameters is depicted in table 4.

Table 4. Physical and chemical properties of initial experimental soil

Sl.no.	Soil properties		Value	Remarks
Physical parameters				
1.	Bulk density (Mg m^{-3})		1.25	
2.	Soil texture		Sandy loam	
	Clay (%)		24.64	
	Silt (%)		15.89	
	Sand (%)		59.47	
Chemical parameters				
3.	pH		6.74	Neutral
4.	EC (dSm^{-1})		1.51	Non saline
5.	Organic carbon (%)		2.16	High
6.	Available N		174.45	Low
7.	Available P		71.32	High
8.	Available K	(kg ha^{-1})	281.11	High
9.	Available Ca		218.61	Deficient
10.	Available Mg		10.69	Deficient
11.	Available S		232.21	Sufficient
12.	Available Fe		122.48	Sufficient
13.	Available Cu	(mg kg^{-1})	0.1987	Deficient
14.	Available Zn		12.761	Sufficient
15.	Available Mn		5.668	Sufficient
16.	Available B		0.604	Sufficient
17.	Exchangeable Na		164.28	High
18.	Exchangeable Al		10.68	High
Biological parameters				
19.	Microbial biomass carbon (μg g^{-1} soil)		235.7	

4.1.2. Soil analysis after harvest of rice

Soil management was the primary objective of the study so that effect of various calcium treatment on soil parameters namely pH, EC, organic carbon, available N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, B and exchangeable Na and Al and also microbial biomass carbon were analysed after the harvest of rice also and the result are presented below.

4.1.2.1. Effect of treatments on pH, EC and organic carbon

Soil reaction, electrical conductivity and organic carbon of samples from different treatments were given in Table 5. Highest soil pH was observed in T_3 (5.14) and T_6 (5.14) and lowest was in T_1 (4.14). The treatments were significantly different as per the observed data. Except T_1, all other treatments *viz.* T_2 (5.11), T_3 (5.14) T_4 (4.36), T_5 (4.67), T_6 (5.13) were on par. Electrical conductivity (EC) of soil samples did not have any significant variation among treatments. The EC values ranged from 1.59 dSm^{-1} (T_4) to 1.75 dSm^{-1} (T_2, T_6). Organic carbon content in soil ranged from 2.23 per cent (T_5) to 2.33 per cent (T_2). There was no significant difference among treatments with respect to organic carbon content.

Table 5. Effect of treatments on pH, EC and organic carbon after the harvest of rice

Treatments	pH	EC (dSm^{-1})	OC (%)
T_1- Absolute control	4.14^{b}	1.60^{a}	2.32^{a}
T_2- Calcium nitrate	5.11^{a}	1.75^{a}	2.33^{a}
T_3- Calcium chloride	5.14^{a}	1.65^{a}	2.28^{a}
T_4-Calcium sulphate	4.36^{ab}	1.59^{a}	2.33^{a}
T_5- Rock phosphate	4.67^{ab}	1.71^{a}	2.23^{a}
T_6- Dolomite	5.14^{a}	1.75^{a}	2.32^{a}
CD	0.0507	NS	NS
SE (d)	0.28	0.121	0.131

4.1.2.2. Effect of treatments on major nutrients of the soil

Effect of different treatments on major nutrients has been given in Table 6. There was significant difference with respect to available N among different treatments. The highest available N were recorded in T_2 (609.11 kg ha^{-1}) and the treatments T_4 (601.06 kg ha^{-1}), T_1 (554.83 kg ha^{-1}), T_3 (534.72 kg ha^{-1}) and T_6 (538.74 kg ha^{-1}) were on par with T_2. Lowest available N was observed in T_5 (500.55 kg ha^{-1}). There was no significant difference as regards to available P and values ranged from 58.25 kg ha^{-1} (T_6) to 68.61 kg ha^{-1} (T_5). Available K content showed significant difference among treatments. Highest value recorded in T_2 (593.73 kg ha^{-1}) and the treatments T_3 (582.25 kg ha^{-1}) and T_4 (465.66 kg ha^{-1}) were on par with T_2. The lowest available K content was found in T_6 (303.14 kg ha^{-1}).

Table 6. Effect of treatments on major nutrients of the soil after the harvest of rice

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1-Absolute control	554.83^{ab}	61.02^{a}	375.61^{bc}
T_2-Calcium nitrate	609.11^{a}	62.65^{a}	593.73^{a}
T_3- Calcium chloride	534.72^{ab}	62.25^{a}	582.25^{a}
T_4- Calcium sulphate	601.06^{a}	65.18^{a}	465.66^{ab}
T_5- Rock phosphate	500.55^{b}	68.61^{a}	376.33^{bc}
T_6-Dolomite	538.74^{ab}	58.25^{a}	303.14^{c}
CD	77.93	NS	86.22
SE (d)	36.23	2.56	40.09

4.1.2.3. Effect of treatments on secondary nutrients of the soil

Effect of treatments on available Ca, Mg and S content of soil after the harvest of rice is presented in Table 7. Available Ca, Mg and S did not show any significant difference among the treatments. Available Ca content in soil ranged from 169.99 mg kg^{-1} (T_1) to 227.73 mg kg^{-1} (T_4). The available Mg content was highest in T_6 (14.37 mg kg^{-1}) and least value was observed in T_5 (14.09 mg kg^{-1}). Available S content in soil ranged from 1121.39 mg kg^{-1} (T_3) to 1466.15 mg kg^{-1} (T_6).

Table 7. Effect of treatments on secondary nutrients of the soil after the harvest of rice

Treatments	Available Ca (mg kg^{-})	Available Mg (mg kg^{-})	Available S (mg kg^{-})
T_1- Absolute control	169.99^a	14.15^a	1156.16^a
T_2- Calcium nitrate	219.84^a	14.24^a	1177.46^a
T_3- Calcium chloride	209.44^a	14.26^a	1121.39^a
T_4- Calcium sulphate	227.73^a	14.12^a	1362.18^a
T_5- Rock phosphate	193.72^a	14.09^a	1249.72^a
T_6- Dolomite	223.03^a	14.37^a	1466.15^a
CD	NS	NS	NS
SE (d)	21.01	0.14	159.9

4.1.2.4. Effect of treatments on micro nutrients of the soil

Available micro nutrient content of soil samples in various treatments are shown in Table 8. Among the micro nutrients, available Fe content showed significant variation among different treatments. Highest available Fe content was observed in T_1 (306.55 mg kg^{-1}) and the least content was seen in T_2 (201.63 mg kg^{-1}) and T_3 (202.95 mg kg^{-1}). The treatments T_4 (286.96 mg kg^{-1}) and T_5 (272.75 mg kg^{-1}) were on par with T_1.

As shown in table 8, available Cu content in soil ranged from 1.073 mg kg^{-1} (T_1) to 1.157 mg kg^{-1} (T_6) and available Mn content ranged from 4.192 mg kg^{-1} (T_1) to 6.427 mg kg^{-1} (T_6). But there was no significant difference among the treatments with respect to available Cu and Mn.

Available Zn content showed significant difference among various treatments and highest and lowest values were recorded in T_3 (9.453 mg kg^{-1}) and T_6 (7.001 mg kg^{-1}) respectively. The treatment T_1 (8.271 mg kg^{-1}), T_2 (8.559 mg kg^{-1}), T_4 (9.163 mg kg^{-1}) and T_5 (8.360 mg kg^{-1}) were on par with T_3.

Available B showed significant difference among treatments. Highest available B content was observed in T_6 (1.206 mg kg^{-1}). Among the six treatments, T_2 recorded least value (0.486 mg kg^{-1}) and treatments T_1 (0.912 mg kg^{-1}), T_3 (0.702 mg kg^{-1}), T_4 (1.085 mg kg^{-1}) and T_5 (0.977 mg kg^{-1}) were on par with T_6.

Table 8. Effect of treatments on micro nutrients of the soil after the harvest of rice

Treatments	Available micronutrients (mg kg^{-1})				
	Fe	Cu	Mn	Zn	B
T_1-Absolute control	306.55^{a}	1.073^{a}	4.192^{a}	8.271^{ab}	0.912^{ab}
T_2- Calcium nitrate	201.63^{c}	1.112^{a}	5.211^{a}	8.559^{ab}	0.486^{b}
T_3- Calcium chloride	202.95^{c}	1.105^{a}	5.882^{a}	9.453^{a}	0.702^{ab}
T_4- Calcium sulphate	286.96^{ab}	1.134^{a}	5.481^{a}	9.163^{a}	1.085^{ab}
T_5- Rock phosphate	272.75^{ab}	1.148^{a}	6.308^{a}	8.360^{ab}	0.977^{ab}
T_6- Dolomite	241.88^{bc}	1.157^{a}	6.427^{a}	7.001^{b}	1.206^{a}
CD	34.86	NS	NS	1.294	NS
SE (d)	16.20	0.051	0.77	0.602	0.474

57

4.1.2.5. Effect of treatments on exchangeable Na and Al content of the soil

Exchangeable Na content in the soil differed significantly between the treatments. The highest content was observed in T_1 (95.15 mg kg^{-1}) and lowest value found in T_3 (71.55 mg kg^{-1}). The treatments T_1 (95.15 mg kg^{-1}) and T_2 (90.85 mg kg^{-1}) were on par (Table 9).

There was a significant increase in exchangeable Al content in the treatment T_1 (42.73 mg kg^{-1}) and the other treatments T_2 (29.02 mg kg^{-1}), T_3 (29.15 mg kg^{-1}), T_4 (28.88 mg kg^{-1}), T_5 (28.04 mg kg^{-1}) and T_6 (28.04 mg kg^{-1}) were on par (Table 9).

Table 9. Effect of treatments on exchangeable Na and Al content of the soil after the harvest of rice

Treatments	Exchangeable Na (mg kg^{-1})	Exchangeable Al (mg kg^{-1})
T_1- Absolute control	95.15^{a}	42.73^{a}
T_2- Calcium nitrate	90.85^{ab}	29.02^{b}
T_3- Calcium chloride	71.55^{c}	29.15^{b}
T_4- Calcium sulphate	81.60^{bc}	28.88^{b}
T_5- Rock phosphate	77.30^{c}	28.04^{b}
T_6- Dolomite	81.27^{bc}	27.58^{b}
CD	1.494	6.818
SE (d)	3.484	3.17

4.1.2.6. Effect of treatments on microbial biomass carbon of the soil after the harvest of rice

Effect of treatment on soil microbial biomass carbon after rice harvest is given in Table 10. The treatments were significantly different with respect to microbial biomass carbon content in soil. Significant reduction in the microbial biomass carbon content was recorded in T_1 (268.98 μg g^{-1} soil). Except T_1, all other treatments T_2 (320.42 μg g^{-1} soil), T_3 (327.20 μg g^{-1} soil), T_4 (334.09 μg g^{-1} soil), T_5 (329.83 μg g^{-1} soil) and T_6 (345.91 μg g^{-1} soil) were on par.

Table 10. Effect of treatments on microbial biomass carbon of the soil after rice harvest

Treatments	Microbial biomass carbon (μg g^{-1} soil)
T_1- Absolute control	268.98^{a}
T_2- Calcium nitrate	320.42^{b}
T_3- Calcium chloride	327.20^{b}
T_4- Calcium sulphate	334.09^{b}
T_5- Rock phosphate	329.83^{b}
T_6- Dolomite	345.91^{b}
CD	62.24
SE (d)	28.94

4.1.3. Soil analysis after the harvest of prawn

It is quiet inquisitive that once again field is flooded and change in soil properties was assessed so that extent of retention of ameliorant was assessed after the prawn harvest to monitor especially with regards to the consumption of the soil nutrients. The reassurance of consistency of treatment can be measured, typically with a long term sustainable view point. Same soil parameters namely pH, EC, organic carbon, available N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, B and exchangeable Na and Al and also microbial biomass carbon which were analysed earlier in rice harvesting stage was again analysed after the harvest of prawn and the result are presented below.

4.1.3.1. Effect of treatments on pH, EC, organic carbon after the harvest of prawn

Soil pH, EC and organic carbon content of soil samples of different treatments after the harvest of prawn were shown in table 11. The soil pH ranged from 5.21 (T_4) to 5.94 (T_1) and there was no significant difference observed among them. Electrical conductivity ranged between 7 dS m^{-1} (T_4) to 8.37 dS m^{-1} (T_5) and the data showed no significant different among treatments. In contrast organic carbon content showed significant difference among treatments after the harvest of prawn. Higher organic carbon content was recorded in T_2 (2.54 per cent) and the least value observed in T_4 (2.32 per cent). The treatments T_1 (2.37 per cent), T_5 (2.39 per cent) and T_6 (2.46 per cent) were on par with T_2.

Table 11. Effect of treatments on pH, EC and organic carbon after the harvest of prawn

Treatments	pH	EC (dSm^{-1})	OC (%)
T_1- Absolute control	5.94^a	8.15^a	2.37^{ab}
T_2- Calcium nitrate	5.64^a	7.40^a	2.54^a
T_3- Calcium chloride	5.75^a	7.27^a	2.33^b
T_4- Calcium sulphate	5.21^a	7.27^a	2.32^b
T_5- Rock phosphate	5.92^a	8.32^a	2.39^{ab}
T_6- Dolomite	5.63^a	7.47^a	2.46^{ab}
CD	NS	NS	0.162
SE (d)	0.302	0.42	0.70

4.1.3.2. Effect of treatments on major nutrients after the harvest of prawn

Among the major nutrients, available N content in soil ranged from 533.12 kg ha^{-1} (T_1) to 658.56 kg ha^{-1} (T_2) and available P content was in the range of 66.90 kg ha^{-1} (T_3) to 85.65 kg ha^{-1} (T_5). Available potassium varied from 967.45 kg ha^{-1} (T_3) to 1189.65 kg ha^{-1} (T_5). Available N, P and K contents in the soil were not significantly different between the treatments (table 12).

Table 12. Effect of treatments on major nutrients after the harvest of prawn

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1- Absolute control	533.12^a	82.72^a	988.90^a
T_2- Calcium nitrate	658.56^a	83.62^a	1109.90^a
T_3- Calcium chloride	564.48^a	80.05^a	967.45^a
T_4- Calcium sulphate	564.48^a	66.90^a	1101.65^a
T_5- Rock phosphate	564.48^a	85.65^a	1189.65^a
T_6- Dolomite	595.84^a	82.73^a	988.35^a
CD	NS	NS	NS
SE (d)	79.33	5.706	71.38

4.1.3.3. Effect of treatments on secondary nutrients after the harvest of prawn

The available Ca content varied from 401.70 mg kg^{-1} (T_1) to 436.50 mg kg^{-1} (T_5) and there was no significant difference observed among the treatments. But available Mg content of soil samples varied significantly among treatments. Higher available Mg in soil was recorded in T_4 (24.24 mg kg^{-1}) and the least value was recorded in T_1 (22.98 mg kg^{-1}). The treatments T_2 (23.84 mg kg^{-1}), T_3 (23.48 mg kg^{-1}) and T_5 (23.93 mg kg^{-1}) were on par with T_4. As per the data from table 13, available S showed significant difference among the treatments. Highest available S content found in T_6 (1999.50 mg kg^{-1}) and lower value was observed in T_1 (1594 mg kg^{-1}). The treatments T_2 (1636.75 mg kg^{-1}), T_3 (1825.50 mg kg^{-1}), T_4 (1995.27 mg kg^{-1}) and T_5 (1902.25 mg kg^{-1}) were on par with T_6 (Table 13).

Table 13. Effect of treatments on secondary nutrients after the harvest of prawn

Treatments	Available Ca (mg kg^{-1})	Available Mg (mg kg^{-1})	Available S (mg kg^{-1})
T_1- Absolute control	401.70^{a}	22.98^{c}	1594.00^{b}
T_2- Calcium nitrate	406.90^{a}	23.84^{abc}	1636.75^{ab}
T_3- Calcium chloride	429.27^{a}	23.48^{abc}	1825.50^{ab}
T_4- Calcium sulphate	436.17^{a}	24.24^{a}	1995.27^{a}
T_5- Rock phosphate	436.50^{a}	23.93^{ab}	1902.25^{ab}
T_6- Dolomite	422.50^{a}	23.22^{bc}	1999.50^{a}
CD	NS	0.607	267.8
SE (d)	26.11	0.282	124.5

4.1.3.4. Effect of treatments on micro nutrients after the harvest of prawn

Regarding micronutrients, available Fe content showed significant difference among treatments. The treatment, T_1 recorded highest available Fe content of 582.95 mg kg^{-1} and T_3 recorded least value of 361.50 mg kg^{-1}. Treatments T_4 (499.35 mg kg^{-1}), T_5 (478.60 mg kg^{-1}) and T_6 (470.60 mg kg^{-1}) were on par with T_1.

There was no significance difference among treatments with respect to available Cu content and the values ranged from 0.199 mg kg^{-1}(T_2) to 0.361 mg kg^{-1}(T_3).

Available Mn content differed significantly among the treatments. Highest available Mn content observed in T_1 (11.15 mg kg^{-1}) and lowest in T_2 (5.744 mg kg^{-1}). Treatment T_1 (11.15 mg kg^{-1}) was on par with T_4 (8.509 mg

kg^{-1}). Treatment T_2 (5.744 mg kg^{-1}), T_3 (6.323 mg kg^{-1}), T_5 (6.083 mg kg^{-1}) and T_6 (7.659 mg kg^{-1}) were on par.

Available Zn content showed significant difference among the treatment. Highest available Zn content was observed in T_4 (21.59 mg kg^{-1}) and lowest value in T_3 (15.08 mg kg^{-1}). The treatments T_1 (20.41 mg kg^{-1}), T_2 (15.73 mg kg^{-1}), T_4 (21.59 mg kg^{-1}), T_5 (20.73 mg kg^{-1}) and T_6 (19.95 mg kg^{-1}) were on par with T_4.

Available B content ranged from 0.0935 mg kg^{-1} (T_6) to 1.167 mg kg^{-1} (T_5). There was no significant different among the treatments.

Table 14. Effect of treatment on micro nutrients after the harvest of prawn

Treatments	Available micro nutrients (mg kg^{-1})				
	Fe	Cu	Mn	Zn	B
T_1- Absolute control	582.95^{a}	0.311^{a}	11.15^{a}	20.41^{ab}	1.130^{a}
T_2- Calcium nitrate	467.25^{bc}	0.199^{a}	5.744^{b}	15.73^{ab}	1.065^{a}
T_3- Calcium chloride	361.50^{b}	0.361^{a}	6.323^{b}	15.08^{b}	1.138^{a}
T_4- Calcium sulphate	499.35^{ab}	0.268^{a}	8.509^{a}	21.59^{a}	1.044^{a}
T_5- Rock phosphate	478.60^{ab}	0.333^{a}	6.083^{b}	20.73^{ab}	1.167^{a}
T_6- Dolomite	470.90^{ab}	0.301^{a}	7.659^{b}	19.95^{ab}	0.935^{a}
CD	82.56	NS	1.735	3.749	NS
SE (d)	38.38	0.197	0.807	1.743	0.224

4.1.3.5. Effect of treatments on exchangeable Na and Al after the harvest of prawn

Exchangeable Na content showed significant difference among the treatments. Higher content of exchangeable Na was observed in T_5 (217.90 mg kg^{-1}) and lower value recorded in T_6 (163.25 mg kg^{-1}). Treatments T_1 (201.65 mg kg^{-1}) was on par with T_5 (217.90 mg kg^{-1}). The treatments T_1 (201.65 mg kg^{-1}), T_2 (176.32 mg kg^{-1}), T_3 (164.85 mg kg^{-1}) and T_4 (164.97 mg kg^{-1}) were on par with T_6.

Exchangeable Al content varied from 3.819 mg kg^{-1} (T_5) to 4.434 mg kg^{-1} (T_1) and there was no significant difference among treatments (Table 15).

Table 15. Effect of treatments on exchangeable Na and Al after the harvest of prawn

Treatments	Exchangeable Na (mg kg^{-1})	Exchangeable Al (mg kg^{-1})
T_1- Absolute control	201.65^{ab}	4.434^{a}
T_2- Calcium nitrate	176.32^{b}	7.452^{a}
T_3- Calcium chloride	164.85^{b}	7.067^{a}
T_4- Calcium sulphate	164.97^{b}	5.750^{a}
T_5- Rock phosphate	217.90^{a}	3.819^{a}
T_6- Dolomite	163.25^{b}	4.764^{a}
CD	26.08	NS
SE (d)	12.12	1.633

4.1.3.6. Effect of treatments on microbial biomass carbon of soil after the harvest of prawn

Soil microbial biomass carbon varied significantly among different treatments. Significant reduction in soil microbial biomass carbon was recorded in T_1 (315.36 µg g^{-1} soil) and the treatments, T_2 (344.84 µg g^{-1} soil), T_3 (336.33 µg g^{-1} soil), T_4 (338.62 µg g^{-1} soil), T_5 (349.89 µg g^{-1} soil) and T_6 (357.16 µg g^{-1} soil) were on par (Table 16).

Table 16. Effect of treatments on microbial biomass carbon of the soil after prawn harvest

Treatments	Microbial biomass carbon (µg g^{-1} soil)
T_1- Absolute control	315.36^{b}
T_2- Calcium nitrate	344.84^{a}
T_3- Calcium chloride	336.33^{a}
T_4- Calcium sulphate	338.62^{a}
T_5- Rock phosphate	349.89^{a}
T_6- Dolomite	357.16^{a}
CD	68.40
SE (d)	31.80

4.3. PLANT ANALYSIS

Plant samples were collected at the time of harvest and analysed for N, P, K, Ca, Mg and Na separately for shoot and root so as to assess source sink relationship.

4.3.1. Effect of treatments on major nutrients

The treatments differed significantly with respect to N content in the shoot, Higher content of shoot N was observed in T_2 (3.58 per cent) and lower content was recorded in T_1 (2.84 per cent). The treatments T_3 (3.34 per cent), T_5 (3.20 per cent) and T_6 (3.38 per cent) were on par with T_2. But there was no significant difference observed with respect to N content in the plant roots. It ranged from 1.19 per cent (T_6) to 1.61 per cent (T_2).

Phosphorus content in shoot and root differed significantly between treatments. Higher shoot P content was observed in T_5 (0.405 per cent) and lowest in T_1 (0.252 per cent). The treatments T_2 (0.305 per cent), T_3 (0.350 per cent), T_4 (0.320 per cent), and T_6 (0.375 per cent) were on par with T_5. Root P content showed higher value in T_5 (0.357 per cent) and least value was in T_1 (0.252 per cent). Treatments T_3 (0.320 per cent), T_4 (0.290 per cent) and T_5 (0.357 per cent) were on par.

Potassium content in shoot and root ranged from 1.638 per cent (T_1) to 1.880 per cent (T_4) and 0.186 per cent (T_6) to 0.241 per cent (T_3) respectively. Treatments however did not differ significantly.

4.3.2. Effect of treatments on Ca, Mg and Na contents of plants

Shoot Ca content showed significant difference among the treatments. The treatment, T_2 recorded highest value of 0.240 per cent and T_1 recorded least shoot Ca content (0.061 per cent). The treatments T_3 (0.216 per cent), T_4 (0.192 per cent), T_5 (0.206 per cent) and T_6 (0.171 per cent) were on par with T_2. Ca content in roots differed significantly among treatments. Highest Ca content in plant roots was observed in T_5 (0.067 per cent) lowest was in T_1 (0.20 per cent).

Treatments T_3 (0.047 per cent), T_4 (0.029 per cent) and T_6 (0.061 per cent) were on par with T_5.

Shoot Mg content ranged from 0.083 per cent (T_4) to 0.097 per cent (T_6) and the treatments did not differ significantly. In contrast, Mg content in roots showed significant difference between treatments. Highest value was observed in T_6 (0.054 per cent) and least value in T_1 (0.025 per cent). Treatments T_3 (0.053 per cent), T_4 (0.050 per cent), T_5 (0.054 per cent) and T_6 (0.054 per cent) were on par (Table 18).

Shoot Na content differed significantly among treatments. Highest shoot Na content was recorded in T_1 (0.192 per cent) and the least content in T_5 (0.045 per cent). The treatments, T_2 (0.052 per cent), T_4 (0.195 per cent) and T_6 (0.060 per cent) were on par with T_5. As per the data, there was no significant difference between treatments with respect to root Na content and it ranged from 0.185 % (T_6) to 0.225 % (T_1).

4.3.3. Plant nutrient status

Plant N content ranged from 2.84 per cent (T_1) to 3.58 per cent (T_2) and all the treatments recorded sufficiency level (1-5 per cent). Phosphorus content in plants varied from 0.405 per cent (T_5) to 0.252 per cent (T_1) and was above the sufficiency level. Adequate amount of potassium was recorded in plant samples from all the treatments and it ranged from 1.638 per cent (T_1) to 1.880 per cent (T_4). Plant Ca content recorded from treatment T_1 (0.061 per cent), T_4 (0.192 per cent) and T_6 (0.171 per cent) were found below sufficiency level of 0.2-1 per cent. Treatments T_2 (0.240 per cent), T_3 (0.216 per cent) and T_5 (0.206 per cent) were found above sufficiency level. The Mg content in plants ranged from 0.083 per cent (T_4) to 0.097 per cent (T_6). The observed values of plant Mg content in all the treatments were below the sufficiency limit of 0.1-0.4 per cent. Sodium content in the control treatment was significantly higher compared to other treatments.

68

Table 17. Effect of treatments on major plant nutrient content

Treatment	N (%)		P (%)		K (%)	
	Shoot	Root	Shoot	Root	Shoot	Root
T_1- A.control	2.84^{b}	1.26^{a}	0.252^{b}	0.235^{c}	1.638^{a}	0.203^{a}
T_2- $Ca(NO_3)_2$	3.58^{a}	1.61^{a}	0.305^{ab}	0.260^{bc}	1.817^{a}	0.235^{a}
T_3- $CaCl_2$	3.34^{ab}	1.47^{a}	0.350^{ab}	0.320^{ab}	1.800^{a}	0.241^{a}
T_4- $CaSO_4$	2.95^{b}	1.47^{a}	0.320^{ab}	0.290^{abc}	1.880^{a}	0.218^{a}
T_5- R.Phosphate	3.20^{ab}	1.26^{a}	0.405^{a}	0.357^{a}	1.762^{a}	0.216^{a}
T_6- Dolomite	3.38^{ab}	1.19^{a}	0.375^{a}	0.222^{c}	1.806^{a}	0.186^{a}
CD	0.321	NS	0.061	0.057	NS	NS
SE (d)	0.149	0.146	0.028	0.026	0.171	0.019

Table 18. Effect of treatments on Ca, Mg and Na contents of plants

Treatment	Ca (%)		Mg (%)		Na (%)	
	Shoot	Root	Shoot	Root	Shoot	Root
T_1- A.control	0.061^{b}	0.020^{c}	0.091^{a}	0.025^{c}	0.192^{a}	0.225^{a}
T_2- $Ca(NO_3)_2$	0.240^{a}	0.026^{bc}	0.095^{a}	0.043^{b}	0.052^{bc}	0.195^{a}
T_3- $CaCl_2$	0.216^{a}	0.047^{abc}	0.084^{a}	0.053^{a}	0.112^{b}	0.195^{a}
T_4- $CaSO_4$	0.192^{ab}	0.029^{abc}	0.083^{a}	0.050^{ab}	0.057^{bc}	0.195^{a}
T_5- R.Phosphate	0.206^{ab}	0.067^{a}	0.093^{a}	0.054^{a}	0.045^{c}	0.192^{a}
T_6- Dolomite	0.171^{ab}	0.061^{ab}	0.097^{a}	0.054^{a}	0.060^{bc}	0.185^{a}
CD	0.099	0.03	NS	0.006	0.045	NS
SE (d)	0.046	0.014	0.006	0.003	0.021	0.01

69

4.3.4. Effect of treatment on uptake of plant nutrients

Among the major nutrients, the total uptake of N was highest in T_2 (211.21 kg ha^{-1}). As per the data from the table 24, there was significance difference among the treatments with respect to uptake of N. The treatments T_3 (136.47 kg ha^{-1}), T_4 (107.78 kg ha^{-1}), T_5 (120.28 kg ha^{-1}), T_6 (125.98 kg ha^{-1}) and T_1 (96.40 kg ha^{-1}) were on par.

Total uptake of P significantly differed among the treatments. Highest P uptake was recorded in T_2 (22.76 kg ha^{-1}) and least value was in T_1 (11.43 kg ha^{-1}). The treatments T_2 (22.76 kg ha^{-1}), T_3 (18.92 kg ha^{-1}) and T_5 (20.37 kg ha^{-1}) were on par.

Total potassium uptake showed significant difference among the treatments. Significant increment in K uptake was found in T_2 (83.39 kg ha^{-1}). The treatment T_1 (43.06 kg ha^{-1}), T_3 (57.51 kg ha^{-1}), T_4 (50.49 kg ha^{-1}), T_5 (54.08 kg ha^{-1}) and T_6 (54.44 kg ha^{-1}) were on par (Table 19).

Table 19. Effect of treatments on uptake of plant nutrients (kg ha^{-1})

Treatment	N	P	K	Ca	Mg	Na
T_1- A.control	96.40^{b}	11.43^{c}	43.06^{b}	1.886^{c}	2.718^{c}	9.525^{a}
T_2- $Ca(NO_3)_2$	211.21^{a}	22.76^{a}	83.39^{a}	10.78^{a}	5.680^{a}	10.06^{a}
T_3- $CaCl_2$	136.47^{b}	18.92^{ab}	57.51^{b}	7.467^{ab}	3.929^{b}	8.054^{ab}
T_4- $CaSO_4$	107.78^{b}	14.57^{bc}	50.49^{b}	5.378^{bc}	3.253^{bc}	6.121^{b}
T_5- R.Phosphate	120.28^{b}	20.37^{ab}	54.08^{b}	7.451^{ab}	3.970^{b}	6.308^{b}
T_6- Dolomite	125.98^{b}	15.98^{bc}	54.44^{b}	6.330^{abc}	4.116^{b}	6.649^{b}
CD	32.34	3.485	16.07	3.168	0.790	1.487
SE (d)	15.03	1.620	7.472	1.473	0.367	0.691

4.3.5. Effect of treatments on Ca : Mg and K: Na ratios of plant

Inter relationships among plant nutrients was assessed by calculation of different ratios as Ca: Mg, K: Na separately for shoot and root in plant. The balanced comparative assessment was made by the simultaneous presentation of these ratio in the following table.

Table 20. Effect of treatments on Ca : Mg and K : Na ratios of plant

Treatment	Ca : Mg		K : Na	
	Shoot	Root	Shoot	Root
T_1- A.control	0.677^{b}	0.791^{a}	9.301^{c}	0.922^{a}
T_2- $Ca(NO_3)_2$	2.491^{a}	0.609^{a}	35.55^{a}	1.202^{a}
T_3- $CaCl_2$	2.555^{a}	0.891^{a}	19.89^{bc}	1.266^{a}
T_4- $CaSO_4$	2.307^{ab}	0.585^{a}	33.75^{a}	1.119^{a}
T_5- R.Phosphate	2.218^{ab}	1.254^{a}	40.87^{a}	1.120^{a}
T_6- Dolomite	1.759^{ab}	1.116^{a}	29.91^{ab}	1.015^{a}
CD	1.101	NS	8.292	NS
SE (d)	0.512	0.246	3.855	0.111

Ratio of Ca:Mg in plant shoot significantly varied from 0.677 to 2.55 among different treatments. Highest ratio was observed in T_3 and lowest was in T_1. The treatment T_2 (2.491), T_4 (2.307), T_5 (2.218) and T_6 (1.759) were on par with T_3. Ratio of Ca:Mg in plant roots ranged from 0.609 (T_2) to1.254 (T_6) and did not show any significant difference among treatments.

Ratio of K: Na in plant shoot showed significant difference among different treatments which ranged from 9.30 to 40.87. Highest ratio was obtained in T_5 (40.87) and lowest in T_1. The treatments, T_2 (35.55), T_3 (19.89), T_4 (33.75) and T_6 (29.91) were on par with T_5. Ratio of K: Na in plant root did not have any significant difference. The ratio in plant roots ranged from 0.922 (T_1) to 1.266 (T_3).

4.4. BIOMETRIC OBSERVATIONS

Rice variety Vytila 6, the widely adopted variety was raised in the first season from June to October 2017. The major biometric observation on the crop namely, plant height, number of tillers, grain yield and dry matter content of rice were recorded. In the second season December to April, the Pokkali field was stocked with seeds of tiger prawn (*Penaeus monodon).* Prawn yield was also recorded from experiment field.

There was no significant difference with regard to observations such as plant height and number of tillers among treatments (Table.21). Plant height ranged from 92.25 cm (T_4) to 100.50 cm (T_2) and number of tillers ranged from 11.25 (T_5) to 13.50 (T_2). As per the observed data, significant difference was observed among the treatment with respect to grain yield. Highest grain yield was recorded in T_2 (3300 kg ha^{-1}) and the other treatments such as T_3 (2192 kg ha^{-1}), T_4 (1908 kg ha^{-1}), T_5 (2063 kg ha^{-1}), T_6 (2098 kg ha^{-1}) and T_1 (1850 kg ha^{-1}) were on par (Table.22). Plant dry matter content was significantly increased in T_2 (4067.67 kg ha^{-1}) and the other treatments, T_3 (2192 kg ha^{-1}), T_4 (1908 kg ha^{-1}), T_5 (2063 kg ha^{-1}), T_6 (2098 kg ha^{-1}) and T_1 (2344.18 kg ha^{-1}) were on par (Table 23).

Table 21. Effect of treatments on height, number of tillers of plant per hill

Treatments	Plant height (cm)	No. of tillers
T_1- Absolute control	100.00^a	11.50^a
T_2- Calcium nitrate	100.50^a	13.50^a
T_3- Calcium chloride	96.50^a	12.00^a
T_4- Calcium sulphate	92.25^a	11.50^a
T_5- Rock phosphate	92.50^a	11.25^a
T_6- Dolomite	98.50^a	11.75^a
CD	NS	NS
SE (d)	4.126	1.312

Table 22. Effect of treatments on grain yield

Treatments	Grain yield (kg ha^{-1})
T_1- Absolute control	1850^b
T_2- Calcium nitrate	3300^a
T_3- Calcium chloride	2192^b
T_4- Calcium sulphate	1908^b
T_5- Rock phosphate	2063^b
T_6- Dolomite	2098^b
CD	779.02
SE (d)	362.18

Table 23. Effect of treatments on plant dry matter content

Treatments	Dry matter content (kg ha^{-1})
T_1- Absolute control	2344.18^b
T_2- Calcium nitrate	4067.67^a
T_3- Calcium chloride	2839.88^b
T_4- Calcium sulphate	2428.59^b
T_5- Rock phosphate	2695.89^b
T_6- Dolomite	2729.23^b
CD	589.64
SE (d)	274.13

4.4.1. Prawn yield

Prawns registered a medium growth and attained final size of 15 to 18 cm in 107 days of culture. Total catch composed of tiger prawns, other species of prawns, crabs, pear spot and many other fishes. Total of 50 kg prawns were harvested from 2000 m^2 experimental area except control and productivity recorded was 300 kg ha^{-1}. Productivity of control recorded least value of 180 kg ha^{-1}.

Table 24. Productivity of major fish species

	Control (kg ha^{-1})	Treatment plot (kg ha^{-1})
Tiger prawn	180	300
Other fishes		
Pearl spot (*Etroplus suratensis*)	50	70
Pallathi (*Etroplus maculatus*)	75	80

Table 25. Benefit cost ratio of rice-prawn integrated farming system

Treatment	Rice cultivation					Prawn cultivation		Gross cost	Gross benefit	BC ratio
	Expenditure				Returns	Expenditure	Returns			
	Labour cost (Rs.)	Seed cost (Rs.)	Fertilizer cost (Rs.)	Total (Rs.)						
A. Control	85250	6500	-	91750	120,250	87,600	1,08,000	179,350	2,28,250	1.27
CN	85250	6500	1,93,500	285,250	214,500	87,600	1,80,000	372,850	3,94,500	1.06
CC	85250	6500	78,468	170,218	142,480	87,600	1,80,000	257,818	3,22,480	1.25
CS	85250	6500	34,190	125,940	124,020	87,600	1,80,000	213,540	3,04,020	1.42
RP	85250	6500	22,384	114,134	134,095	87,600	1,80,000	201,734	3,14,095	1.56
D	85250	6500	15,144	106,894	136,370	87,600	1,80,000	194,494	3,16,370	1.63

*CN- $Ca(NO_3)_2$, CC- $CaCl_2$, CS- $CaSO_4$, RP- R.Phosphate, D- Dolomite

Discussion

DISCUSSION

The study "Management of soil salinity with calcium salts in rice–prawn farming system in *Pokkali* lands" was carried out to evaluate the effect of calcium salts on the growth and nutrition of rice, yield of prawn and soil properties, which was conducted in the Thathapilli padasekharam of Kottuvally Panchayath in Ernakulam district. Results of this experiments are discussed here with supporting research works from literature.

5.1. INITIAL PROPERTIES OF SOIL

5.1.1. Physical attributes

Physical parameters like soil texture and bulk density were assessed initially. Soil texture was found to be sandy loam with 24.64, 15.89 and 59.47 per cent of clay, silt and sand fractions respectively. Joseph (2014) observed that soil texture varied from sandy clay loam to clay in *Pokkali* soil. Mohan (2016) reported wide variations in silt, clay and sand percent of soils from different *Pokkali* fields. Clay content ranged from 15 to 60.87 percent in different locations. Silt content ranged between 6.04 to 19.82 percent. Varghese *et al.,*(1970) reported that coarse and fine fractions of sand were 32.3 and 35.1 percent respectively in the *Pokkali* soils. The tidal influx brought about significant changes in the soil properties of *Pokkali* soils. According to Joseph (2014) this might be the reason for variations in the particle size distribution.

The bulk density of the experimental field was found to be 1.25 Mg m^{-3}. Joseph (2014) reported that bulk density values were low in all the *Pokkali* land use system and the values ranged from 0.56 Mg m^{-3} to 1.17 Mg m^{-3}. This is because of the presence of high organic matter content in *Pokkali* soils.

5.1.2. Chemical attributes

Soil pH in the initial analysis was recorded as 6.74. According to Padmaja *et al.*,(1994) pH of *Pokkali* soil ranged from 3.10 to 5.80. Joseph (2014) reported that soil pH in different *Pokkali* land use system ranged from 5.69 to 7.26. Initial soil sampling was carried out in June. Occurrence of heavy rain created changes in soil acidity due to leaching effects. Electrical conductivity of the soil was 1.51 dS m^{-1}. Salinity of the *Pokkali* lands is influenced by periodic sea water inundations and *Pokkali* lands did not have any protection from direct entry of saline water (Santhosh, 2013). Heavy rain influences the electrical conductivity. It dilutes the salts present in the water. In rainy season water was almost fresh. Organic carbon status was observed to be high (2.16 percent) in initial sample. Joseph (2014) reported the organic carbon status in different *Pokkali* land use system ranging from 0.79 to 2.09 percent.

Among the major nutrients, available N content recorded was 174.4 kg ha^{-1}. Mohan (2016) reported that available N varied from 142.16 to 215.33 kg ha^{-1} in *Pokkali* lands during mound preparation stage. According to Acharya (1935) mineralisation of organic matter was lower or slower in submerged soil than an aerobic soil. Available P content in the initial sample was high (71.34 kg ha^{-1}). Joseph (2014) observed that available P was high in all the *Pokkali* land use systems. Sasidharan (2004) reported that it was due to tidal influence. Available K content was also found to be high (281.11 kg ha^{-1}), just like phosphorus, due to influence of tidal action.

Regarding secondary nutrients, available Ca content in the soil was 218.61 mg kg^{-1}. Anilkumar and Annie (2010) reported that available Ca content in soil during the low saline phase ranged from 76 to 256 mg kg^{-1}. The available Mg content showed very low value of 10.69 mg kg^{-1} and it was under deficiency level. Aryalekshmi (2016) reported a Mg content of 26.17 mg kg^{-1} in *Pokkali* soil. Available sulphur recorded a high value of 232.21 mg kg^{-1}. This was in accordance with studies of Santhosh (2013).

78

Among the micro nutrients, available Fe and Mn were found to be very high in *Pokkali* lands and toxicity due to high content of these elements were also noticed by Mohan (2016). Available Fe and Mn contents in initial soil sample were 122.48 mg kg^{-1} and 5.66 mg kg^{-1} respectively. Available Fe content in *Pokkali* soils ranged between 171 to 2321 mg kg^{-1} (Shylaraj *et al.,* 2013). Available Zn and B contents in the soil sample were sufficient whereas, available copper was found to be deficient (0.198 mg kg^{-1}). Santhosh (2013) reported that direct marine influences along with high organic matter content contributed to high content of available boron in organically complexed form in *Pokkali* tracts. Chelation of Cu by organic colloids resulted in unavailability of Cu and increased organic matter content favoured chelation process.

Exchangeable Na and Al contents in the soil samples were 164.28 mg kg^{-1} and 10.68 mg kg^{-1} respectively. Mohan (2016) reported that exchangeable Na and Al content in soil showed significant variations among different stage of cultivation. This might be due to variation in the salts present in sea water. Soil microbial biomass carbon was also calculated in order to found out the microbial load. It was found to be 235.7 μg^{-1} soil. Mohan (2016) reported that microbial biomass carbon in *Pokkali* soil ranged from 95 to 227 μg^{-1} soil during mound preparation stage. Joseph (2014) reported lowest value of microbial biomass carbon in shrimp alone land use system and highest in fallow land use system among the different *Pokkali* ecosystems.

5.2. EFFECT OF TREATMENTS ON SOIL PROPERTIES AFTER RICE AND PRAWN CULTIVATION

Analysis of soil samples from different treatments to assess the effect of calcium salts on various soil properties was carried out separately after the harvest of rice and after the harvest of prawn so that residual effect of treatments can also be studied. The results are discussed here with supporting literature.

5.2.1. Soil reaction

Significant difference was observed among treatments in the case of soil reaction after the rice cultivation. In the control plot pH was found to be low compared to all other treatments. This indicated the effect of calcium salts to reduce soil acidity. Many scientists substantiated the effect of calcium compounds in controlling soil acidity. Liming is the most common practice used to overcome the impacts of soil acidification (Bolan, 2003). All the calcium salt treatments showed a superiority over control. Dolomite is efficiently used as soil ameliorant in strongly acidic soils of Kuttanad (Devi *et al.,* 2017). There was no significant difference among the treatment in soil reaction after the cultivation of prawn. This might be due to increase in soil salinity as a result of tidal action. Lime application in acidic soil significantly reduced the total acidity, exchangeable acidity and hydrolytic acidity in soil in an incubation period of 21 days and the magnitude of decrease was correlated to the quantity of lime applied (Badole *et al*., 2015).

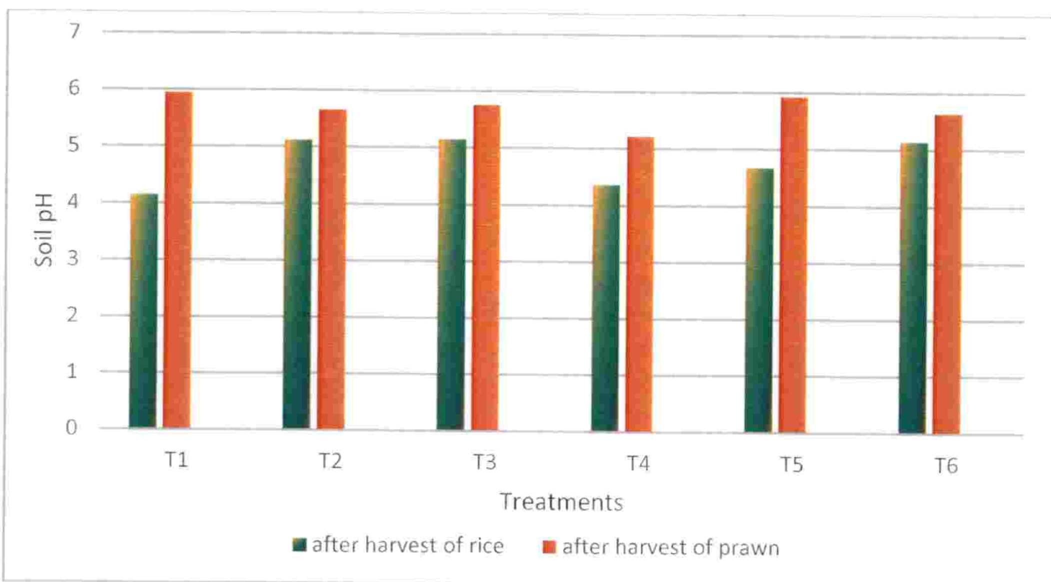

Figure 2: Effect of treatments on soil pH after the harvest of rice and prawn

80

5.2.2. Electrical conductivity

Electrical conductivity of treatments did not differ significantly as a result of Ca treatments in both stages of cultivation, after the harvest of rice and after the harvest of prawn. Mohan (2016) reported an average EC of 2.37 dS m^{-1} at harvesting stage of rice. Tidal action have a significant effect on soil electrical conductivity (Sasidharan, 2004).

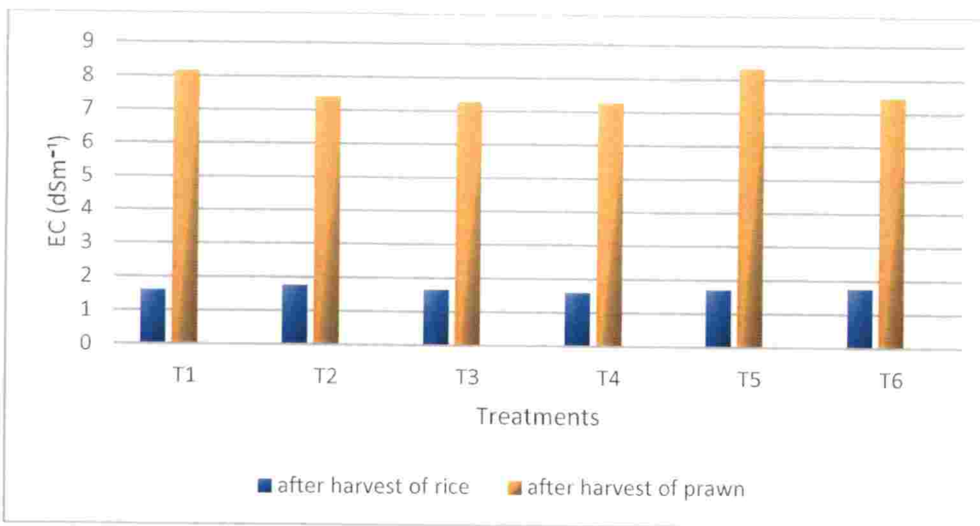

Figure 3: Effect of treatments on soil electrical conductivity after the harvest of rice and prawn

5.2.3. Organic carbon content

Organic carbon status of soil was not affected by application of calcium salts after the rice cultivation. But variation in the organic carbon status after prawn cultivation was noticed in the different treatments. Calcium nitrate treatment recorded higher organic carbon content after prawn harvest. This may be due to the higher dry matter content produced during rice cultivation in the treatment and slower decomposition of plant residues in submerged soil. Organic carbon content range of 0.45 to 2.90 per cent in *Pokkali* soils during low saline phase was reported by Anilkumar and Annie (2010).

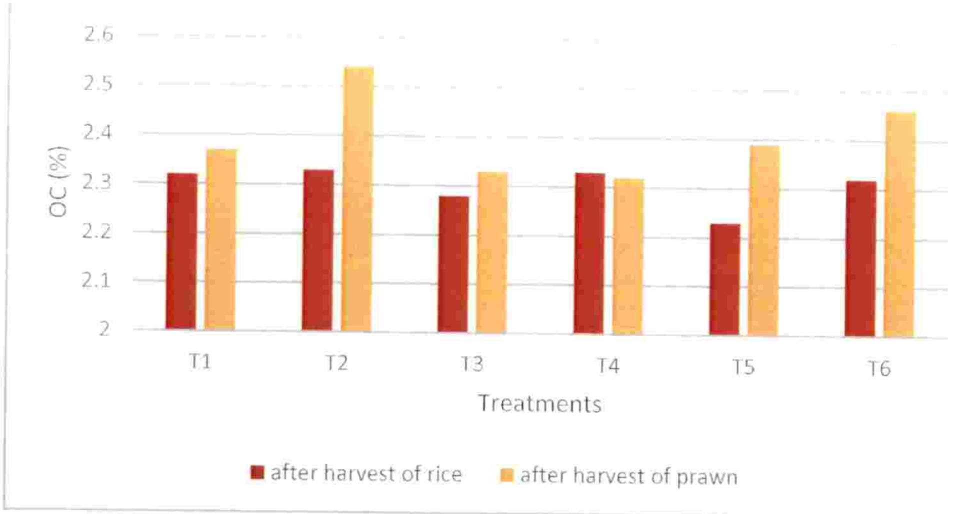

Figure 4: Effect of treatments on soil organic matter after the harvest of rice and prawn

5.2.4. Available major nutrients

Available N content in soil varied significantly among different calcium treatments during the time of rice harvest and prawn harvest and recorded high fertility status. Joseph (2014) reported highest available N content in paddy shrimp land use system among other land use systems in *Pokkali*. Available N was high in calcium nitrate treatment after the harvest of rice even though there was no significant difference. This was due to the addition of N as nitrate. Higher dry matter production was recorded from calcium nitrate treatment. Increased amount of available N after prawn harvest might be due to breakdown of plant residue and N mineralisation takes time due to submergence.

Higher content of available P was observed in all treatments. Sasidharan (2004) reported that higher amount of P in *Pokkali* field is due to tidal action. Among the different treatments, rock phosphate increased the available P content in soil after the harvest of rice. But there was no significant difference among the treatments with respect to available P. Available P increased in all treatments after prawn harvest.

Available K content in *Pokkali* soil was recorded as high. There is no significant effect on treatments on available soil K after the cultivation of prawn.

In pokkali soil available K content varied between 13 to 1777 kg ha^{-1} (Anilkumar and Annie, 2010). Sasidharan (2004) reported that tidal action significantly increased the available K content. Joseph (2014) reported highest available K in paddy shrimp land use system among different *Pokkali* land use system.

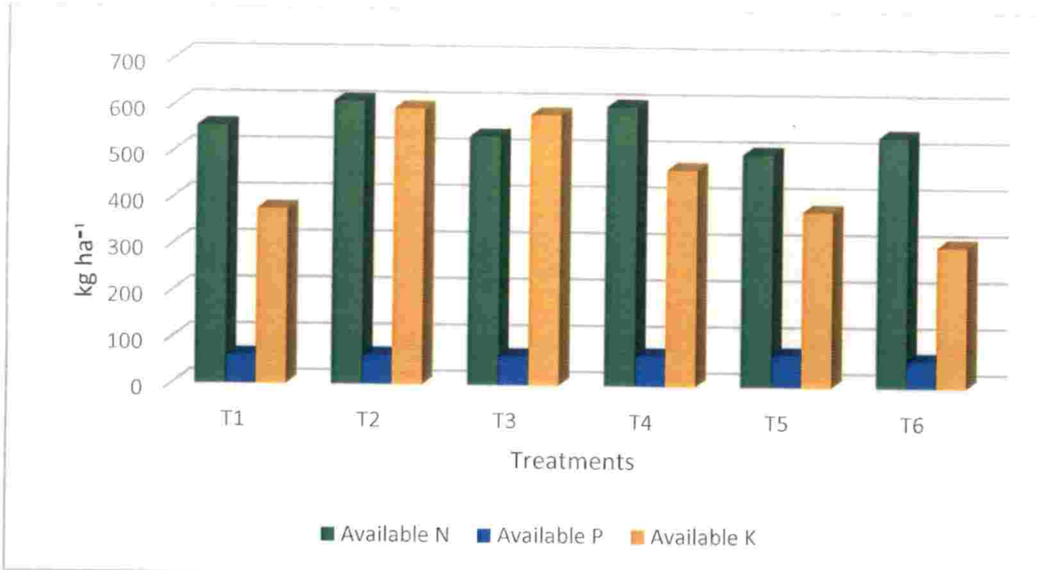

Figure 5: Effect of treatments on available N, P and K after the harvest of rice

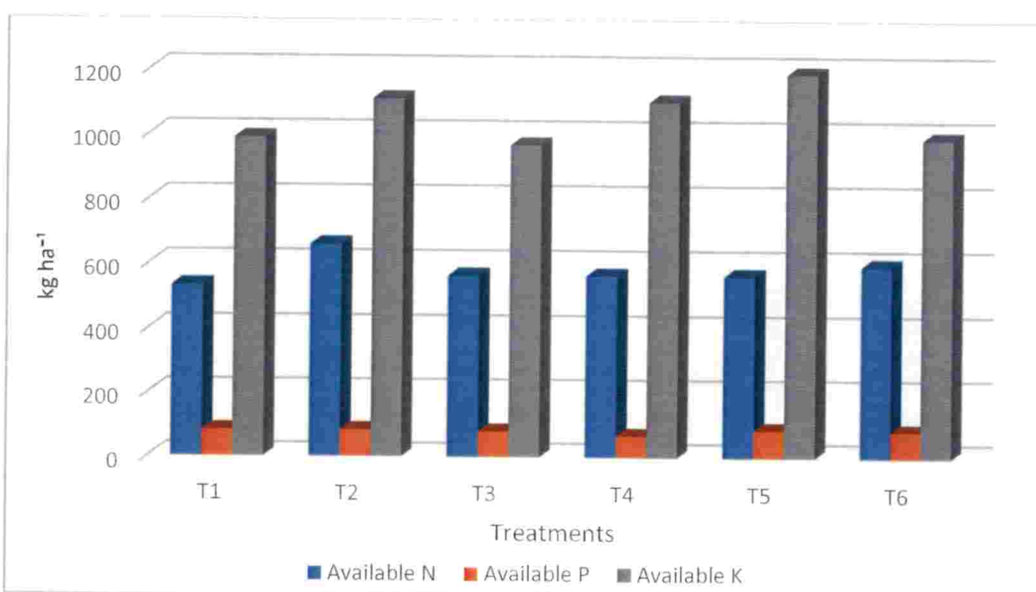

Figure 6: Effect of treatments on available N, P and K after the harvest of prawn

82A

5.2.5. Secondary nutrients

Available Ca content was found to be high in most of the treatments over the control. Application of Ca salts increased the calcium content in soil after the harvest of rice but there was no significant difference among the treatments. Amount of available Ca almost doubled after the harvest of prawn. This may be due to deposition of Ca rich exuvia of prawns (Tacon, 1987). In *Pokkali* lands Ca is found in water soluble form and organic complexed Ca so that available Ca content in *Pokkali* fields are directly influenced by tidal action and organic matter content (Bhindu, 2017). A positive correlation was reported among organic complexed Ca with organic carbon which indicate chelation of Ca by organic colloids in soils with organic matter (Bhindu, 2017).

Available Mg content of all the treatments was found to be low after the rice and prawn harvest, even after application of dolomite as one of the treatment. Mohan (2016) reported lower Mg values during mound preparation, mound dismantling and harvest stages of rice cultivation in *Pokkali* fields. Most of the Mg minerals are highly soluble to persist in soils with pH below 7.5 (Lindsay, 1979).

Available S content was extremely high in all the treatments after the rice as well as prawn harvest. Yoshidha (1981) reported that organic acids and sulphide may be present to cause toxicity to lowland rice. High content of S was reported in *Pokkali* and *kaipad* lands due to the acid sulphate nature (Santhosh, 2013).

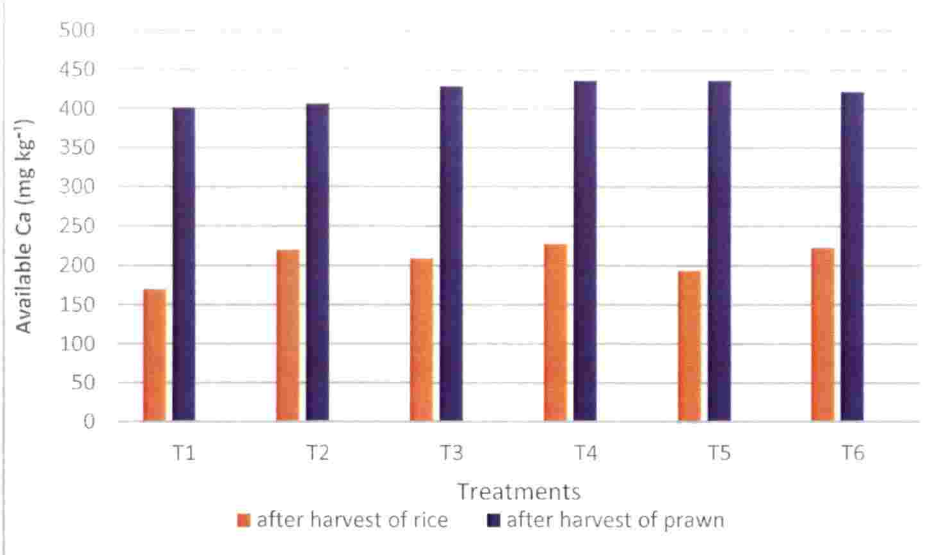

Figure 7: Effect of treatments on available Ca after the harvest of rice and prawn

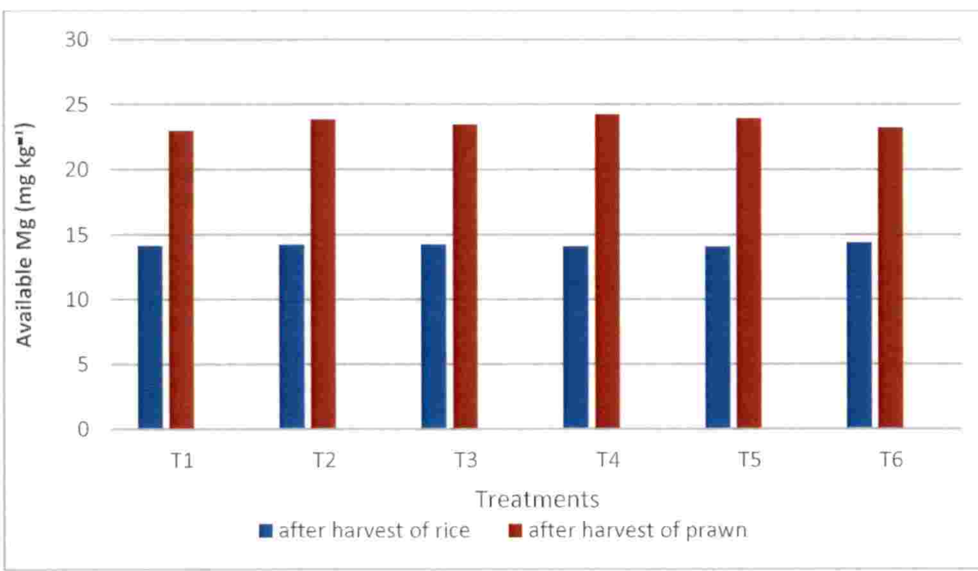

Figure 8: Effect of treatments on available Mg after the harvest of rice and prawn

84

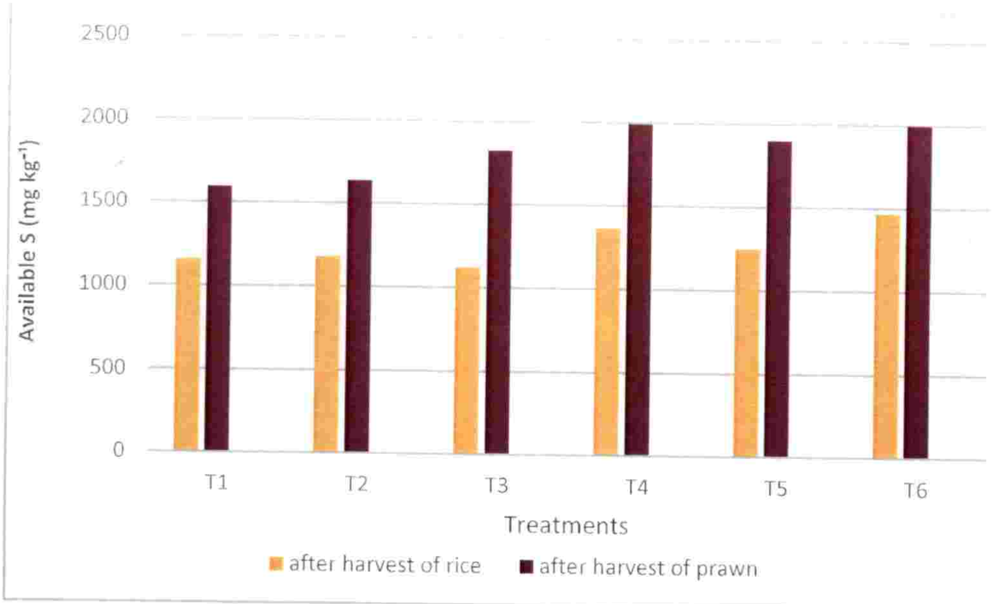

Figure 9: Effect of treatments on available S after the harvest of rice and prawn

5.2.6. Micro nutrients

Available Fe and Mn in *Pokkali* soil were found to be high during rice harvesting stage and prawn harvesting stage. Joseph (2014) and Mohan (2016) reported Fe and Mn toxicity in *Pokkali* soils. Available Fe content ranged from 171 to 232 mg kg^{-1} in low saline phase and 172 to 2028 mg kg^{-1} in high saline phase in *Pokkali* soils (Shylaraj *et al.,* 2013). Available Fe and Mn content were comparatively lower in treatments with calcium salts over the control. This is because of the ameliorating effect of Ca. Nhung and Ponnamperuma (1966) reported that calcium compounds like $CaCO_3$ can increase the soil pH which consecutively reduce Fe^{2+}, Al^{3+}, Mn^{2+} and SO_4^{2-}in the soil solution. Available Zn content was found to be high in rice harvesting stage and the prawn harvesting stage. According to Bhindu (2017), among the micronutrient cations in the low lands of *Pokkali* tract, Mn was dominant while the other sites were occupied by Fe, Zn and Cu in exchange complex. Available Cu showed higher value in all the treatments at rice harvest stage but its content was reduced at the time of prawn harvest. This might be due to chelation of Cu by organic colloids and increased

85

organic matter content favoured chelation process. Available B content in soil was high during rice harvesting stage as well as in prawn harvesting stage. The direct marine influences along with high organic matter content has resulted in the high content of available B in organically complexed form in lowlands of *Pokkali* tract (Santhosh, 2013).

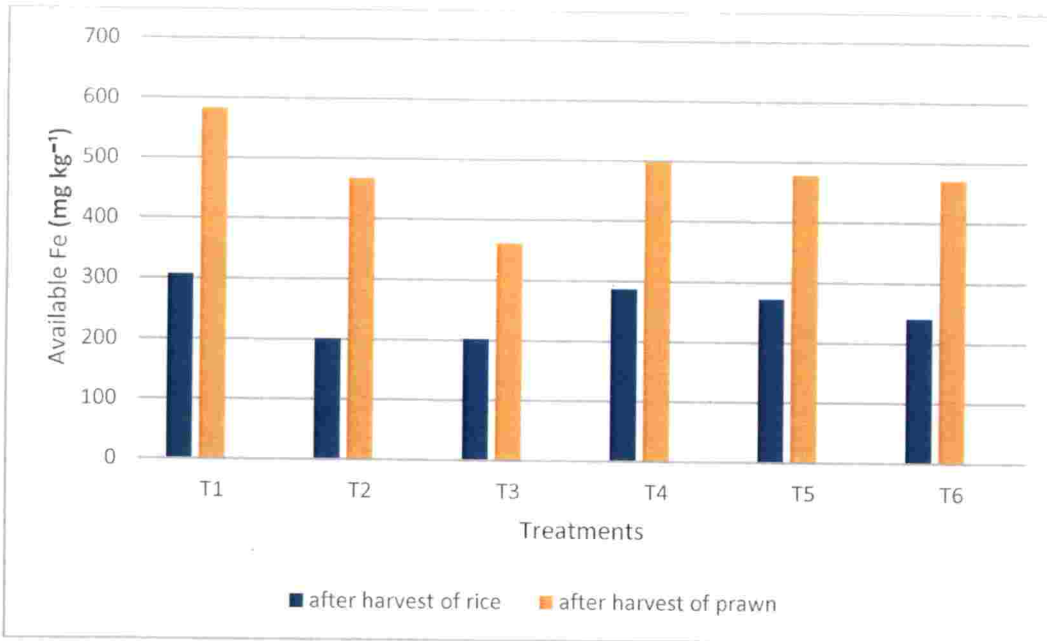

Figure 10: Effect of treatments on available Fe after the harvest of rice and prawn

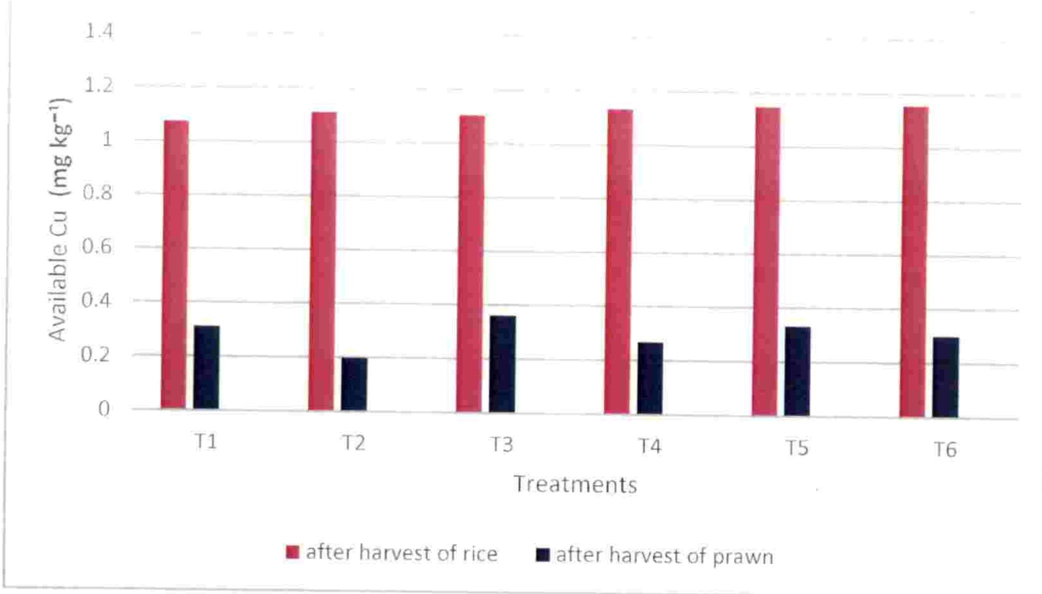

Figure 11: Effect of treatments on available Cu after the harvest of rice and prawn

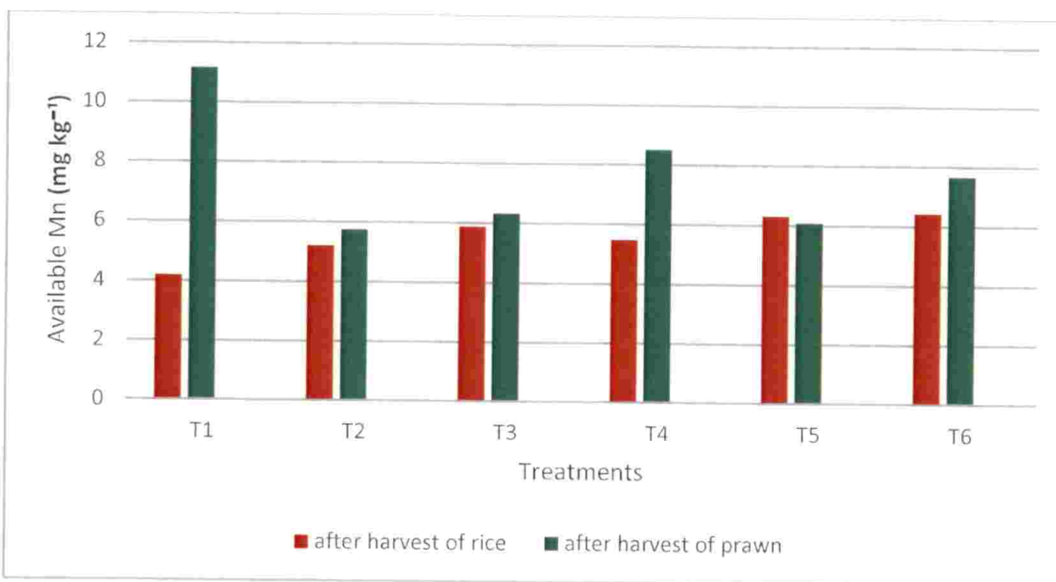

Figure 12: Effect of treatments on available Mn after the harvest of rice and prawn

87

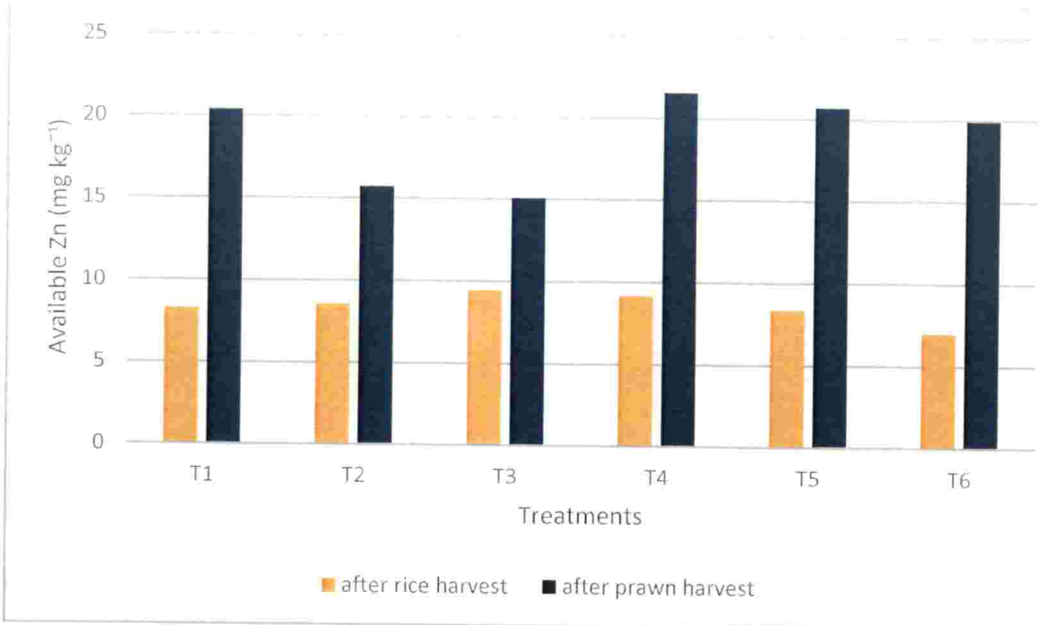

Figure 13: Effect of treatments on available Zinc after the harvest of rice and prawn

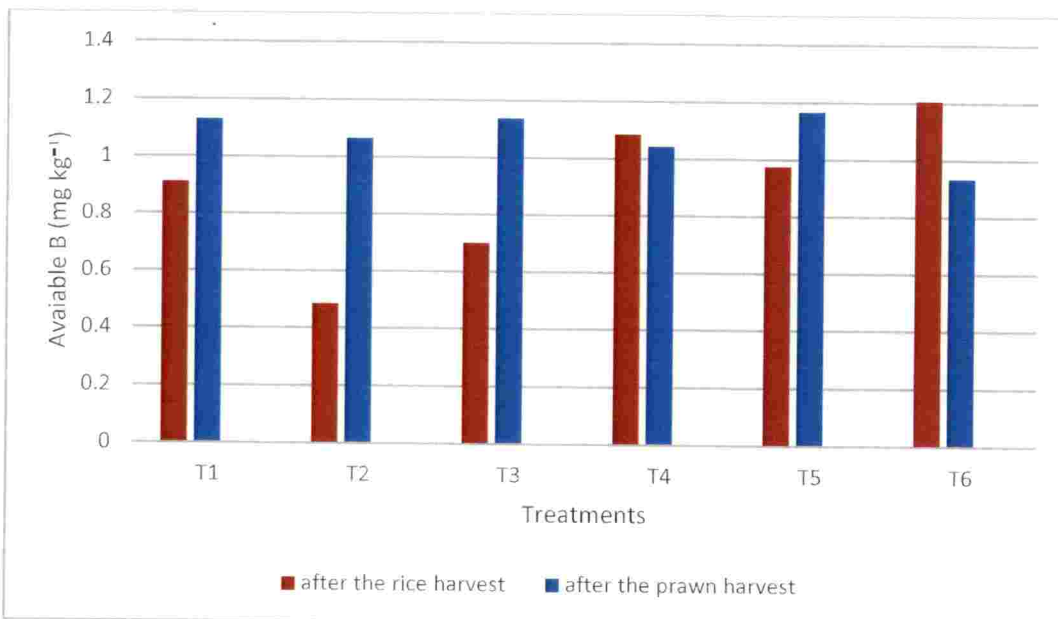

Figure 14: Effect of treatments on available Boron after the harvest of rice and prawn

5.2.7. Exchangeable Na and Al

Exchangeable Na in rice harvesting stage varied significantly. Higher content of exchangeable Na was recorded in control. Exchangeable Na content was comparatively low in calcium chloride and rock phosphate treatments. Rock phosphate being a less soluble fertilizer, satisfactory utilization of rock phosphate takes place under pH 6 (Ellis *et al.*, 1955). Its dissolution rate varies and there may be a chance of displacements among Ca and Na ions in the soil exchange complex.

Higher exchangeable Al was recorded in control treatment after the rice harvest. Reduction in exchangeable Al content was observed in all calcium treatments in a similar way, except control. According to Sanchez (1976) Al toxicity can be reduced to some extent by addition of calcium and magnesium. Sasidharan (2004) found out that removal of Al toxicity is much difficult in *Pokkali* soil because of tidal action. Periodic inundation of marine water greatly influences the acid saline soils of *Pokkali* lands and Na and Al are the dominant cations in the inundation process (Bhindu, 2017).

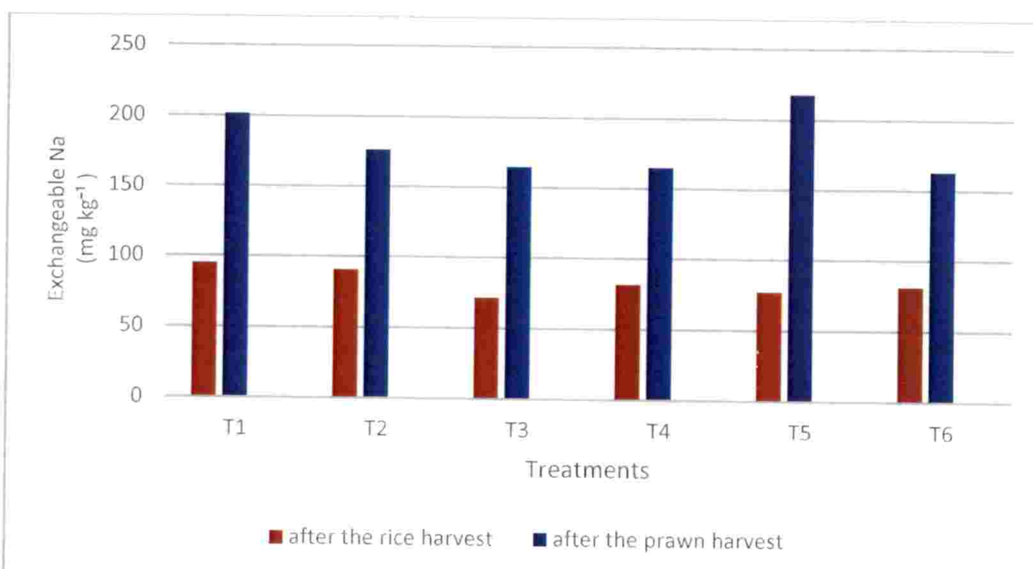

Figure 15: Effect of treatments on exchangeable Na after the harvest of rice and prawn

89

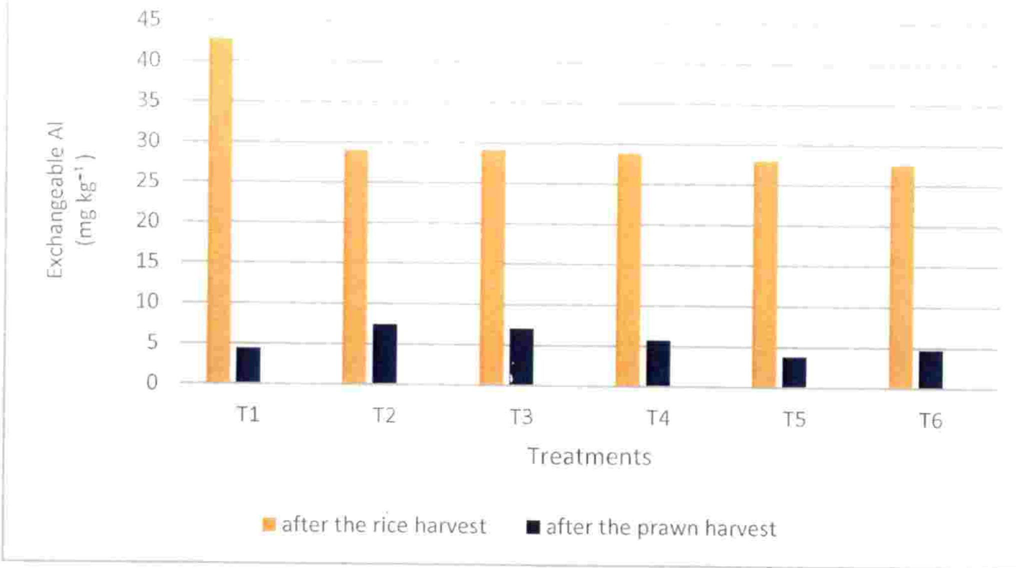

Figure 16: Effect of treatments on exchangeable Al after the harvest of rice and prawn

5.2.8. Microbial biomass carbon

Microbial biomass carbon was found to be higher in all the calcium treatments except control after the harvest of rice as well as prawn. Liming increases microbial biomass and also enzyme activity in soil (Haynes and Swift, 1988). Haynes and Naidu (1998) also pointed out that liming causes a temporary flush in soil microbial activity. Chendrayan *et al.,* (1980) reported significant dehydrogenase activity in flooded soil, indicating the presence of anaerobic bacteria in flooded soils.

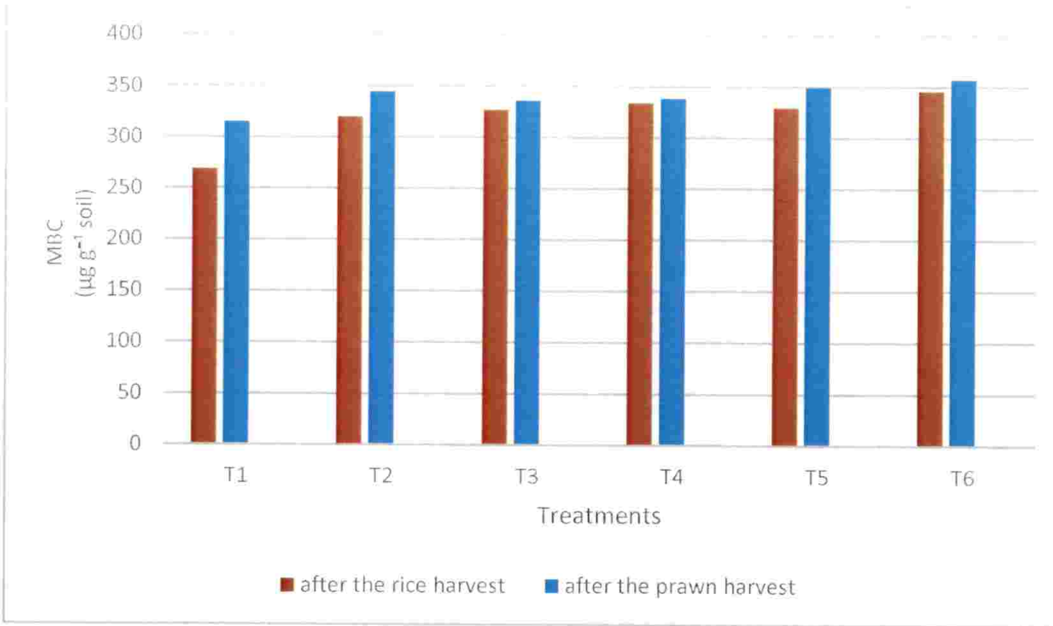

Figure 17: Effect of treatments on microbial biomass carbon after the harvest of rice and prawn

5.3. TEMPORAL VARIATIONS IN SOIL NUTRIENT DYNAMICS

Pokkali soils are acid saline in nature and its soil characteristics vary according to temporal and spatial changes. The tidal and fluvial effect varied with the climate in each year and this resulted in variation in chemical characteristics. Soil pH was very strongly acidic to strongly acid range in most of the treatment after rice harvest. It changed to moderately acid after the prawn harvest. Wide variations were observed in case of electrical conductivity. Soil electrical conductivity was non saline after the rice cultivation among all treatments and become slightly saline after prawn harvest. This specify the importance of low and high saline phases in *pokkali* cultivation. An increment in organic carbon content was observed among two stages and it remained high after rice and prawn harvest. Available N showed low status in soil after rice harvest except in T_2 and became high after prawn harvest. Available P content was high in both stages but it increased after prawn harvest in all treatments. Available K content almost doubled after the cultivation of prawn invariably in all treatments and rated as

91

high. Available Ca status fluctuated from deficient to sufficient level after prawn harvest among treatments and available Mg content remained low. High level of available S was observed in two stages.

Regarding micro nutrients, high increment was noticed in case of available Fe, Zn, Mn and B after the prawn harvest and remained high in status. Available Cu content was reduced from sufficient limit to deficiency level in all treatments after prawn harvest. Exchangeable Na content in soil fluctuated from lower to higher value and remained high. Exchangeable Al content exceeded sufficiency range after rice harvest and changed to sufficiency limit after prawn harvest.

Table.13. Temporal variations in soil properties after the harvest of rice and prawn

Sl No.	Soil properties	T1		T2		T3		T4		T5		T6	
		ARH	APH	ARH	APH	ARH	APH	ARH	APH	ARH	APH	ARH	APH
1	pH	4.14	5.94	5.11	5.64	5.14	5.75	4.36	5.21	4.67	5.92	5.14	5.63
2	EC (dSm^{-1})	1.60	8.15	1.75	7.40	1.65	7.27	1.59	7.27	1.71	8.32	1.75	7.47
3	OC (%)	2.32	2.37	2.33	2.54	2.28	2.33	2.33	2.32	2.23	2.39	2.32	2.46
4	N (kg ha^{-1})	554.83	533.12	609.11	658.56	534.72	564.48	601.06	564.48	500.55	564.48	538.74	595.84
5	P kg ha^{-1})	61.02	82.72	62.65	83.62	62.25	80.05	65.18	66.90	68.61	85.65	58.25	82.73
6	K (kg ha^{-1})	375.61	988.90	593.73	1109.9	582.25	967.45	465.66	1101.6	376.33	1189.6	303.14	988.35
7	Ca (mg kg^{-1})	169.99	401.70	219.84	406.90	209.44	429.27	227.73	436.17	193.72	436.50	223.03	422.50
8	Mg (mg kg^{-1})	14.15	22.98	14.24	23.84	14.26	23.48	14.12	24.24	14.09	23.93	14.37	23.22
9	S (mg kg^{-1})	1156	1594	1177	1636	1121	1825	1362	1995	1249	1902	1466	1999
10	Fe (mg kg^{-1})	306.55	582.95	201.63	467.25	202.95	361.50	286.96	499.35	272.75	478.60	241.88	470.90
11	Cu (mg kg^{-1})	1.073	0.311	1.112	0.199	1.105	0.361	1.134	0.268	1.148	0.333	1.157	0.301
12	Zn (mg kg^{-1})	8.271	20.41	8.559	15.73	9.453	15.08	9.163	21.59	8.360	20.73	7.001	19.95
13	Mn (mg kg^{-1})	4.192	11.15	5.211	5.744	5.882	6.323	5.481	8.509	6.308	6.083	6.427	7.659
14	B (mg kg^{-1})	0.912	1.130	0.486	1.065	0.702	1.138	1.085	1.044	0.977	1.167	1.206	0.935
15	Exchangeable Na (mg kg^{-1})	95.15	201.65	90.85	176.32	71.55	164.85	81.60	164.97	77.30	217.90	81.27	163.25
16	Exchangeable Al (mg kg^{-1})	42.73	4.434	29.02	7.452	29.15	7.067	28.88	5.750	28.04	3.819	27.58	4.764
17	MBC (μg^{-1} soil)	268.98	315.36	320.42	344.84	327.20	336.33	334.09	338.62	329.83	349.89	345.91	357.16

*ARH- After Rice Harvest, APH- After Prawn Harvest

93

5.4. EFFECT OF TREATMENTS ON PLANT NUTRIENT CONTENT

5.4.1. Plant nitrogen

Nitrogen content in shoot and root showed significant difference among treatments. All the treatments showed superiority over the control. This indicated that adequate supply of Ca can enhance N use efficiency in the plant tissue by increased deposition of metabolites in the seed (Fenn *et al.*, 1995). Treatment with calcium nitrate resulted in higher shoot and root N content than other treatments. Calcium nitrate treatment lead to good stimulation of plant growth because of the presence of nitrate.

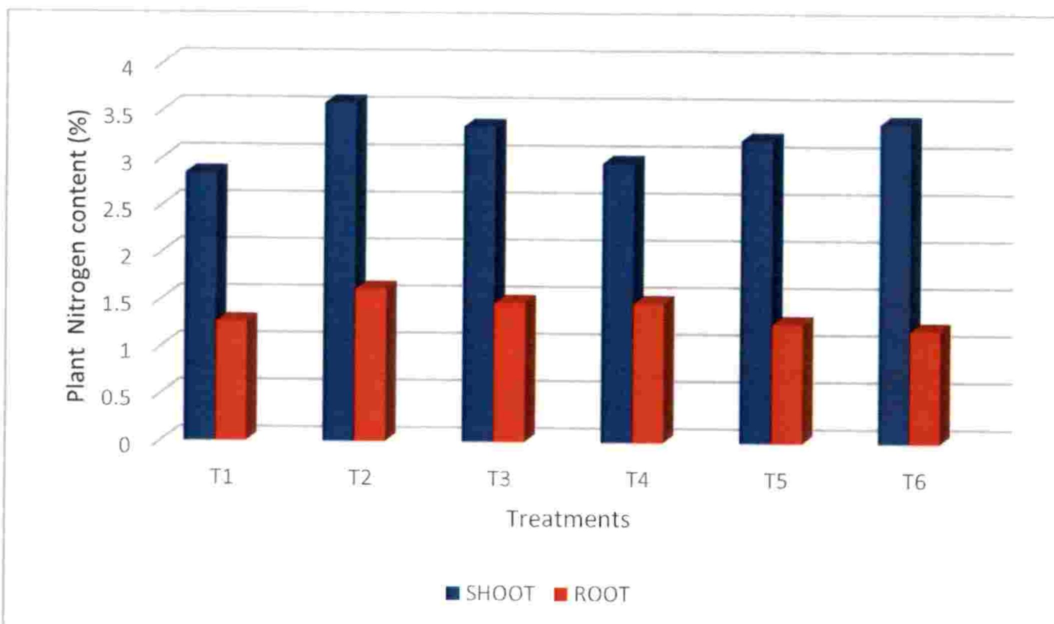

Figure 18: Effect of treatments on N content in shoot and root

94

5.4.2. Plant phosphorus

Shoot and root P content showed higher value in all the treatments except control. Relative increase in P concentration was found in shoot and root of plants as a response to P supplied as rock phosphate. According to Sing *et al.,* (1988) increased P content in shoot and root of plants was observed as a result of increase in P content in saline soil. Kawasaki (1995) reported that under certain ion concentration ranges in nutrient solution, Ca stimulates the absorption of P and K in to plants.

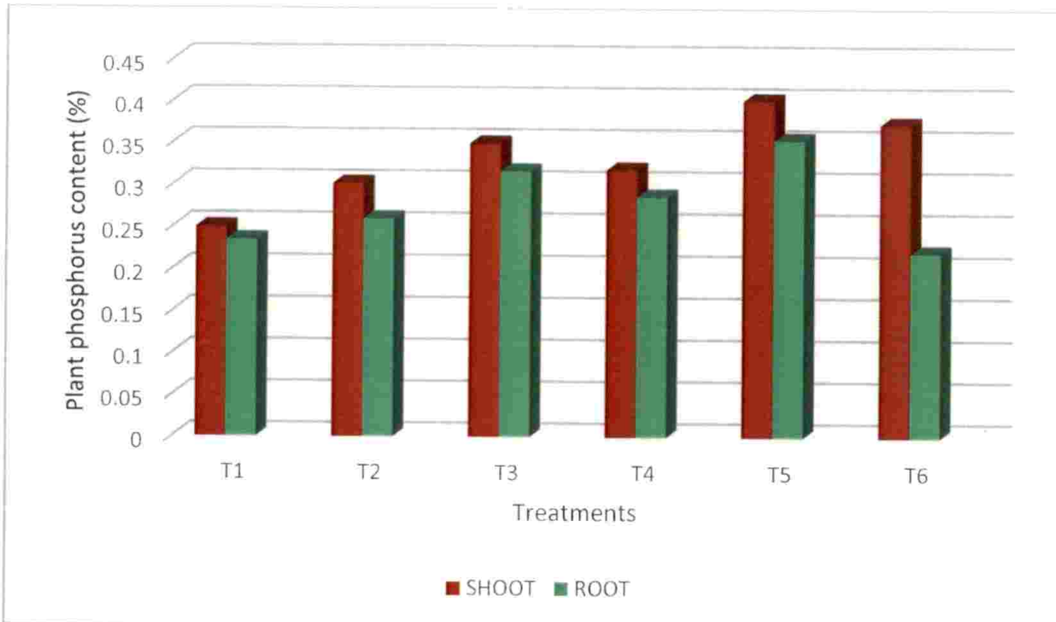

Figure 19: Effect of treatments on P content in shoot and root

5.4.3. Plant potassium

Plant K content did not show significant difference among the treatments even though there was a significant difference in available K in the soil after the cultivation of rice. Concentration of K was high in shoot than roots. But calcium sulphate, calcium nitrate, dolomite and calcium chloride treatments recorded higher plant K in shoot and root. In saline conditions high concentration of Na may block the transport of K which interferes with growth of some plant species (Cramer *et al.,* 1986). Alam *et al.,* (2002) reported apparent antagonism between plant Na and K in rice plants. This was due to direct competition between K and Na at ion uptake site of roots (Epstein, 1966). According to Kent and Lauchli (1985) K concentration in roots of cotton was reduced by salinity and it was restored by supplemental Ca. Leopold and willing (1984) reported that higher concentration of Na affect intercellular accumulation of K and its deficiency was regarded as the detrimental effect of NaCl.

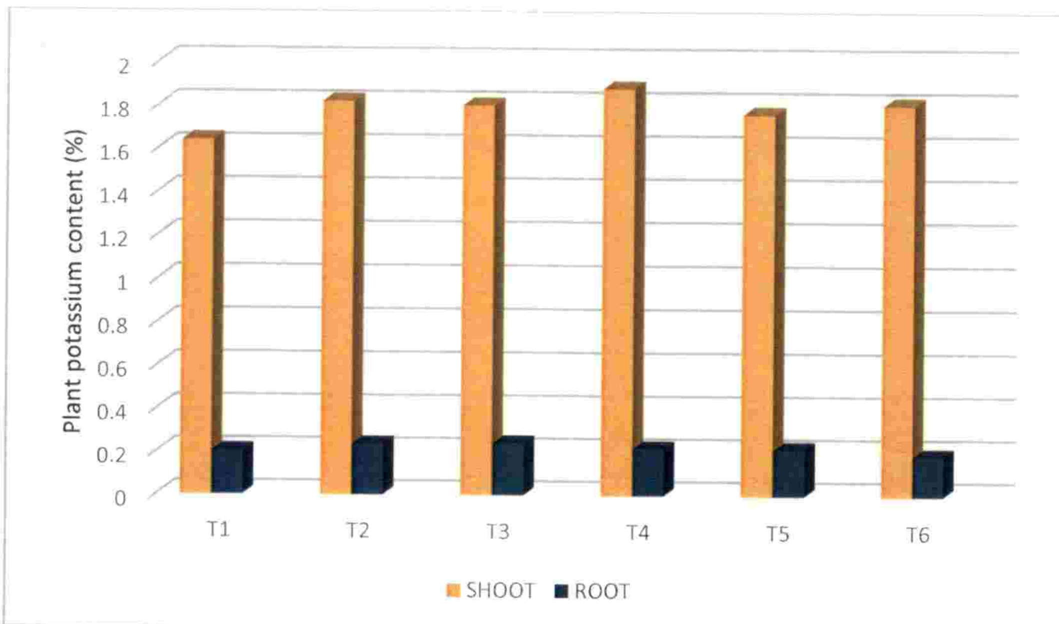

Figure 20: Effect of treatments on K content in shoot and root

5.4.4. Plant calcium

An increased content of plant Ca was reported in all the treatments over control. Ca concentration in shoot and root of the plant was increased by the application of calcium nitrate, calcium chloride and rock phosphate. Accumulation of Ca in shoot and root decreased in control treatment because of high salinity due to Na ions. Ca concentration of shoots was higher than roots. Higher Na content in soil solution inhibits the action of Ca and negatively affect

96

the uptake and transport of calcium in to plants and resulted in calcium deficiency in plants (Aslam *et al.*, 2003).

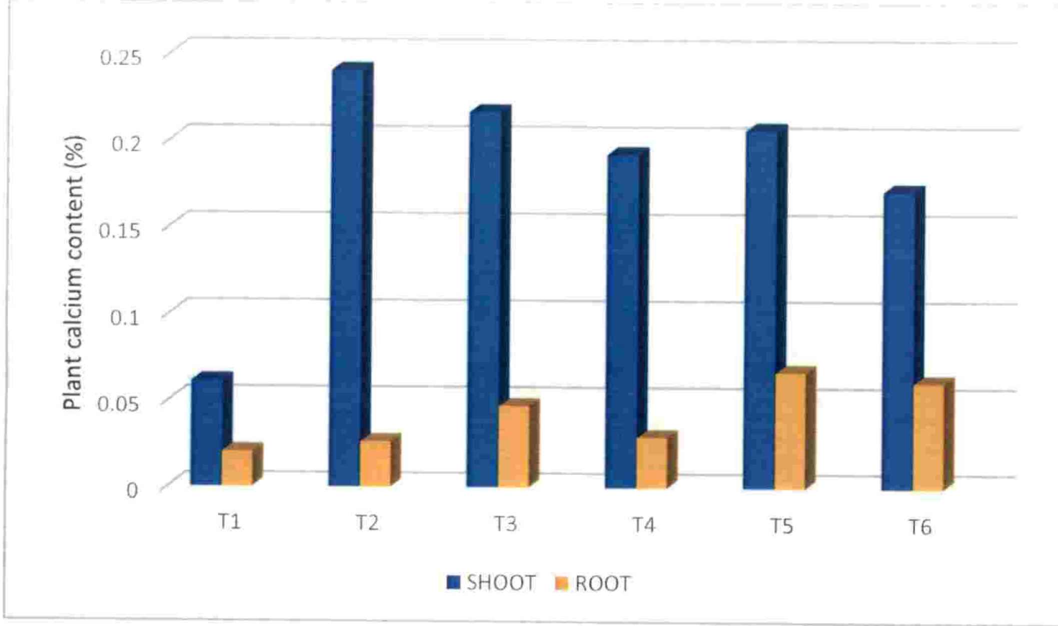

Figure 21: Effect of treatments on Ca content in shoot and root

5.4.5. Plant magnesium

Plant Mg content was found to be deficient in all the treatment including control. This might be the result of low available Mg status in soil. Mg concentration in shoots did not showed significant difference and all the treatments were on par. This indicated that calcium treatments did not have any effect on shoot Mg content. Grattan and Maas (1988) reported that decrease in Mg content was due to increase of Ca/Na ratio in soybean because of the competition of Ca.

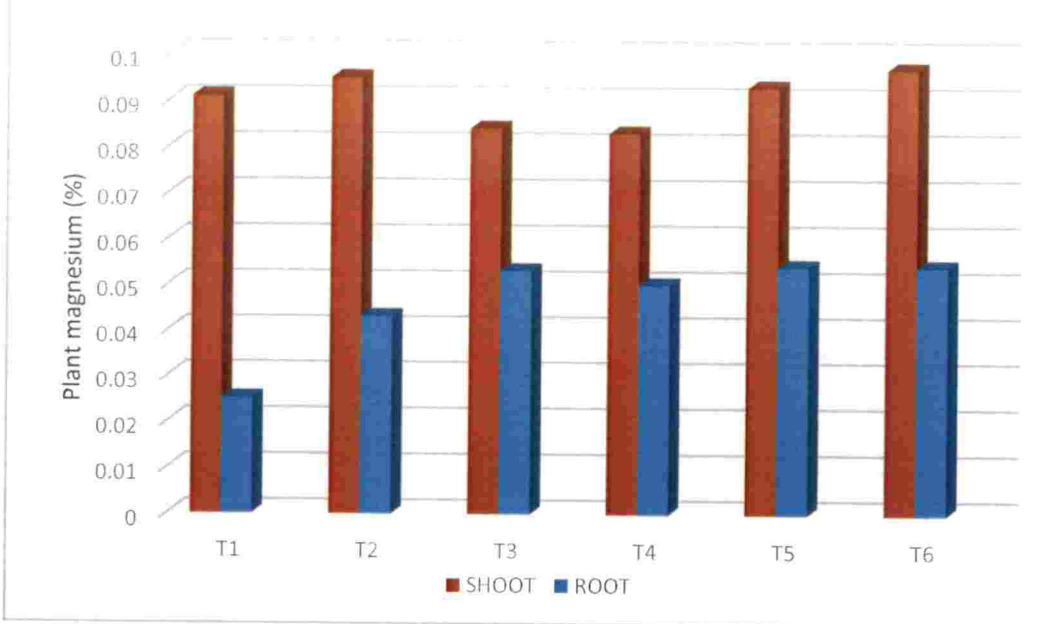

Figure 21: Effect of treatments on Mg content in shoot and root

5.4.6. Plant sodium

Sodium content in shoot and root of plant was higher in control and Na concentration in roots was higher than in shoots. According to Dionisio-Sese and Tobita (2000) salt tolerance in rice was associated with reduction in shoot Na accumulation. Alam *et al.*,(2002) reported that salinity increased the concentration of Na in shoots and roots of rice varieties. It has been reported that salinity tolerant crop accumulate more Na in their roots rather than in shoot and this allows more Ca to reach the shoots (Bar *et al.*, 1997).

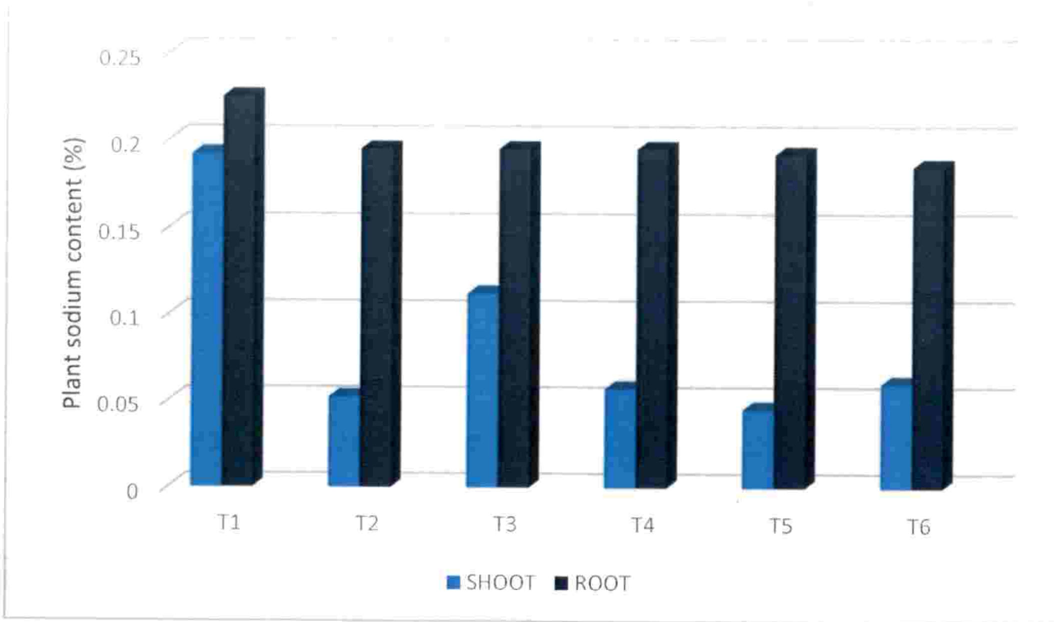

Figure 22 : Effect of treatments on Na content in shoot and root

5.5. EFFECT OF TREATMENTS ON Ca : Mg AND K: Na RATIOS OF PLANT

Significant differences were observed among treatments with respect to Ca : Mg ratio. Highest Ca : Mg ratio was in calcium nitrate and calcium chloride treatments and lowest in control. Improved Ca : Mg ratios will increase the concentration of K in the plant leaves and reduces the concentration of Na (Butt *et al,* 1995). Improved Ca content in plants help to overcome salts stress, which restrict the entry of Na into the plant cells. So increased Ca : Mg ratio indicate salinity tolerance.

The K : Na ratio in shoot and root was higher in rock phosphate and calcium nitrate treatments and least in control. According to Alam *et al*., (2002), soil salinity decreases the K : Na ratio in shoot and root of plants which is a result of less translocation of Na from roots to shoots. In rice, the K/Na ratio has been correlated with the plant survival rate (Zhu *et al.,* 2001) seedling growth and grain yield under salt stress (Lutts et al., 1995; Akita and Cabuslay, 1990) Grattan and Grieve (1999) reported that application of supplemental Ca in the substrate influences the selectivity of K : Na by shifting the uptake ratio in favour of K at the expense of Na.

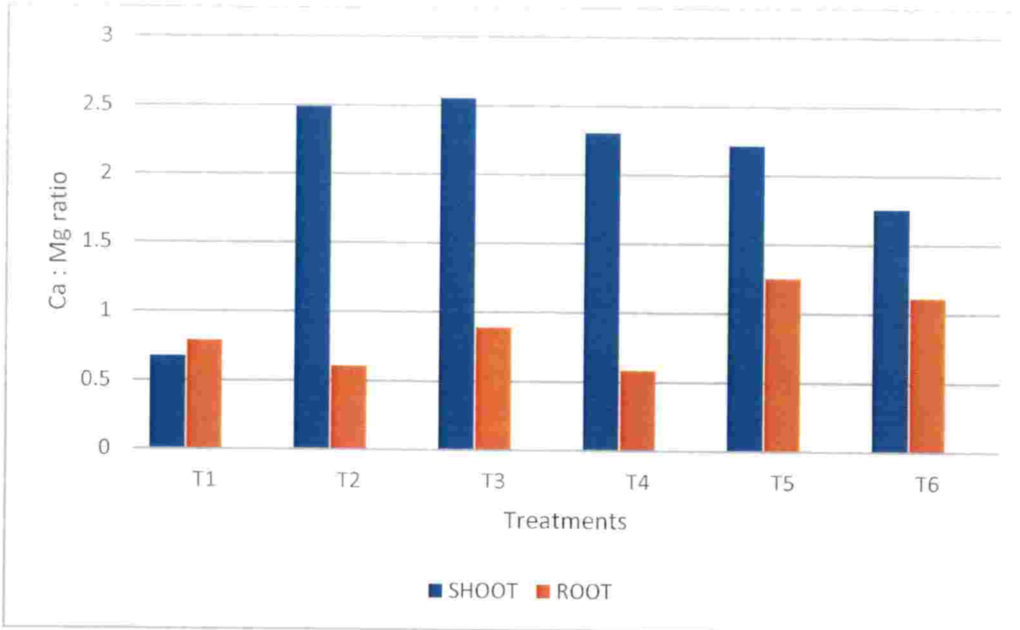

Figure 23: Effect of treatments on Ca : Mg ratio in shoot and root

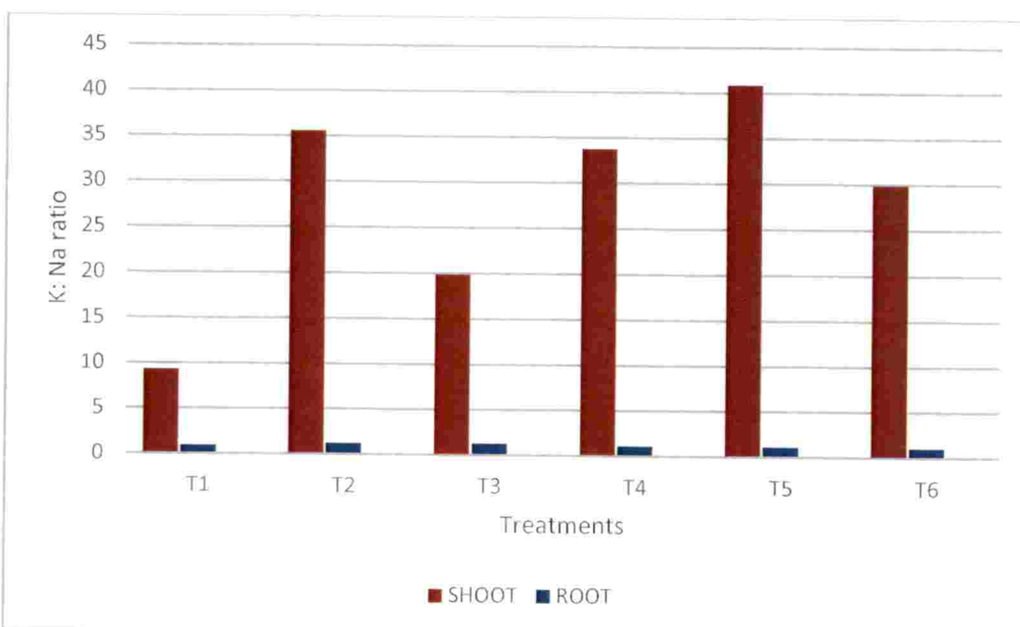

Figure 24 : Effect of treatments on K : Na ratio in shoot and root

5.6. EFFECT OF TREATMENT ON NUTRIENT UPTAKE

Uptake of a nutrient gives an index on response of crop to that particular nutrient. It varies with nutrient availability of that added fertilizer, particular soil type and climatic condition and also the variety. The uptake of N was highest in calcium nitrate treatment. This is because of improved N content in soil after the application of treatment. The N and P uptake in rice plants ranged from 96.40 to 211.21 kg ha^{-1} and 11.43 to 22.76 kg ha^{-1} respectively among treatments. The P uptake was also found to be highest in calcium nitrate and rock phosphate treatments. Rock phosphate adds phosphorus to soil, excess to that of native P found in low lands, which improves the P uptake by rice plants (Visakha, 1992). Mohan (2016) reported that the P uptake in *pokkali* soil ranged from 6.34 to 18.59 kg ha^{-1}. Padmam (1992) reported Ca uptake of 18.21 to 24.41kg ha^{-1} at harvest stage of rice. Uptake of Mg and Na ranged from 2.718 to 5.680 kg ha^{-1} and 6.121 to 10.06 kg ha^{-1} respectively. Mohan (2016) pointed out Mg uptake during harvesting stage ranged from 0.76 to 3.27 kg ha^{-1} and Na uptake ranged from 0.47 to 43.99 kg ha^{-1}. Ujwala Ranade (2011) reported some examples of synergism with respect to nutrient uptake of plants. It shows that optimum supply of nitrogen ensures optimum uptake of potassium as well as phosphorus and uptake of phosphorus and potassium is improved by optimal levels of calcium and zinc in soil.

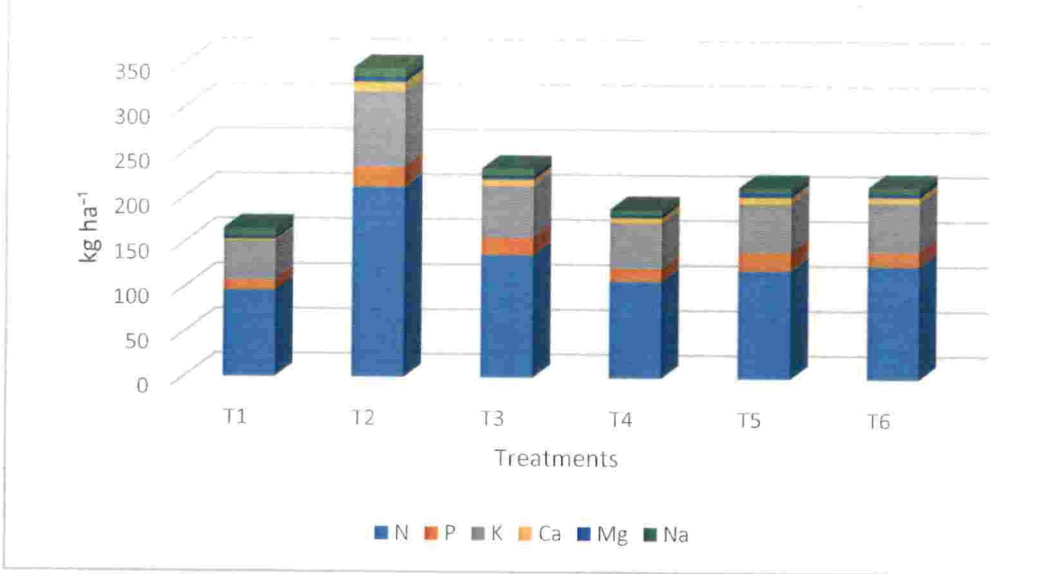

Figure 25 : Effect of treatments on uptake of plant nutrients (kg ha^{-1})

5.7. EFFECT OF TREATMENTS ON BIOMETRIC PARAMETERS

There was no significant difference observed in biometric parameters like plant height and number of tillers. But higher values of these two were observed in calcium nitrate treatment. According to Singh and Mandal (1997) increased plant height and number of tillers is a result of addition of adequate nutrients which improves the supply of assimilates from source to sink.

The grain yield of rice ranged from 1850 kg ha^{-1} to 3300 kg ha^{-1} in different treatments. Sebastian (1977) reported a rice yield of 1.967 to 3.400 t ha^{-1} in saline soils. Highest yield was recorded in calcium nitrate treatment and least in control. All other calcium salt treatments were on par with control but showed superiority over control. Calcium has been shown to ameliorate adverse effects of salinity on plants. The nutrients P and K together with N will be able to support the rice yield better and N may increase the number of grains per panicle (Fairhurst *et al.*, 2007). According to the study conducted by Devi *et al.*, (2017) higher yield was obtained for dolomite treatment, which was due to the contribution of Mg in addition to Ca in acid sulphate soils of Kuttanad.

Highest dry matter content was observed in calcium nitrate treatment and all the other treatments were on par. Calcium nitrate application increased the vegetative growth of plants which improved photosynthesis rate and dry matter production and crop yield is fully depend upon photosynthesis rate. According to Watson (1952) leaf area and photosynthesis rate is the main cause of difference in yield. For rice grown in acid sulphate soils, Ca and Mg content were mostly correlated to dry matter production and its deficiency leads to poor plant growth (Bhindu, 2017).

5.7.1 Yield characters and yield of prawn

In the present study, during a period from 28th December to 15th April was used for prawn culture. Variations in production of prawns from treatment plots and control were recorded during experiment. The total productivity from calcium salts treatments and from that of control were recorded separately. The treatment plot recorded highest productivity of 300 kg ha^{-1} and control plot registered a yield of 180 kg ha^{-1}. Fluctuations in productivity was observed during every year. Different climatic parameters, tidal action, incidence of diseases might be the reason for declining productivity. According to Sasidharan (2004), tiger prawn survival rate of 49 per cent followed by 425 kg ha^{-1} yield was recorded from *pokkali* field. Optimum concentration of minerals and ionic balance are essential for better growth of prawns. Additional supply of calcium salts during the time of rice cultivation might have improved the water and soil mineral concentration and ionic balance. Increased content of soil available nutrients were also noticed after the harvest of prawn. An increment in the productivity of tiger prawn over the control also agreed with the residual effect of calcium treatments. Total catch of other fishes from the treated plot and control plot also differed and treated plot recorded higher number.

Summary

SUMMARY

The study "Management of soil salinity with calcium salts in rice–prawn farming system in *Pokkali* lands" was carried out to evaluate the effect of calcium salts on the growth and nutrition of rice, yield of prawn and soil properties, which was conducted in the Thathapilli padasekharam of Kottuvally Panchayath in Ernakulam district. The experiment was laid out in randomized block design with six treatments and four replications having plot size of 100 m^2. The treatments consisted of absolute control, calcium nitrate, calcium chloride, calcium sulphate, rock phosphate and dolomite at the rate of 45, 30, 34, 27 and 25 kg per plot so as to adjust the ratio of 1:5 for Na : Ca in the exchange complex on the basis of content of Na and Ca in soils. The Ca salts were applied before the rice crop only. Rice variety, Vyttila 6 was raised in the first crop season. Soil samples were collected from the treatment plots during three stages; before the sowing of crop, after the harvest of rice and after the harvest of prawn. The soil samples are analysed for various physical (soil texture, bulk density), chemical (pH, EC, organic carbon, available N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, B and exchangeable Na and Al) and biological parameters (microbial biomass carbon). The main findings from the experiments are summarised below.

- Soil texture of the experimental field was found to be sandy loam with bulk density of 1.25 Mg m^{-3}
- Among the six treatments soil pH was significantly lower in absolute control compared to all other calcium salt treatments after the harvest of rice
- Electrical conductivity values ranged from 1.5 d Sm^{-1} to 8.32 d Sm^{-1} in the field
- Organic carbon status of soil was not affected by application of calcium salts after the rice cultivation. But variations was noticed after prawn cultivation in the different treatments due to high dry matter content
- Higher content of available P and K were observed in all treatments

- Application of Ca salts increased the Ca content in soil after the harvest of rice even though significant difference was absent and amount of available Ca almost doubled after the harvest of prawn due to deposition of Ca rich exuvia of prawns
- Available Mg content of all the treatments was found to be low after the rice and prawn harvest, even after application of dolomite as one of the treatments
- Available sulphur content was extremely high in all the treatments after the rice as well as prawn harvest due to the acid sulphate nature of soil
- Available Fe and Mn in *Pokkali* soil were found to be high in both rice and prawn harvesting stage and it can be reduced by application of calcium salts
- Chelation of Cu by organic colloids and increased organic matter content favoured chelation process after prawn cultivation resulted in Cu deficiency
- Exchangeable Na content was comparatively high in absolute control
- Reduction in exchangeable Al content was observed in all calcium salt treatments after the harvest of rice
- Significant reduction in MBC was observed in control treatment and all the calcium treated plots recorded highest MBC after the harvest of rice and prawn
- Higher shoot N content was recorded in calcium nitrate treatment
- Shoot and root P content showed higher value in all the treatments except control
- An increased content of plant Ca was reported in all the treatments over control
- Plant Mg content was found to be deficient in all the treatment including control
- Na content in shoot and root of plant was higher in control and Na concentration in roots was higher than in shoots
- Significant increase in shoot Ca : Mg and K : Na ratios were observed in all calcium treatments except control, indicated salinity tolerance

- Highest grain yield was recorded in calcium nitrate treatment (3300 kg ha^{-1}) which was significantly higher from other treatments
- Highest dry matter content were recorded in calcium nitrate treatment
- The calcium treated plots recorded highest productivity of 300 kg ha^{-1} and control registered 180 kg ha^{-1} of prawns
- Dolomite treatment recorded highest BC ratio followed by rock phosphate because of the low input cost

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108

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Management of soil salinity with calcium salts in rice–prawn farming system in *Pokkali* lands

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ABSTRACT OF THE THESIS

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ABSTRACT

Pokkali is the unique system of rice cultivation in the water-logged coastal saline acid soils of Kerala. These are tidal wetlands characterized by multi stressed conditions such as acidity, salinity and waterlogging. *Pokkali* soils are the major salt affected soils in Kerala. Plant growth is affected by salinity at all stages of development resulting in reduced grain yield, dry matter production and total decrease in productivity. Excess sodium present in the saline environment creates adverse conditions for plant growth. High salinity in the root zone results in osmotic imbalance and ionic toxicity and thereby modifies nutritional status in soil and plant.

In this context, the present study entitled "Management of soil salinity with calcium salts in rice–prawn farming system in *Pokkali* lands", was conducted with the following objectives (i) to manage the soil salinity by application of calcium salts in *pokkali* lands (ii) to assess the effect of calcium salts on the growth and nutrition of rice, yield of prawn and soil properties. The experiment was conducted in the Thathapilli padasekharam (10°12'N, 76°26' E) of Kottuvally Panchayath in Ernakulam district, during June 2017 to April 2018. The experiment was laid out in randomized block design with six treatments and four replications having plot size of 100 m^2. The treatments consisted of absolute control, calcium nitrate, calcium chloride, calcium sulphate, rock phosphate and dolomite at the rate of 45, 30, 34, 27 and 25 kg per plot so as to adjust the ratio of 1:5 for Na : Ca in the exchange complex on the basis of content of Na and Ca in soils. The Ca salts were applied before the rice crop only. Rice variety, Vyttila 6 was raised in the first crop season. Soil samples were collected from the treatment plots during three stages; before the sowing of crop, after the harvest of rice and after the harvest of prawn and analyzed for various physical (soil texture, bulk density), chemical (pH, EC, organic carbon, available N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, B and exchangeable Na and Al) and biological parameters (microbial biomass carbon). Plant samples were collected at the time of harvest and analyzed for N, P, K, Ca, Mg and Na separately for shoot and root so as to assess the source sink relationship.

Initial soil analysis revealed that texture of soil was sandy loam with a bulk density of 1.25 Mg m^{-3}. Initial soil pH was 6.74 and electrical conductivity was 1.51 dSm^{-1}. Soil was deficient in available N, Ca, Mg and Cu and all other nutrients were in sufficiency level. Data on analysis of soil samples after the harvest of rice revealed that, all the treatments showed a superiority over control with respect to chemical parameters and biological parameter. The EC values ranged from 1.59 dSm^{-1} to 1.75 dSm^{-1}. Exchangeable Na and Al content were highest in control. Among the different treatments, calcium nitrate registered peak values of organic carbon and available nutrients especially nitrogen and it reduced the available Fe content to an extent. Application of calcium nitrate significantly increased the grain yield (3300 kg ha^{-1}) and dry matter content and plant nutrient uptake. Increased shoot and root N content was also recorded and increment was reflected in the case of other plant nutrients also. Consequent reduction in the shoot Na content was observed as a result of reduced salinity. Highest Ca:Mg and K:Na ratio observed in plant samples of calcium nitrate treatment revealed better plant survival rate under salt stress. Next to calcium nitrate treatment, calcium chloride and dolomite treatments recorded higher in grain yield of 2192 kg ha^{-1} and 2098 kg ha^{-1} respectively and also the nutrient uptake. Soil analysis after the harvest of prawn recorded an increase in available major and secondary nutrients and reduced the Fe and Mn content in all the treatment with slight variation from control. Yield of prawn was highest in calcium treated plots as a whole than control plot and these variations in the productivity was a result of calcium salt treatments during rice cultivation and its residual effect retained in soil. Thus it can be concluded that application of calcium salts in *pokk*ali soils increased the yield of rice and prawns, improved the soil properties and nutrient uptake by plants. Increase in grain yield was higher in calcium nitrate followed by calcium chloride and dolomite treatments. The highest B:C ratio was recorded in dolomite treatment because of the less input cost.