# REGULATION OF PLANT Na/K RATIO FOR PRODUCTIVITY ENHANCEMENT IN *POKKALI* RICE

**By**

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**(2017-11-029)**

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**VELLANIKKARA, THRISSUR - 680 656**

**KERALA, INDIA**

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## THESIS

***Submitted in partial fulfillment of the***

***requirement for the degree of***

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**KERALA, INDIA**
**2019**

## DECLARATION

I, hereby declare that the thesis entitled **"Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice"** is a bonafide record of research done by me during the course of research and that it has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara, EMILY ALIAS

Date: 2017-11-029

# CERTIFICATE

Certified that this thesis entitled **"Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice"** is a record of research work done independently by **Ms. Emily Alias (2017-11-029)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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# CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Emily Alias (2017-11-029)**, a candidate for the degree of **Master of Science in Agriculture** with major field in **Agronomy**, agree that this thesis entitled **"Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice"** may be submitted by **Ms. Emily Alias,** in partial fulfillment of the requirement for the degree.

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**EMILY ALIAS**

**Affectionately dedicated to my beloved parents and siblings**

# CONTENTS

## LIST OF TABLES

## LIST OF TABLES (Contd.)

## LIST OF TABLES (Contd.)

# LIST OF FIGURES

## LIST OF PLATES

# Introduction

# 1. INTRODUCTION

*Pokkali* is a peculiar and sustainable 'rice farming' system in coastal saline soils of Kerala. *Pokkali* ecosystem has two phases - one a low saline phase (from June to October) during which salinity is partially washed out due to rains and salinity tolerant rice varieties are cultivated and secondly a high saline phase (November to May) during which prawns and other brackish water fishes are grown. *Pokkali* system is unique in the world and has received Geographic Indication Certificate for *Pokkali* brand and Plant Genome Saviour Community Award during 2010-11. *Pokkali*, the most saline tolerant rice variety of the world has proved its dominance as international donor of *Saltol* QTL as recognized by the International Rice Research Institute, Philippines.

Salinity, submergence and high inherent acidity are the major issues underlying this special system of rice cultivation. Distinct from saline soils found elsewhere in India, the origin, genesis and development of these soils are under peculiar climatic and environmental conditions. Soils of *Pokkali* are deep, impervious, clayey, rich in organic matter and acidic with pH ranging from 3.1 - 4.8. Electrical conductivity of soil during summer months ranges from 12 to 24 dS $m^{-1}$. However, the salinity is washed off by heavy monsoon rains and the EC reduces to 6 to 8 $dSm^{-1}$and making the soil conducive for rice cultivation. Fertility and productivity of the field is decided by the tidal flows, which makes the system highly fertile as it contains high concentration of $Na^{+}$, $K^{+}$, $Ca^{2+}$ and $Mg^{2+}$ that are essential for the physiological processes in plant cells .Water soluble salts like sulphates and chlorides of sodium and manganese are present in high proportion especially during summer months. With regard to major nutrient status, the soil is low to medium in phosphorus, medium in nitrogen and high in potassium content.

In saline environment, plants take up excess amounts of sodium which exhibits a significant negative correlation with the uptake of other nutrients like $K^{+}$, $Ca^{2+}$ *etc.* This nutrient imbalance in soil affects the crop growth and may eventually result in yield reduction. Very often, deficit in rains during South West Monsoon leads to regeneration of the inherent acidity. Thus crop failure due to acidity and salinity become common in *Pokkali* system especially in the changing climatic scenario.

Liming is a most important strategy for reducing the soil acidity, by replacing the hydrogen ions with $Ca^{2+}$ ions, thereby regaining the cell wall stability and plasma membrane integrity. This eventually leads to enhanced salt tolerance in plants. It has a significant role in crop production. Liming stimulates soil biological activity and increases the availability of primary and secondary nutrients to plants. In *Pokkali* soils, salinity may increase Na content in the plant tissues even exceeding the levels of the actual metabolic requirement and turn harmful to growth. The resultant high ratio between Na and other ions like K, Ca and Mg within the plant becomes detrimental for crop. Among these, Na/K ratio is the most reliable indicator of the level of salt tolerance in plants. Maintaining a low ratio of Na with other ions especially with K is also necessary for realizing higher yields.

As poor response to soil application of nutrients is observed in *Pokkali* rice, foliar nutrition of potassium is expected to maintain nutritional balance within the plant. Usually potassium and sodium coexist on the soil exchange complex and soil solution. They exert antagonistic or synergistic effects on mutual absorption and translocation within plants, particularly under saline field conditions. *Pokkali* being naturally organic, potassium sulphate is an effective source of potassium for mitigating the adverse effect of sodium and thereby enhancing the crop yield under saline soils.

Hence the objective of present study was to investigate the effect of liming and foliar nutrition of potassium on the growth, yield and mineral nutrient concentrations of *Pokkali* rice. It also aimed at studying the effect of narrowing the Na/K ratio inside the plant by liming and foliar application of potassium in *Pokkali* rice.

# Review of literature

# 2. REVIEW OF LITERATURE

*Pokkali* ecosystem is highly vulnerable to soil and climatic conditions such as soil acidity, high tidal waves causing saline water intrusion to crop fields, high intensity rainfall and crop submergence. There is a need to develop technologies in *Pokkali* rice for enhancing production and to have an edge in mitigating these stress conditions. Relevant literature on *Pokkali* rice culture with reference to soil and nutrient management is reviewed in this chapter.

## 2.1 *Pokkali* cultivation

*Pokkali* is a unique system of saline rice production prevalent in Kerala spreads over the coastal regions of Ernakulam, Alapuzha and Thrissur Districts which are traditionally cultivated with *Pokkali* rice. *Pokkali* soils are inherently acidic in nature and become acid saline due to sea water ingression. *Pokkali* rice is considered to be a traditional salt-resistant rice variety that thrives under high acidic and submerged soil conditions. In this method, rice cultivation begins during the low saline phase of the production cycle (June to mid-October/early November) followed by prawn farming during the high saline phase (mid- November to mid-April).

The land preparation of *Pokkali* system of rice cultivation starts in the month of April with strengthening of outer bunds. Mounds of $1m^2$ base and 0.5 m height are taken when the field becomes dry. With the onset of monsoon, dissolved salts from the surface of mounds are drained out from the field and the soil becomes favourable for sowing. These mounds also act as an elevated *in-situ* nursery which protects the rice seedlings from flash floods. Sprouting of rice seeds is facilitated by tightly packing them in a basket made of coconut leaves, the inside of which is lined by banana or teak leaves. Seeds are then soaked in fresh water for 12 to 15 hours. The pre-germinted seeds are sown on the top of these mounds and are plastered with clay. After one month, mounds are dismantled and seedlings are uniformly spread in the field. Crop is harvested within 120 days (Thomas, 2002; Paimpillil, 2007; Shylaraj *et al.,* 2013).

### 2.1.1 Soil characteristics of *Pokkali*

*Pokkali* soils are acid sulphate soils and are characterized by impervious and clayey texture, and deep bluish black colour. *Pokkali* soils are originated from lacustrine and alluvial deposits. Regarding the physical properties, Varghese *et al*, (1970) revealed that the surface of soil appeared to be grey in colour, intensity of the colour increased with depth. Finer soil texture and greater water holding capacity were the other salient features of *Pokkali* soil. Clayey soil rich in organic matter created deep crevices and soil became hard during dry summer and sticky during wet conditions.

Two major factors which decides the availability of nutrients in these soil are pH and electrical conductivity. Acidic pH values in the range of 3.5 to 5.5 were mostly exhibited by these soils. Strong acidic conditions are the main cause for the emergence of infertility in *Pokkali* field. In the case of electrical conductivity, the value varies depending on the seasons. In the summer months it varied from 12.0 to 24.0 dS $m^{-1}$, while in rainy season the value ranged from 6.0 to 8.0 dS $m^{-1}$ (Tomy, 1981).

Soil organic matter is considered as a storehouse of plant nutrients and it helped to maintain the physical, chemical and biological properties of soil. Since *Pokkali* system comprised of paddy cultivation and prawn farming, higher organic carbon content was observed during traditional paddy cultivation and various nitrogenous compounds like ammonia and nitrite were produced through shrimp culture (Krishnani *et al.,* 2011). A study conducted for monitoring the soil and nutrient status of *Pokkali* tract, indicated that the soil was suitable for organic rice production due to high fertility status. 94 per cent of *Pokkali* soils maintained medium to high organic carbon status (Annie *et al*., 2013). Regarding the oxidizable organic matter content, it was found increasing during the first 10 days and then it remained the same thereafter.

Fertility and productivity of *Pokkali* soil is determined by the tidal influx and efflux. According to Kramer (1984), fertility and productivity of the field decided by the tidal flows, made the system highly fertile as it contained high concentration of $Na^{+}$, $K^{+}$, $Ca^{2+}$and $Mg^{2+}$ that were essential for the physiological processes in plant cells. So tidal influx enriched the soil with essential nutrients and washed out cations in toxic level like $Al^{3+}$, $Fe^{2+}$ and $Mn^{2+}$. But the variation in the water supply, drainage, evaporation and transpiration made fluctuations in the accumulation of salt. Excess sodium in soil showed significantly negative correlation with the uptake of other nutrients like $K^{+}$, $Ca^{2+}$ *etc.* Tidal influx also allowed the growth of several beneficial micro organisms in the soil (Sasidharan, 2004).

### 2.2 Chemistry of acid sulfate soils

Acid sulfate soils are ever-present in nature, derived from parent materials rich in pyrite. Acidity is attributed by the presence of sulfuric acid formed by the oxidation of pyrite. One of the major properties of these soils was the presence of either sulfuric horizon or sulfidic materials (Anda *et al*., 2009). Availability and toxicity of nutrients in acid sulfate soil is determined by the soil pH. These soils were having pH less than four. Presence of sufficient quantity of organic carbon and higher soil pH ensured the availability of exchangeable $K^{+}$,$Ca^{2+}$ and $Mg^{2+}$ ions in acid sulfate soil (Behera and Shukla, 2015). Most serious issue associated with acid sulfate soil was the Al toxicity. By releasing organic acids most of the plants detoxified the Al in the rhizosphere. Major organic acids released from the root tips of plants were malic acid and citric acid, these on reaction with Al formed Al-malate or Al-citrate (Panhwar *et al*., 2015).

Micro organisms seen in acid sulfate soil limit the release of nutrients produced by the decomposition of organic matter due to the persistence of unfavorable conditions. Low pH and low phosphatase availability in soil affected the symbiotic fixation of nitrogen by rhizobia in legumes. Also extreme acidity reduced the activity of mycorrhiza, which was associated with the uptake of phosphate in phosphate poor soils. In addition to this, deficiency of calcium, magnesium, potassium, manganese, zinc, copper and molybdenum were also reported in these soils (Dent, 1986).

### 2.2.1 Management of acid sulfate soil

Several conventional and modern practices are recommended for the effective reclamation of acid sulfate soils. Pei (1985) suggested that application of lime, $MnO_2$ and straw can improve grain and straw yield in rice. On the other hand, straw is considered to be as an inexpensive amendment for acid sulfate soils. Physical as well as chemical properties of soil can be improved by adequate drainage, frequent application of water and moderate application of lime. During dry periods of climate, regulation of water table restricts the reaction of oxygen with the iron pyrite layer, thereby reducing the formation of acidity. Flooding, controlled irrigation and formation of subsoil hard pan can be adopted for this purpose (Cho *et al*., 2002). Liming is one among the most suitable methods for reducing the acidity in soil. Efficiency of the lime is determined by high solubility. They are usually applied in the rate of 6.25 - 12.5 ton/ha. Application of any nitrogenous or phosphatic fertilizers along with liming material could improve the productivity of soil (Rattanapichai *et al*., 2013).

In the case of rice cultivation in acid sulfate soils, amendments like lime, basalt or organic fertilizer can be used for the reclamation of soil acidity. Toxic Al ion present will react with lime or basalt and get precipitated as inert Al hydroxides. It led to increase in soil pH to desired level (Shamshuddin *et al*., 2014).

### 2.2.2 Effect of liming in acid sulfate soils

Liming is one of the most important strategies for the reclamation of acid sulphate soils. It has a significant role in crop production. Liming stimulates soil biological activity and increases the availability of the primary and secondary nutrients to plants. As compared to acid soils, limed soils retained more potassium in the available form (Mehlich, 1943; Thomas and Coleman, 1959). Calcium is considered to be a ‘liming element’ due to its property of neutralizing low soil pH and thus enhance the availability of nutrients to plants. In a study conducted to evaluate the effect of liming on phosphate availability, it was reported that at high soil pH values phosphate availability got reduced due to the precipitation of insoluble phosphates in the soil (Diya and Sreelatha, 2019). Also the persistence of Al toxicity in acidic soil inhibited the uptake, translocation and utilization of phosphate by plants. Liming increased the availability of soil phosphorus by the amelioration of Al toxicity and mineralization of soil organic phosphorus (Haynes, 1982). Soil amelioration by liming improves the physiological balance of various nutrients (Ca, K, Mg, S and microelements) in the soil. Lalljee and Facknath (2002) conducted an experiment to assess the effect of lime application on the micronutrient content of soil and yield in *Solanum tuberosum*. It was concluded that, available soil zinc, copper, iron and manganese decreased and available boron increased with lime application. Also it stimulated the activity of earthworm, thereby increasing rainfall infiltration and reduced the potential for runoff and erosion (Zimdahl, 2015).

Common liming materials used for ameliorating acidic soils are lime, dolomite, slaked lime etc. Fenn *et al*. (1995) reported that the nitrogen use efficiency of a plant can be improved by the accumulation of additional metabolites in the seed through the supply of enough calcium sources. Suresh and Savithri (2000) reported increase in grain and straw yields of rice due to liming under field conditions. Loide (2004) reported that liming can incorporate a large quantity of nutrients like calcium, magnesium, potassium *etc* in the soil at a time. It greatly influence the nutrient content in the soil solution and various nutrient ratios such as K/Na ratio, Ca/ Na ratio etc., In addition to the correction of soil acidity, application of dolomite could maintain a balance between the calcium and magnesium content in soil as well as enhance the uptake of magnesium by the crop (Bhindu *et al.*, 2018).

**2.3 Effect of salinity on rice**

Nutrients are abundantly available for better plant growth in normal soils with pH range of 4.5-7.5, electrical conductivity (EC) < 4 dS $m^{-1}$, exchangeable sodium percentage (ESP) <15 and sodium absorption ration (SAR) <15. But in case of salt stressed soils, the presence of high concentration of soluble salts may negatively affect the plant growth. The most serious issue associated with salt stress is the $Na^+$ and $Cl^-$ accumulation in plant tissues and soil. Low soil water potential, $Na^+$ and $Cl^-$ toxicity, $Ca^{2+}$ and $K^+$ deficiency, altered metabolism, membrane destabilization, reduction in cell division and expansion are the major troubles associated with soil salinity. All of these may adversely affect different growth and developmental processes of plants including seed germination, seedling establishment, vegetative development, flowering, fruit formation and quality (Ashraf *et al.,* 2013).

Rice is very much sensitive to salinity stress at early seedling stage compared to tillering stage (Grattan *et al*., 2002; Shereen *et al*., 2005). Zeng and Shannon (2000) reported that salinity stress in rice interferes with the seed germination, seedling growth, leaf size, root length, shoot dry weight, number of tillers per plant, flowering, spikelet number, per cent of sterile florets and productivity. There was a significant reduction in the seedling biomass production and rice stand density under salt stress. They further observed the existence of a negative linear relationship between salt stress and many yield components such as number of tillers per plant, number of spikelets per panicle, and percent of sterile florets. Detailed investigations in these soils showed reduction in mean root length, mean root numbers per plant, and shoot length occurred under increased salt stress (Jamil *et al*., 2006; Jiang, 2010). Therefore, shoot and root lengths are considered to be as two indicators of rice plant response to salt stress. Salinity mainly affected growth and development, plant adaptation and stress responses in plants. This might result in sterility in rice if it happened during the pollination and fertilization time (Pearson and Bernstein, 1959).

There exists an antagonistic relationship between sodium and potassium concentrations in plant tissues under saline conditions (Jung *et al*., 2009). Higher concentration of sodium in the soil will lead to the reduction of potassium in root and shoot tissues of the plant. According to Lynch and Lauchli (1985), higher Na/Ca ratios in saline medium might inhibit the uptake and transport of $Ca^{2+}$ in plants and thus creates $Ca^{2+}$ deficiency. Moreover, salinity hindered the growth of plants by limiting the nitrogen availability (Abdelgadir *et al*., 2005).

### 2.3.1 Salinity tolerance mechanisms in rice

Soil salinity is the most serious issue that affects the crop production in coastal areas. Plants themselves tolerate this salinity stress by using several mechanisms like osmotic tolerance, ion exclusion and tissue tolerance. Firstly, osmotic tolerance is made possible by long distance signals that restricts the shoot growth and is triggered before shoot $Na^+$ accumulation. Osmotic tolerance enhances the ability of the plant to tolerate the extremity of salinity stress and to maintain leaf expansion and stomatal conductance. Ion exclusion mainly includes the removal of $Na^+$ ions from the xylem and move it back to soil. Also it prevents the excess accumulation of $Na^+$ and $Cl^-$ ions in the leaves by facilitating their movement towards root. Sequestration of $Na^+$ in the vacuole, synthesis of compatible solutes and release of enzymes catalyzing detoxification of reactive oxygen species are coming under tissue tolerance mechanism (Roy *et al*., 2014).

In rice, some factors determining the salt tolerance mechanism are plant vigour, restricting initial entry of salts to roots and intracellular compartmentation. Plant growth vigour is considered as a salinity avoidance mechanism which reduces the toxic effects of salinity stress. By using some morphological or physiological adaptations plants restricts the initial entry of salts to roots. Rahman *et al*. (2001) reported that the extension of root cap cells is an adaptive measure against salinity stress in rice plants. Root cap cell accumulates more $K^+$ ions and excludes $Na^+$ ions to maintain a low Na/K ratio inside the plant (Munns and Tester, 2008). The length of the root cap also played an important role in this tolerance mechanism. Usually, sensitive varieties have shorter root cap as compared to tolerant ones. Proliferation of root cap cells is more prominent during early seedling stage; this might be related to exclusion of $Na^+$ or avoidance of $Na^+$ to entry into the roots (Ferdose *et al.*, 2009).

Another mechanism for alleviating the soil salinity stress in plants is intracellular compartmentation. Sodium chloride is the most decisive salt that restricts the crop production in saline areas. Plant restricts the movement of these salts to young meristematic tissues, instead move them to older leaves and leaf sheaths for alleviating the salinity damage to plants (Munns, 2002). Rice is also able to compartmentalize these toxic ions in older leaves and structural tissues. This enhances the senescence of older leaves and maintains the younger leaves at low concentrations. The presence of large vacuole help the older leaves to sequestrate higher concentrations of $Na^+$, $Cl^-$ and $NO^{3-}$ than young leaves (Wang *et al.*, 2012).

Development of salt tolerant varieties by marker assisted selection or introduction of salt tolerance genes through genetic engineering are considered as solutions for this problem. Salt tolerant varieties maintain comparatively lower concentrations of salts in panicle and flag leaves. In the case of panicle, substantially lower salt concentration was found in grain as compared to rice husks and rachis (Reddy *et al.,* 2017).

### 2.3.2 Management of saline soils

Successful cultivation in saline soil is made possible by removing excess soluble salts through reclamation techniques. It depends on the local conditions, available resources and the kind of crops. Excess salts in the *Pokkali* soils are drained by a unique method, in which, mounds of 1m base and 0.5 m height are taken during land preparation. With the onset of monsoon, water soluble salts are washed off from field and it becomes suitable for sowing (Tomy *et al.,* 1984). There was noticeable reduction in the salinity by the use of various amendments like gypsum, sulphur and organic manures like farm yard manure, press mud, green leaf manures *etc*. Razzaque *et al.* (2010) reported that calcium supplementation has a great role in the salt tolerance of rice grown in saline soils. He continued that, there is an enhanced absorption of $K^+$ and reduced per cent Na content in rice shoots with the addition of calcium. Gypsum is a cheap and easily available source of calcium, can be used for the adjustment of soil salinity.

Genetic modification of crop cultivar is an approach to gain potential yield under environmental stresses. In this method, salt resistance genes in the desired rice cultivar are modified to improve rice tolerance and resistance against stress. Several advanced techniques like gene sequencing, QTL mapping and marker-assisted breeding are also adopted for this purpose (Sing and Sengar, 2014).

Adoption of agronomic strategies like water and nutrient management techniques improved the soil health, plant growth and input use efficiency of plants under salt stress (USSLS, 1954). A wise water management strategy is needed for drainage and leaching of salt concentration from root zone of rice is very important for survival of crop and grain yield (Ezeaku *et al*. 2015). On the other hand, better nutrient management is necessary to cope up with salt stress issue for better agriculture production. Hussain *et al*. (2001) reported improvement of soil characteristics, plant biomass and grain productivity in rice, wheat and millets with the application of 100 per cent gypsum, pyrite, combination of gypsum + farm yard manure (FYM) + $H_2SO_4$, $CaSO_4 \cdot 2H_2O$ + FYM + chiseling and humic acid (HA). Addition of humic acid made the nutrients available by chelating with unavailable nutrients (P, K, Ca, Fe, Zn, Cu) and buffering the pH value. Thereby it enhanced the soil microbial, enzymatic and physiological activities in saline soils (Barron and Wilson, 1981; Khattak *et al*., 2013).

## 2.4 Nutrient management in *Pokkali*

Padmaja *et al.* (1994) suggested lime application @1000 kg $ha^{-1}$, 50 per cent at the time of mound preparation and the remaining at the time of dismantling of mounds. It maintained the potential nutrient cycling of the major and minor nutrients in soil. Usually rice is cultivated along with a rotation of shrimps. Waste released from shrimp cultivation forms manure for paddy. Some adaptations exhibited by paddy seedlings include plant growing up to 2 metre to thrive under submerged conditions. During harvest, panicles are cut and the rest of stalks are left to decay in the water, which serves as feed for shrimps**.** Thus the remnants of these rice residues form fertilizer for rice in the next season, which eventually reduce the input requirement of rice. In addition to the tremendous microbial activity due to the presence of large quantities of organic matter (decomposed aquatic weed mass and paddy stubbles), the daily tidal inflows and outflows make the *Pokkali* field more fertile (Chandramohanan and Mohanan, 2011).

Various experiments were conducted to standardize the nutrient recommendation in *Pokkali* soils. It is found out that there was 35 per cent increment in yield with the application of 20 kg N and 40 kg $P_2O_5$ $ha^{-1}$ at the time of mound dismantling and transplanting. Among primary nutrients, nitrogen contributed more to yield enhancement as compared to phosphorus and potassium. Efficiency of organic manures and bio-fertilizer in *Pokkali* cultivation were also analysed and it is reported that there was fifteen per cent increase in grain yield with the application of green leaves at 5 t/ha and application of blue green algae could not produce significant effect in yield (Shylaraj *et al.,* 2013).

**2.5 Na/K ratio**

According to Wang *et al*. (2012), selective absorption and transport abilities of nutrients are depended on the level of salt resistance in plants. Under saline conditions there will be reduction in the accumulation of potassium and instead of potassium, sodium gets accumulated in plant tissues. This may further lead to the nutrient imbalances in plant (Nedjimi and Daoud, 2009). Therefore, it is essential to maintain a high K/Na ratio in plant tissues for better tolerance to salt stress (Maathuis and Amtmann, 1999). K/Na ratio is a most reliable criterion of salt tolerance in plants. Also it is considered to be as a good indicator of potassium homeostasis in leaves under salt stressed conditions. Rodrigues *et al.* (2013) observed that desired leaf K/Na ratio in jatropha ranges from 1.0 to 2.0 for higher rates of photosynthesis and better plant growth.

Higher the K/Na ratio, higher the salt tolerance (Gorham, 1990; Ashraf and Khanum, 1997; Al-Ghumaiz *et al.,* 2016). Plants have adopted several strategies like regulation of $K^+$ uptake and preventing $Na^+$ entry and the efflux of $Na^+$ from cells for the maintenance of desirable K/Na ratios in the cytosol (Khan *et al.,* 2009). Translocation of $Na^+$ takes place from roots to shoots in salt sensitive plants while salt tolerant variety is associated with low $Na^+$ accumulation in shoots, especially in leaf blade. Hence, lower Na/K ratio in leaf blade of salt tolerant variety is considered as an index of physiological tolerance to salinity (Tareq *et al.,* 2011).Studies showed that the uptake of $Na^+$ increased and the uptake of $K^+$ decreased in the shoots of rice with increasing salinity irrespective of rice genotypes, however resistant genotypes like *Pokkali* contained significantly lower amounts of $Na^+$ and higher amounts of $K^+$ as compared to susceptible genotypes (Hakim *et al*., 2014).

Zhang *et al*. (2010) observed that application of supplemental calcium have a role in mitigating the toxic effects of sodium in saline soils by the replacement of displaced $Ca^{2+}$, thereby regaining the cell wall stability and plasma membrane integrity, maintaining higher K/Na ratio in plant tissues. This led to the enhanced salt tolerance in plants. An experiment conducted by Wu and Wang (2012) indicated that application of calcium at low saline conditions reduce the $Na^+$ accumulation in roots and increase the $K^+$ accumulation in shoots. However, there was no effect on sodium and potassium accumulation in plant tissues under high saline conditions. Therefore, it is suggested to apply Ca under low salinity for regulating the K/Na homeostasis in plants. Ashraf *et al.* (2017) reported that addition of K as potassium sulfate nutrition cotton plant at different levels of salinity reduced the Na accumulation in plant tissues, increased in shoot $K^+$, $K^+$: $Na^+$ ratio and $Ca^{2+}$ and ultimately enhanced the yield attributes and fiber quality.

### 2.5.1 Effect of potassium nutrition in maintaining low Na/K ratio

Potassium is a primary nutrient which is essential for cell wall development, carbon assimilation, photosynthesis, synthesis and translocation of organic and inorganic nutrients from soil to plant. Two critical stages of rice highly sensitive to salinity are early seedling growth and flowering. It is essential to maintain a low Na/K ratio at least during these stages. This can be reduced to an extent by the application of potassium fertilizers (Yoshida, 1981).A significant increase in the dry weight and corresponding reduction in the accumulation of sodium were observed with the addition of potassium in rice grown under salt stress (Muhammed *et al*., 1987).

Bohra and Doerffling (1993) reported that under saline conditions potassium application was found to enhance the plant height, number of tillers and shoot dry weight. They conducted an experiment in wheat and observed that application of potassium significantly increased the photosynthetic activity, percentage of filled spikelets, yield and K concentration in straw. At the same time, there was significant reduction in Na and Mg concentration and thus improved the K/Na, K/Mg and K/Ca ratios in plant tissues. Foliar spray of SOP had positive influence on various attributes such as plant height, number of productive tillers, spike length and number of spikelets per spike of all the wheat cultivars under saline conditions (Ashraf *et al*., 2013). Enhanced yield, starch accumulation and high dry matter production of wheat plants in saline soils with the application of SOP is mainly due to the presence of sulfur, at the same time synergistic relationship of SOP with other nutrients might be another reason for better results with SOP treatment (Kumar *et al.,* 2008).

# *Materials and methods*

# 3. MATERIALS AND METHODS

The research work entitled "Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice" was conducted during 2018-2019 at Rice Research Station, Vyttila. The details of materials and methodologies used in this experiment are given below.

## 3.1 Location

The experiment was conducted in Rice Research Station, Vyttila which is situated in a representative site in the middle of the *Pokkali* tract. It is the only institute which investigates the various aspects of the rice based farming system of the salinity prone coastal tracts in Kerala. Geographical location of the field is at $10^0$ N latitude, $76^0$ $15^1$ E longitude and at an altitude of 1.2 m above the mean sea level.

## 3.2 Soil

*Pokkali* soils are rich in organic matter, tidal ingression playing a major role in maintaining the nutrient status of the soil. These soils are inherently acidic and become acid saline due to sea water ingression. They are classified as clay loam in texture. The high salinity in the soil resulting from tidal actions from the sea distinguishes *Pokkali* soil from other soil types of Kerala. Water soluble salts like sulphates and chlorides of sodium and manganese are present in high proportion. In dry conditions white incrustations of aluminium hydroxide also develop on soil surface. The electrical conductivity (EC) of soils during the high saline phase (November - May) varies from 12 to 24 dS $m^{-1}$ and average salt content reaches up to 20 mg $kg^{-1}$. During low saline phase (June - October) water becomes almost fresh, salt content reduces to traces and EC ranges between 6 and 8 dS $m^{-1}$. The physico-chemical characteristics of soil in the experimental site are detailed in Table 1.

**Table 1. Physico - chemical properties of soil**

| Particulars | Content | Method used |
|---|---|---|
| Coarse sand (%) | 11.27 | Robinson international pipette method (Piper, 1966) |
| Fine sand (%) | 48.2 | |
| Silt (%) | 15.89 | |
| Clay (%) | 24.64 | |
| pH | 4.22 | Soil water suspension 1:2.5 and read in a pH meter (Hesse, 1971) |
| EC | 0.96 | Soil water suspension 1:2.5 read in a conductivity meter A(Jackson, 1958) |
| Organic carbon (%) | 2.33 | Walkley and Black method ( Jackson, 1958) |
| Available N (kg $ha^{-1}$) | 353.3 | Alkaline permanganate method (Subbiah and Asija, 1956) |
| Available P (kg $ha^{-1}$) | 26.5 | Bray-I extractant ascorbic acid reductant method (Watnabe and Olsen, 1965) |
| Available K (kg $ha^{-1}$) | 368.8 | Neutral normal ammonium acetate extractant flame photometry ( Jackson, 1958) |
| Available Ca (mg $kg^{-1}$) | 263.0 | Neutral normal ammonium acetate extractant flame photometry (Jackson, 1958) |
| Available Mg (mg $kg^{-1}$) | 44.0 | Neutral normal ammonium acetate extract method with atomic absorption spectrophotometer (Jackson, 1958) |
| Available S (mg $kg^{-1}$) | 38.5 | Calcium chloride extraction and estimation by turbidimetry (Tabatabai,1982) |

### 3.3 Season

The field experiment was conducted during the *kharif* season, which was the only suitable period for *Pokkali* rice cultivation. The total duration of the crop was 137 days.

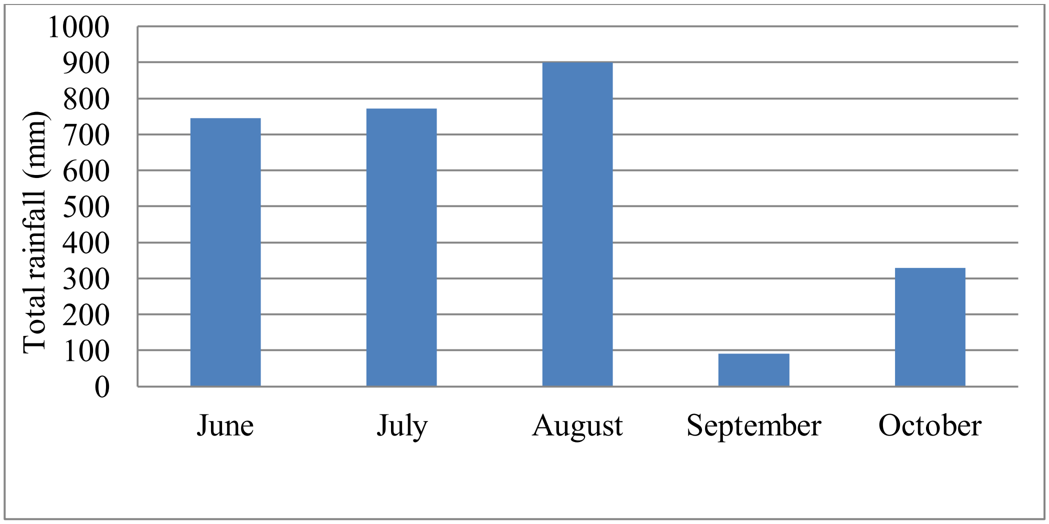
### 3.4 Climate and weather

The area of the experimental site enjoys a tropical humid climate. The mean weekly averages of important meteorological parameters which prevailed during the experimental period are illustrated in Figure 1a and 1b, respectively. The mean annual rainfall of the area was 250 mm, the major part of which was received during the south west monsoon. Unlike in previous years, during 2018 -19, heavy floods occurred twice during the cropping season, *i.e.,* during July 15 to 21 and again during August 15 - 28. During flash floods of July, the crop was completely submerged for a period of 5 days and in August the submergence was for a period of 8 days. The maximum day temperature varied from $28^0$C to $40^0$C and minimum temperature from $23^0$C to $27^0$C. The relative humidity was varied from 68 to 84% during the cropping season. The weather which prevailed during the experimental period was highlighted by heavy rainfall and total flooding.

### 3.5 Crop variety

VTL-8 was the variety used for the field experiment. It is tolerant to submergence, salinity and high acidity and hence highly suited for cultivation in *Pokkali* tract and other coastal saline ecosystems. The grains are medium bold, awn less with red kernel.

**a. Total rainfall (mm)**




**b. Temperature and Relative Humidity**

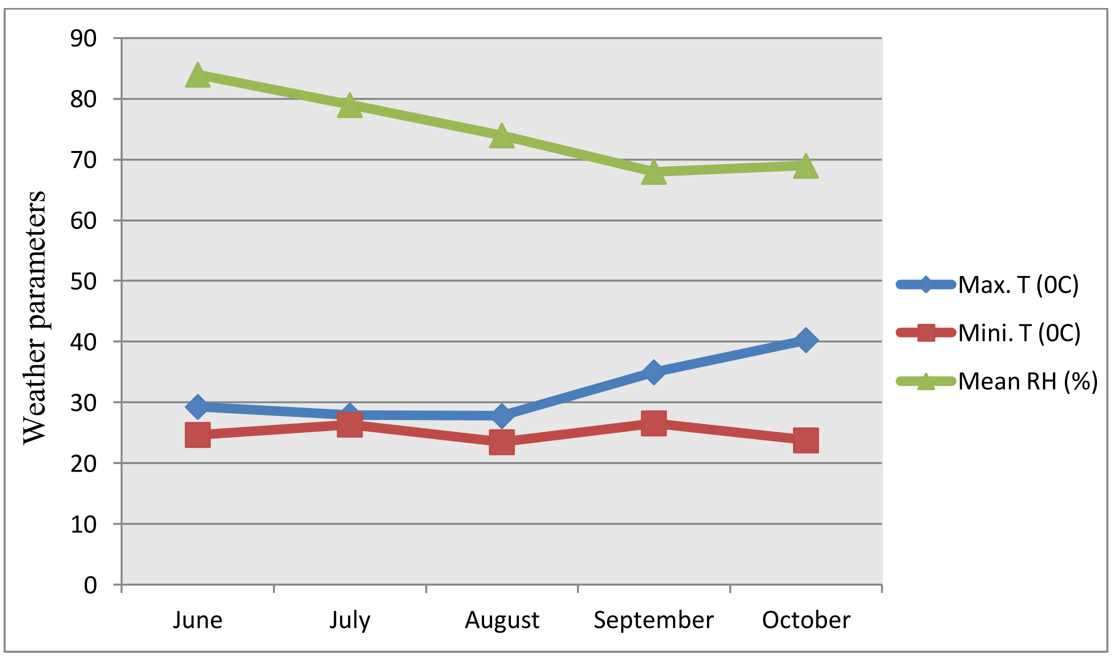



**Fig. 1 a and b Important weather parameters prevailed during the cropping period**

### 3.6 Experimental details

Design : RBD

Replications : 3

Treatments : 10

Variety : Vyttila 8

Plot size : 5 m × 4 m

Season : *Kharif* 2018

Location : RRS, Vyttila

#### 3.6.1 Treatment details

$T_1$ - Control (no fertilizers and no ameliorants)

$T_2$ - Lime (CaO) @ 500 kg $ha^{-1}$

$T_3$ - Lime @1000 kg $ha^{-1}$

$T_4$ - Dolomite @ 800 kg $ha^{-1}$

$T_5$ - Dolomite @ 1600 kg $ha^{-1}$

$T_6$ - Foliar spray of K (2% spray)* at 20 and 40 days after transplanting (DAT)

$T_7$ - Lime @ 500 kg $ha^{-1}$+ K (2% spray) at 20 and 40 DAT

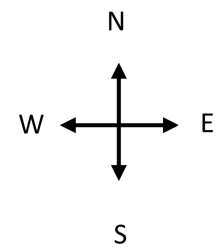
$T_8$ - Lime @1000 kg $ha^{-1}$+ K (2% spray) at 20 and 40 DAT

$T_9$ - Dolomite @ 800 kg $ha^{-1}$+ K (2% spray) at 20 and 40 DAT

$T_{10}$ - Dolomite @ 1600 kg $ha^{-1}$+ K (2% spray) at 20 and 40 DAT

*Sulphate of potash (SOP) was used as the source of K for foliar spray

**Fig.2 Layout of the experimental field**




4 m

5 m

| | | |
|---|---|---|
| $T_2R_1$ | $T_7R_2$ | $T_9R_3$ |
| $T_4R_1$ | $T_9R_2$ | $T_3R_3$ |
| $T_8R_1$ | $T_3R_2$ | $T_6R_3$ |
| $T_5R_1$ | $T_4R_2$ | $T_1R_3$ |
| $T_{10}R_1$ | $T_6R_2$ | $T_4R_3$ |
| $T_3R_1$ | $T_5R_2$ | $T_7R_3$ |
| $T_6R_1$ | $T_8R_2$ | $T_{10}R_3$ |
| $T_9R_1$ | $T_1R_2$ | $T_2R_3$ |
| $T_7R_1$ | $T_{10}R_2$ | $T_8R_3$ |
| $T_1R_1$ | $T_2R_2$ | $T_5R_3$ |

### 3.7 Field operations

### 3.7.1 Land preparation

Land preparation was started by April before the onset of monsoon. Bunds were strengthened and sluices were repaired for regulating the water level in the field. Water in the field was drained during low tide and shutters were placed preventing further entry of water. On dry field, layout was initiated with the formation of plots of 5m x 4 m dimension separated by bunds (Fig. 2). Mounds of $1m^2$ base and 0.5 m height were made to facilitate the washing down of salts during rains. With the onset of monsoon, dissolved salts from the surface of mounds were flushed out from the field.

### 3.7.2 Sowing and transplanting

Mounds act as an elevated *in-situ* nursery which protects the rice seedlings from flash floods. Pre-germinated seeds were broadcasted on these mounds and were then plastered with soil to prevent the predation by birds. Mounds were dismantled 21 days after sowing and seedlings were uniformly transplanted in the field at a spacing of 20cm ×15 cm.

### 3.7.3 Imposition of treatments

Lime and dolomite were applied to the field before transplanting as per the treatments in technical programme. Foliar spray of SOP was done at 20 and 40 days after transplanting.

### 3.7.4 Harvest

Crop duration was 137 days. Water logging at two different growth phases affected the production and performance of the crop. The rice crop was sown during June $5^{th}$ and harvested on $21^{st}$ October 2018.

**Plate 1. Field preparation and mound preparation**

**Plate 2. Mound dismantling and transplanting**

**Plate 3. Foliar spray of SOP and sample collection**

**Plate 4. Harvest and threshing**


### 3.7.5 Water management

Bunds were strengthened and sluices were set up before monsoon to control the level of water. During continuous heavy rains, management of water was not possible and crop experienced complete submergence. When rain subsided, water from the field was drained out using petti and para. Water flow into the field was withheld two weeks before harvesting in order to dry the field.

### 3.7.6 Weed management

Major weeds present in the field were *Echinochloa crus-galli, Monochoria vaginalis, Marsilea quadrifolia* and *Ludwigia octovalois*. Hand weeding was done to manage weeds at 20 and 40 DAT.

### 3.7.7 Management of pest and disease

Generally pest and disease occurance is less in *Pokkali* as compared to other systems of rice cultivation. There were no major disease incidences during the cropping season. Major pest seen in the field was rice bug. Application of fish amino acid was adopted to bring its population below threshold level. Non insect pests like sparrows and purple moorhen were found during flowering and were devastating. The entire field was covered with net to minimize their attack.

## 3.8 Observations

### 3.8.1 Biometric observations

#### a. Plant height

Ten plants were randomly selected and tagged from different rows other than border row were used for the measurement of plant height at 40 DAT, flowering and at harvest. Plant height was taken from the ground level to the top of the tallest leaf and panicle and was recorded in centimeter (cm) during vegetative and flowering stages respectively. Quadrat of 0.5 × 0.5 m dimension was used to determine the plot wise details of different growth parameters.

**b. Number of tiller per $m^2$**

Tiller count at flowering and at harvest were recorded using a quadrat of 0.5 m × 0.5 m dimension and was expressed as number of tillers per $m^2$.

**c. Number of panicles per $m^2$**

Number of productive tiller per square meter was counted for each plot just before harvesting the crop. The tillers having panicles were recorded as productive tillers.

**d. Grains per panicle**

Total number of grains per panicle was counted manually from the panicles which were selected randomly from 10 hills of each plot. The mean of ten randomly selected panicles from plot were used to determine the number of grains per panicle.

**e. Test weight**

Thousand grains were selected randomly from each plot and weighed with the help of portable automatic electronic balance at about 12 per cent moisture content. The thousand grain weight was expressed in gram (g).

**f. Percentage of filled grains**

Number of grains and filled grains per panicle was counted at the time of harvest. Total number of grains and filled grains per panicle were used to assess sterility percentage.

**g. Grain yield and straw yield**

The weight of grain from each net plot was recorded and expressed as kg $ha^{-1}$. Grains were dried to a moisture content of 12 per cent. The straw obtained from the net plot area of each plots were sun dried for 3-4 days and weighed.

**h. Leaf area index (LAI)**

Number of tillers from ten randomly selected hill were noted. Leaf area was calculated by multiplying the maximum length and breadth of each leaf on the middle tiller with a factor (K= 0.75) for all stages except seedling and maturity for which K= 0.67.

LAI = sum of leaf area per hill of 10 hills/land area covered by 10 hills

**i. Dry matter production**

Grain yield and straw yield were calculated separately and were added together to obtain total dry matter production and was expressed as kg $ha^{-1}$.

### 3.8.2 Collection of soil and plant samples

Plant and soil samples were collected from the treatment plots at various stages of crop growth. Soil samples were taken during different periods like before the planting of crop, 20 DAT, flowering and finally at harvest.

**Soil analysis**

Collected soil samples were dried and sieved through 0.5 mm sieve for the analysis of organic carbon and 2 mm sieve for the analysis of all the other nutrients. Estimation of pH, EC, organic carbon, primary and secondary nutrients were done using the following methods.

**Plant analysis**

Plant samples were collected at 20, 40DAT, flowering and at harvest. Grain and straw were separately analysed to know the degree of nutrient partitioning among them. They were dried in hot air oven at a temperature of 70 + 5ºC and powdered.

## 3.9 Economics

*Pokkali* rice fetches higher price in the market because of its special nutraceutical and medicinal properties. Benefit: cost ratio was calculated for each treatment plot based on the cost of cultivation and gross returns in terms of straw and grain yield obtained from the field. Being naturally organic, *Pokkali* rice fetches Rs.65/kg in the market.

## 3.10 Statistical analysis

The data recorded from various treatment plots were subjected to statistical analysis with the help of software called WASP 2.0.

**Table 2. Analytical methods used for soil analysis**

| Parameter | Method | Reference |
|---|---|---|
| p H | pH meter | Hesse, 1971 |
| EC | Soil water suspension 1:2.5 read in a conductivity meter | Jackson, 1958 |
| Organic carbon | Walkley and Black chromic acid wet digestion method | Jackson, 1958 |
| Available N | Alkaline permanganate method | Subbiah and Asija, 1956 |
| Available P | Bray extraction and photoelectric colorimetry using spectrophotometer | Watnabe and Olsen, 1965 |
| Available K and Na | Neutral normal ammonium acetate extraction and estimation with flame photometer | Jackson, 1958 |
| Available Ca and Mg | Extraction using neutral normal ammonium acetate and estimation using Atomic Absorption Spectro photometer | Jackson, 1958 |
| Available S | Calcium chloride extraction and estimation by turbidimetry | Tabatabai, 1982 |
| Available B | Hot water extraction and estimation using Azomethine-H colorimetry | Gupta, 1972 |

**Table 3. Analytical methods used for plant analysis**

| Element | Method | Reference |
|---|---|---|
| Nitrogen | Microkjeldhal method | Piper, 1966 |
| Phosphorus | Digestion of plant samples using diacid extract followed by colorimetric estimation in spectrophotometer by Vanadomolybdate yellow color method. | Piper, 1966 |
| Potassium and Sodium | Digestion of plant samples using diacid extract followed by filtration and determined by flame photometer | Piper, 1966 |
| Calcium and Magnesium | Determination using atomic absorption spectrophotometer | Piper, 1966 |
| Sulphur | Turbidimetric method using spectrophotometer | Chesnin and Yein, 1951 |
| Boron | Dry ashing of plant tissue followed by determination using Spectrophotometer | Gupta, 1972 |

# Results

# 4. RESULTS

The study entitled "Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice" was conducted to determine the effect of soil amelioration and foliar spray of potassium in improving the yield of *Pokkali* rice. Field experiment was carried out at Rice Research Station, Vyttila from 6th June 2018 to 21st October 2018. Data generated were statistically analyzed and the results obtained are presented below:

## 4.1 Growth parameters

### a. Plant height

There was no significant influence of different treatments on plant height at 40 days after transplanting. At flowering, treatment $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] resulted in taller plants when compared to other treatments. At harvest, the highest plant height was observed for the treatment $T_7$ [lime @ 500 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] which was on par with treatments $T_4$, $T_8$, $T_9$, $T_{10}$ and the control treatment (Table 4). Even though treatments showed significant variation in plant height, no specific trend was observed in this variation. This might be due to the reduced plant height as a result of the removal of decayed leaf portion formed by the complete submergence that occurred twice due to heavy floods.

### b. Number of tillers/$m^2$

Data furnished in Table 4 showed that treatments significantly influenced the number of tillers per sq. m. At flowering, application of lime or dolomite followed by foliar spray of SOP had a positive influence on the number of tillers. Significantly highest number was noted in treatment $T_8$ which was on par with $T_7$, $T_9$ and $T_{10}$. And at harvest also, the highest number of tillers was noticed for the treatment $T_8$ [lime @ 1000 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] followed by $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] and were on par with treatments $T_3$ (

lime @ 1000 kg ha$^{-1}$), $T_7$ [lime @ 500 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT] and $T_5$ (dolomite @ 1600 kg /ha).

**c. Leaf area index**

At 40 days after transplanting, highest leaf area index was observed for the treatment $T_7$ [lime @ 500 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT] which was on par with $T_{10}$ [dolomite @ 1600 kg ha$^{-1}$ + SOP (2% spray) at 20 and 40 DAT] and $T_8$ [lime @ 1000 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT]. During flowering, highest value was recorded by the treatment $T_{10}$ followed by $T_8$ (Table 4).

**4.2 Yield attributes**

**a. Number of panicles per m$^2$**

From the Table 5, it is clear that the treatment $T_8$ [lime @ 1000 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT] could produce significant influence on number of panicles per m$^2$ (428) and was on par with $T_{10}$ [dolomite @ 1600 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT]. The lowest number of panicles per m$^2$ (254) was noted for the control treatment. Amelioration alone at higher levels (lime @1000kg ha$^{-1}$, dolomite @1600 kg ha$^{-1}$) also resulted in comparable number of panicles per m$^2$ with that of $T_{10}$. Foliar spray of SOP also was comparable with liming @1000kg ha$^{-1}$.

**b. Number of grains per panicle**

Significant influence of treatments on the number of grains per panicle is evident from the data given in Table 5. Treatment $T_5$ (dolomite @ 1600 kg ha$^{-1}$) recorded highest number of filled grains per panicle and was on par with treatments $T_3$ (lime @ 1000 kg ha$^{-1}$) and $T_9$ [dolomite @ 800 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT]. Lowest number of grains was observed for the control treatment with no amelioration and no foliar spray. Grains per panicle varied from 72 to 98.

**c. Percentage of filled grains**

The data on percentage of filled grains showed that the treatments had significant effect. Treatment $T_8$ [lime @ 1000 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] recorded highest percentage (89.4 %) and was on par with treatments $T_4$, $T_9$ and $T_{10}$. This showed that the effect of foliar spray was significant in increasing the percentage of filled grains per panicle. The least value was noted for the treatment $T_5$ (dolomite @ 1600 kg $ha^{-1}$).

**d. Thousand grain weight**

Data revealed that application of treatments did not show significant influence on thousand grain weight. And the values ranged from 24.6 g to 26.0 g (Table 5)

**f. Grain yield**

Data on effect of soil ameliorants and K foliar spray on grain yield are shown in Table 6. Grain yield was found to be significantly influenced by treatments. Significantly highest grain yield of 2975 kg $ha^{-1}$ was obtained from treatment $T_8$ [lime @ 1000 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] compared to other treatments. The yield increase was about 100 per cent more than control. This was followed by $T_5$ (2360 kg $ha^{-1}$) and $T_{10}$ (2276 kg $ha^{-1}$) wherein dolomite @ 1600 kg $ha^{-1}$was applied. And the lowest value was observed in treatment $T_2$ (lime @ 500 kg $ha^{-1}$) which was comparable with the control treatment wherein no ameliorant or fertilizer was applied. Similarly a lower dose of dolomite ($T_4$ and $T_9$) also resulted in low yield compared to that of a higher dose. The grain yield in general was less due to submergence.

**g. Straw yield**

The data in the Table 6 reveals that the treatments did not show significant influence on straw yield. This might be due to the fact that the portion of the biomass lost due to submergence could not be accounted.

**h. Dry matter production**

Dry matter production in general was very less as both grain and straw yield were affected by flooding. Various treatments had significant influence on the plant dry matter content at the end of the experiment as observed from the Table 6. The treatment $T_5$ [dolomite @ 1600 kg $ha^{-1}$] recorded highest value (6168 kg $ha^{-1}$) followed by treatment $T_8$ and treatment $T_{10}$ which were all on par. Lowest dry matter content was observed for the control treatment with 3524 kg $ha^{-1}$.

**4.3 B: C ratio**

From the Table 7, it is clear that treatment $T_8$ [lime @ 1000 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] recorded highest B: C ratio (1.84). Treatments with lower doses of liming ($T_2$, $T_7$ and $T_9$) recorded B: C ratio less than one.

**Table 4. Effect of amelioration and foliar spray of SOP on plant height, number of tillers and LAI of *Pokkali* rice**

| Treatments | Plant height (cm) | | | Number of tillers/m$^2$ | | Leaf area index | |
|---|---|---|---|---|---|---|---|
| | 40 DAT | flowering | Harvest | flowering | harvest | 40 DAT | flowering |
| $T_1$- Control | 62.9 | 79.4$^{bc}$ | 85.0$^{abcd}$ | 320$^{bc}$ | 383$^{bcd}$ | 3.7$^{bcd}$ | 4.9$^{bc}$ |
| $T_2$ - Lime 500 | 66.3 | 82.3$^{abc}$ | 82.8$^{cd}$ | 257$^{d}$ | 375$^{d}$ | 2.6$^{e}$ | 5.1$^{bc}$ |
| $T_3$ - Lime 1000 | 67.8 | 79.9$^{bc}$ | 83.8$^{bcd}$ | 309$^{bc}$ | 424$^{abc}$ | 2.3$^{e}$ | 4.2$^{c}$ |
| $T_4$ - Dolomite 800 | 58.0 | 83.5$^{ab}$ | 86.6$^{abc}$ | 248$^{d}$ | 385$^{bcd}$ | 2.6$^{e}$ | 4.7$^{bc}$ |
| $T_5$ - Dolomite 1600 | 62.5 | 82.1$^{abc}$ | 83.8$^{bcd}$ | 297$^{cd}$ | 428$^{ab}$ | 3.4$^{cde}$ | 5.0$^{bc}$ |
| $T_6$ - SOP | 63.0 | 82.8$^{abc}$ | 81.4$^{d}$ | 314$^{bc}$ | 376$^{cd}$ | 3.1$^{de}$ | 4.6$^{c}$ |
| $T_7$ - Lime 500 +SOP | 67.7 | 85.1$^{a}$ | 89.2$^{a}$ | 359$^{ab}$ | 425$^{ab}$ | 5.2$^{a}$ | 4.4$^{c}$ |
| $T_8$ - Lime 1000 + SOP | 70.3 | 84.5$^{a}$ | 87.1$^{abc}$ | 377$^{a}$ | 458$^{a}$ | 4.4$^{abc}$ | 5.7$^{ab}$ |
| $T_9$ - Dolomite 800 + SOP | 69.2 | 78.4$^{c}$ | 88.0$^{ab}$ | 340$^{abc}$ | 361$^{d}$ | 3.0$^{de}$ | 4.3$^{c}$ |
| $T_{10}$ - Dolomite 1600 + SOP | 67.0 | 85.9$^{a}$ | 86.8$^{abc}$ | 352$^{ab}$ | 438$^{a}$ | 4.8$^{ab}$ | 6.3$^{a}$ |
| CD (0.05) | NS | 4.42 | 4.49 | 50.47 | 48.30 | 1.15 | 1.15 |

**Table 5. Effect of soil amelioration and foliar spray of SOP on yield attributes of *Pokkali* rice**

| Treatments | Number of panicles per m$^2$ | Grains per panicle | Percentage of filled grains | 1000 seed weight (g) |
|---|---|---|---|---|
| $T_1$- Control | 254$^{e}$ | 72$^{e}$ | 80.8$^{bcd}$ | 25.4 |
| $T_2$ - Lime 500 | 300$^{de}$ | 78$^{de}$ | 75.6$^{de}$ | 25.1 |
| $T_3$ - Lime 1000 | 332$^{bcd}$ | 98$^{a}$ | 78.8$^{cde}$ | 26.0 |
| $T_4$ - Dolomite 800 | 346$^{bcd}$ | 78$^{de}$ | 84.7$^{abc}$ | 25.3 |
| $T_5$ - Dolomite 1600 | 357$^{bc}$ | 98$^{a}$ | 73.7$^{e}$ | 24.8 |
| $T_6$ - SOP | 324$^{cd}$ | 84$^{cd}$ | 80.7$^{bcd}$ | 25.5 |
| $T_7$ - Lime 500 +SOP | 333$^{bcd}$ | 88$^{c}$ | 77.8$^{de}$ | 25.0 |
| $T_8$ - Lime 1000 + SOP | 428$^{a}$ | 82$^{cd}$ | 89.4$^{a}$ | 25.6 |
| $T_9$ - Dolomite 800 + SOP | 305$^{d}$ | 89$^{abc}$ | 84.3$^{abc}$ | 24.6 |
| $T_{10}$ - Dolomite 1600 + SOP | 381$^{ab}$ | 78$^{de}$ | 86.5$^{ab}$ | 25.7 |
| CD (0.05) | 50.92 | 9.71 | 6.18 | NS |

**Table 6. Effect of amelioration and foliar spray of SOP on grain yield, straw yield and dry matter production of *Pokkali* rice**

| Treatments | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | Dry matter production (kg ha$^{-1}$) |
|---|---|---|---|
| $T_1$ - Control | 1495.0$^{ef}$ | 2029.0 | 3524.0$^{d}$ |
| $T_2$ - Lime 500 | 1407.0$^{f}$ | 3092.1 | 4499.0$^{cd}$ |
| $T_3$ - Lime 1000 | 1770.0$^{de}$ | 3051.4 | 4821.3$^{c}$ |
| $T_4$ - Dolomite 800 | 1670.0$^{def}$ | 3067.5 | 4737.7$^{c}$ |
| $T_5$ - Dolomite 1600 | 2360.0$^{b}$ | 3807.5 | 6167.7$^{a}$ |
| $T_6$ – SOP | 1975.0$^{cd}$ | 2977.1 | 4952.0$^{bc}$ |
| $T_7$ - Lime 500 +SOP | 1461.0$^{ef}$ | 2454.8 | 3916.0$^{cd}$ |
| $T_8$ - Lime 1000 + SOP | 2975.0$^{a}$ | 3149.6 | 6125.0$^{a}$ |
| $T_9$ - Dolomite 800 + SOP | 1483.5$^{ef}$ | 3292.8 | 4776.3$^{c}$ |
| $T_{10}$ - Dolomite 1600 + SOP | 2276.0$^{bc}$ | 3707.6 | 5983.3$^{ab}$ |
| CD (0.05) | 356.68 | NS | 1113.7 |

**Table 7. Effect of amelioration and foliar spray of SOP on B:C ratio of *Pokkali* rice cultivation**

| Treatments | Net returns | Total cost of cultivation | B:C ratio |
|---|---|---|---|
| $T_1$ - Control | 97175 | 87500 | 1.11 |
| $T_2$ - Lime 500 | 91455 | 94000 | 0.97 |
| $T_3$ - Lime 1000 | 115050 | 100500 | 1.14 |
| $T_4$ - Dolomite 800 | 108550 | 93900 | 1.16 |
| $T_5$ - Dolomite 1600 | 153400 | 100300 | 1.53 |
| $T_6$ – SOP | 128375 | 92250 | 1.39 |
| $T_7$ - Lime 500 +SOP | 94965 | 98750 | 0.96 |
| $T_8$ - Lime 1000 + SOP | 193375 | 105250 | 1.84 |
| $T_9$ - Dolomite 800 + SOP | 96427 | 98650 | 0.98 |
| $T_{10}$ - Dolomite 1600 + SOP | 147940 | 105050 | 1.41 |

### 4.4 Soil analysis

#### a. pH

Data on effect of treatments on pH is presented in the Table 8. At 20 DAT, treatments did not show any significant influence on pH of soil. But at flowering, all treatments except control were on par and a slight increase in pH over control was observed, but treatments performed similarly. At harvest, higher pH was observed in plots applied with higher dose of lime or dolomite. Highest pH value (5.3) was recorded by treatment $T_8$ [lime @ 1000 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] which was on par with treatments $T_{10}$, $T_7$, $T_6$ and $T_3$.

#### b. Electrical conductivity (EC)

At 20 DAT, highest EC value of 2.2 dS $m^{-1}$ was noted for the control treatment with no amelioration and no foliar spray of SOP, which differed significantly from others (Table 8). The lowest was observed in case of both $T_5$ (dolomite @ 1600 kg $ha^{-1}$) and $T_9$ [dolomite @ 500 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT]. After flooding, EC got reduced, but there was no noticeable difference in the electrical conductivity of soil between treatments at flowering and harvest stage. Analysed data showed that all the treatments had normal range of electrical conductivity and was safe for crop growth.

#### c. Organic carbon content

Data on effect of treatments on organic carbon content are given in Table 9. All the plots maintained a fairly higher organic carbon content which ranged between 1.5- 2.4. Treatments differed significantly with respect to the organic carbon content at 20DAT, flowering and at harvest, but no definite pattern was observed. At 20 DAT, highest value was recorded in treatment $T_8$ [lime @ 1000 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] and treatments $T_1$, $T_7$ and $T_{10}$ were on par with treatment $T_8$. At flowering and harvest also, higher organic carbon content was recorded for the control treatment (no amelioration and no foliar spray) and treatment $T_2$ (lime (CaO) @ 500 kg $ha^{-1}$) as well as in $T_8$ and $T_{10}$.

**d. Available nitrogen (kg $ha^{-1}$)**

As in the case of organic carbon, available nitrogen varied with treatments, but did not follow a definite pattern due to flooding. At 20 DAT, significantly higher value was observed in the treatment $T_{10}$ (application of dolomite @1600 kg $ha^{-1}$and foliar spray of SOP) which was on par with treatments $T_8$ (lime @1000 kg $ha^{-1}$ and foliar spray of SOP), $T_9$ (dolomite @800 kg $ha^{-1}$and foliar spray of SOP) and control. Lowest value was recorded by treatment $T_4$ (dolomite @ 800 kg $ha^{-1}$) which was on par with$T_2$ (lime @ 500 kg $ha^{-1}$). But at flowering, treatments $T_2$ (lime (CaO) @ 500 kg $ha^{-1}$), $T_7$ [lime @ 500 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT], $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] and control treatment showed higher values. Towards harvest, a different trend among various treatments and treatment $T_{10}$ recorded higher value and was on par with $T_9$, $T_4$, $T_5$ and control treatment (Table 10).

**e. Available phosphorus (kg $ha^{-1}$)**

Treatments significantly influenced the available phosphorus content in soil. At 20 DAT, highest value was recorded by $T_2$ and treatments where liming was done resulted in higher available phosphorus .Treatments $T_3$, $T_5$, $T_6$, $T_7$ and $T_9$ were found to be on par with $T_2$. Lowest value was noted in case of control treatment. At flowering higher dose of amelioration resulted in better available phosphorus content. At flowering and at harvest, treatment $T_8$ [lime @ 1000 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] registered the highest value of available phosphorus in soil (Table 10).

**f. Available potassium (kg $ha^{-1}$)**

Data on effect of treatments on potassium availability in soil are presented in Table 11. There was significant variation among different treatments at the three stages of soil analysis. At 20 DAT, $T_{10}$ [dolomite @ 1600 kg ha$^{-1}$ + SOP (2% spray) at 20 and 40 DAT] contributed significantly highest value of 611 kg ha$^{-1}$ and was on par with $T_8$ (542 kg ha$^{-1}$). Lowest value was recorded by $T_3$ with 394 kg ha$^{-1}$. At flowering, $T_{10}$ [dolomite @ 1600 kg ha$^{-1}$ + SOP spray) and $T_7$ acquired higher values and lowest was observed in $T_9$ (dolomite @ 800 kg ha$^{-1}$ + SOP spray at 20 and 40 DAT) with 451 kg ha$^{-1}$. At the time of harvest, control treatment resulted in the lowest available potassium.

**g. Available Ca (mg kg$^{-1}$)**

Treatments did not show significant influence on availability of calcium in soil at 20 DAT, but showed significant variation on the calcium content at flowering. It was observed that $T_{10}$ (combination of dolomite @ 1600 kg ha$^{-1}$and foliar spray of SOP at 20 and 40 DAT) recorded significantly highest value of 471 kg ha$^{-1}$ (Table 11). Towards maturity a different trend was observed. At the time of harvest, higher available calcium was recorded for treatments $T_7$ [lime @ 500 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT] and $T_8$ [lime @ 1000 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT].

**h. Available Mg (mg kg$^{-1}$)**

The results revealed that the applied treatments had significant effect on available magnesium content in the soil. Data in Table 12 showed that, the available magnesium content was highest for treatment $T_{10}$ (combination of dolomite @1600 kg ha$^{-1}$and foliar spray of SOP at 20 and 40 DAT) at all stages of crop growth phase. At 20 DAT, it was found to be on par with treatments $T_5$ (dolomite @ 1600 kg ha$^{-1}$) and $T_8$ [lime @ 1000 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT]. And the lowest value was recorded for $T_4$ both at 20 DAT and flowering. At flowering, treatment $T_{10}$ was on par with treatments $T_5$, $T_6$, $T_8$ and $T_7$. Coming to harvest, treatment $T_8$ [lime @ 1000 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT] was found to be on par with $T_{10}$.

**i. Available sulphur (mg kg$^{-1}$)**

Data on effect of treatments on the available sulphur content in soil are furnished in Table 12. At 20 DAT, $T_8$ [lime @1000 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT] recorded highest value (80.49 mg kg$^{-1}$) and was on par with treatments $T_2$, $T_6$ and $T_7$. And the least value was noted in treatment $T_9$ (combination of dolomite @ 800 kg ha$^{-1}$and foliar spray of SOP at 20 and 40 DAT). Also during flowering, $T_8$ recorded the higher value of available sulphur content and which was on par with $T_4$, (dolomite @ 800 kg ha$^{-1}$ ), $T_{10}$ and $T_7$ [lime @ 500 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT]. At the time of harvest, all the treatments except control, $T_5$ and $T_9$ significantly influenced the available sulphur content in soil. And $T_3$ (lime @ 1000 kg ha$^{-1}$) recorded the highest value.

**j. Exchangeable sodium**

Table 13 depicts the influence of treatments on exchangeable sodium in soil. All the treated plots showed a considerable reduction in the exchangeable sodium in the soil as compared to control treatment wherein no amelioration and no foliar spray given. At 20 DAT, treatment $T_3$ (lime @ 1000 kg ha$^{-1}$) recorded the least value of 797 kg ha$^{-1}$. At flowering, treatment $T_9$ [dolomite @ 800 kg ha$^{-1}$+ SOP (2% spray) at 20 and 40 DAT] resulted in the lowest value of exchangeable sodium in soil. At the time of harvest, $T_6$ [Foliar spray of SOP (2%) at 20 and 40 DAT] recorded the least value.

**k. Available boron**

Available boron content in the soil varied significantly with respect to different treatments. Treatments $T_4$ (dolomite @ 800 kg ha$^{-1}$) and $T_{10}$ [dolomite @ 1600 kg ha$^{-1}$+ K (2% spray) at 20 and 40 DAT] had a positive influence on enhancing the available boron content in soil especially at 20 DAT (Table 13). But at flowering, treatment $T_6$ recorded higher value of available boron in soil which was on par with $T_2$. At the time of harvest, treatment $T_4$ recorded the higher value.

**Table 8. Effect of amelioration and foliar spray of SOP on pH and electrical conductivity of *Pokkali* soil**

| Treatments | pH | | | EC ($dSm^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 20 DAT | Flowering | harvest | 20 DAT | flowering | harvest |
| $T_1$- Control | 4.6 | $4.5^{b}$ | $4.6^{c}$ | $2.2^{a}$ | 1.5 | 1.3 |
| $T_2$ - Lime 500 | 4.5 | $4.9^{a}$ | $4.6^{c}$ | $1.7^{bc}$ | 1.3 | 1.1 |
| $T_3$ - Lime 1000 | 4.7 | $5.1^{a}$ | $5.2^{a}$ | $1.6^{bcde}$ | 1.4 | 0.9 |
| $T_4$ - Dolomite 800 | 5.0 | $4.9^{a}$ | $4.6^{c}$ | $1.7^{bcd}$ | 1.5 | 1.3 |
| $T_5$ - Dolomite 1600 | 4.9 | $4.9^{a}$ | $4.7^{bc}$ | $1.3^{e}$ | 1.4 | 1.4 |
| $T_6$ – SOP | 4.7 | $4.9^{a}$ | $5.0^{abc}$ | $1.7^{bcd}$ | 1.2 | 0.8 |
| $T_7$ - Lime 500 +SOP | 4.8 | $4.9^{a}$ | $5.2^{ab}$ | $1.5^{cde}$ | 1.7 | 1.4 |
| $T_8$ - Lime 1000 + SOP | 4.6 | $4.9^{a}$ | $5.3^{a}$ | $1.8^{b}$ | 1.4 | 1.0 |
| $T_9$ - Dolomite 800 + SOP | 4.9 | $5.1^{a}$ | $4.5^{c}$ | $1.4^{e}$ | 1.2 | 1.5 |
| $T_{10}$ - Dolomite 1600 + SOP | 4.6 | $5.0^{a}$ | $5.2^{a}$ | $1.4^{de}$ | 1.2 | 1.0 |
| CD (0.05) | NS | 0.28 | 0.51 | 0.30 | NS | NS |

**Table 9. Effect of amelioration and foliar spray of SOP on organic carbon content (%) in *Pokkali* soil**

| Treatments | 20 DAT | flowering | Harvest |
|---|---|---|---|
| $T_1$- Control | $2.3^{ab}$ | $2.5^{a}$ | $2.2^{ab}$ |
| $T_2$ - Lime 500 | $2.2^{bc}$ | $2.4^{ab}$ | $2.2^{abc}$ |
| $T_3$ - Lime 1000 | $1.9^{de}$ | $1.8^{e}$ | $1.8^{d}$ |
| $T_4$ - Dolomite 800 | $2.1^{cd}$ | $2.3^{b}$ | $2.3^{a}$ |
| $T_5$ - Dolomite 1600 | $1.8^{e}$ | $2.1^{cd}$ | $2.0^{c}$ |
| $T_6$ – SOP | $1.8^{e}$ | $2.1^{d}$ | $1.8^{d}$ |
| $T_7$ - Lime 500 +SOP | $2.2^{ab}$ | $1.9^{e}$ | $2.1^{bc}$ |
| $T_8$ - Lime 1000 + SOP | $2.4^{a}$ | $2.2^{bcd}$ | $2.2^{abc}$ |
| $T_9$ - Dolomite 800 + SOP | $1.5^{f}$ | $1.5^{f}$ | $2.3^{a}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $2.3^{ab}$ | $2.3^{bc}$ | $2.3^{a}$ |
| CD (0.05) | 0.16 | 0.15 | 0.16 |

**Table 10. Effect of amelioration and foliar spray of SOP on available N and P ($kg\ ha^{-1}$) in *Pokkali* soil**

| Treatments | Available nitrogen ($kg\ ha^{-1}$) | | | Available phosphorus ($kg\ ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 20 DAT | flowering | harvest | 20 DAT | flowering | harvest |
| $T_1$ - Control | $194.4^{abc}$ | $242.5^{a}$ | $278.1^{abc}$ | $22.8^{d}$ | $26.5^{ab}$ | $25.0^{abc}$ |
| $T_2$ - Lime 500 | $129.6^{de}$ | $236.2^{a}$ | $238.3^{cd}$ | $38.0^{a}$ | $17.7^{d}$ | $21.1^{cde}$ |
| $T_3$ - Lime 1000 | $144.3^{de}$ | $167.3^{cd}$ | $146.3^{e}$ | $35.9^{a}$ | $21.5^{bcd}$ | $22.9^{bcd}$ |
| $T_4$ - Dolomite 800 | $108.7^{e}$ | $154.7^{de}$ | $309.4^{ab}$ | $27.7^{cd}$ | $18.1^{d}$ | $20.2^{cde}$ |
| $T_5$ - Dolomite 1600 | $163.1^{bcd}$ | $190.3^{bc}$ | $324.1^{ab}$ | $34.1^{ab}$ | $19.7^{cd}$ | $17.9^{e}$ |
| $T_6$ – SOP | $140.1^{de}$ | $198.6^{bc}$ | $263.4^{bcd}$ | $37.6^{a}$ | $26.5^{ab}$ | $19.5^{de}$ |
| $T_7$ - Lime 500 +SOP | $148.4^{cde}$ | $232.1^{a}$ | $244.6^{cd}$ | $36.9^{a}$ | $18.1^{d}$ | $16.9^{e}$ |
| $T_8$ - Lime 1000 + SOP | $196.5^{ab}$ | $144.3^{de}$ | $209.1^{d}$ | $28.9^{bcd}$ | $30.9^{a}$ | $28.4^{a}$ |
| $T_9$ - Dolomite 800 + SOP | $167.3^{abcd}$ | $123.3^{e}$ | $309.4^{ab}$ | $33.4^{abc}$ | $23.7^{bcd}$ | $27.1^{ab}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $211.2^{a}$ | $215.3^{ab}$ | $332.8^{a}$ | $27.5^{cd}$ | $25.7^{abc}$ | $21.4^{cde}$ |
| CD (0.05) | 46.66 | 32.99 | 62.05 | 6.17 | 6.04 | 4.87 |

**Table 11. Effect of amelioration and foliar spray of SOP on available K and Ca in *Pokkali* soil**

| Treatments | Available potassium ($kg\ ha^{-1}$) | | | Available calcium ($mg\ kg^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 20 DAT | flowering | harvest | 20DAT | Flowering | Harvest |
| $T_1$ - Control | $457.3^{c}$ | $487.9^{de}$ | $462.1^{e}$ | 332.2 | $327.0^{d}$ | $376.0^{bc}$ |
| $T_2$ - Lime 500 | $462.9^{bc}$ | $552.9^{bc}$ | $551.7^{a}$ | 361.5 | $421.7^{b}$ | $451.2^{b}$ |
| $T_3$ - Lime 1000 | $393.9^{c}$ | $460.7^{ef}$ | $549.5^{a}$ | 327.7 | $430.8^{b}$ | $416.7^{b}$ |
| $T_4$ - Dolomite 800 | $415.9^{c}$ | $494.7^{d}$ | $525.2^{bc}$ | 304.3 | $407.2^{b}$ | $423.9^{b}$ |
| $T_5$ - Dolomite 1600 | $467.0^{bc}$ | $531.6^{c}$ | $545.8^{ab}$ | 390.5 | $371.5^{c}$ | $455.8^{b}$ |
| $T_6$ – SOP | $423.0^{c}$ | $527.5^{c}$ | $503.6^{cd}$ | 314.4 | $325.1^{d}$ | $294.9^{c}$ |
| $T_7$ - Lime 500 +SOP | $456.2^{bc}$ | $597.7^{a}$ | $535.3^{ab}$ | 363.7 | $418.6^{b}$ | $588.7^{a}$ |
| $T_8$ - Lime 1000 + SOP | $542.5^{ab}$ | $566.7^{b}$ | $529.0^{ab}$ | 354.5 | $425.3^{b}$ | $595.7^{a}$ |
| $T_9$ - Dolomite 800 + SOP | $500.6^{bc}$ | $450.6^{f}$ | $484.2^{de}$ | 330.1 | $429.2^{b}$ | $402.8b^{c}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $610.8^{a}$ | $601.4^{a}$ | $542.8^{ab}$ | 379.7 | $471.4^{a}$ | $446.1^{b}$ |
| CD (0.05) | 109.20 | 30.87 | 23.60 | NS | 27.69 | 109.87 |

**Table 12. Effect of amelioration and foliar spray of SOP on available Mg and S in *Pokkali* soil**

| Treatments | Available Mg ($mg\ kg^{-1}$) | | | Available S ($mg\ kg^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 20DAT | flowering | harvest | 20DAT | flowering | Harvest |
| $T_1$ - Control | $51.6^{bc}$ | $50.0^{bcd}$ | $53.0^{cde}$ | $66.4^{cd}$ | $45.5^{bc}$ | $34.8^{bc}$ |
| $T_2$ - Lime 500 | $50.8^{bc}$ | $46.8^{cd}$ | $52.1^{de}$ | $80.3^{a}$ | $35.8^{cd}$ | $36.0^{abc}$ |
| $T_3$ - Lime 1000 | $48.7^{bc}$ | $48.7^{bcd}$ | $50.5^{e}$ | $70.5^{bc}$ | $31.3^{d}$ | $40.5^{a}$ |
| $T_4$ - Dolomite 800 | $47.7^{c}$ | $44.4^{d}$ | $51.4^{de}$ | $62.1^{d}$ | $56.5^{ab}$ | $35.0^{abc}$ |
| $T_5$ - Dolomite 1600 | $56.0^{ab}$ | $54.1^{ab}$ | $58.2^{bcd}$ | $43.7^{e}$ | $27.0^{d}$ | $24.1^{d}$ |
| $T_6$ – SOP | $52.6^{bc}$ | $52.9^{abc}$ | $56.3^{bcde}$ | $79.0^{a}$ | $30.4^{d}$ | $35.8^{abc}$ |
| $T_7$ - Lime 500 +SOP | $52.6^{bc}$ | $48.9^{bcd}$ | $60.6^{bc}$ | $74.8^{ab}$ | $50.9^{ab}$ | $40.1^{ab}$ |
| $T_8$ - Lime 1000 + SOP | $55.7^{abc}$ | $55.5^{ab}$ | $62.1^{ab}$ | $80.5^{a}$ | $61.9^{a}$ | $36.0^{abc}$ |
| $T_9$ - Dolomite 800 + SOP | $52.5^{bc}$ | $52.4^{abc}$ | $54.2^{cde}$ | $43.2^{e}$ | $34.6^{cd}$ | $33.7^{c}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $63.0^{a}$ | $58.8^{a}$ | $68.9^{a}$ | $70.1^{bc}$ | $51.7^{ab}$ | $37.0^{abc}$ |
| CD (0.05) | 8.15 | 7.15 | 7.68 | 6.84 | 12.96 | 5.68 |

**Table 13. Effect of treatments on exchangeable sodium and available boron in *Pokkali* soil**

| Treatments | Exchangeable sodium ($mg\ kg^{-1}$) | | | Available boron ($mg\ kg^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 20 DAT | flowering | harvest | 20 DAT | flowering | harvest |
| $T_1$ - Control | $1438.7^{a}$ | $1057.7^{a}$ | $840.8^{abc}$ | $2.3^{c}$ | $1.7^{d}$ | $1.9^{c}$ |
| $T_2$ - Lime 500 | $1008.2^{bc}$ | $988.5^{ab}$ | $871.7^{ab}$ | $2.9^{b}$ | $3.2^{a}$ | $2.1^{b}$ |
| $T_3$ - Lime 1000 | $797.2^{d}$ | $935.5^{b}$ | $826.8^{bc}$ | $2.1^{c}$ | $2.5^{b}$ | $1.7^{cd}$ |
| $T_4$ - Dolomite 800 | $921.0^{cd}$ | $978.7^{ab}$ | $884.3^{a}$ | $3.6^{a}$ | $2.5^{b}$ | $2.8^{a}$ |
| $T_5$ - Dolomite 1600 | $947.5^{cd}$ | $938.0^{b}$ | $808.5^{cd}$ | $1.6^{d}$ | $2.0^{cd}$ | $2.2^{b}$ |
| $T_6$ – SOP | $972.8^{bcd}$ | $952.5^{b}$ | $761.2^{d}$ | $2.1^{c}$ | $3.4^{a}$ | $1.7^{d}$ |
| $T_7$ - Lime 500 +SOP | $907.7^{cd}$ | $1043.7^{a}$ | $828.7^{bc}$ | $3.0^{b}$ | $2.0^{cd}$ | $2.2^{b}$ |
| $T_8$ - Lime 1000 + SOP | $1011.3^{bc}$ | $926.2^{bc}$ | $790.0^{cd}$ | $2.2^{c}$ | $2.0^{cd}$ | $2.7^{a}$ |
| $T_9$ - Dolomite 800 + SOP | $932.2^{cd}$ | $843.7^{c}$ | $809.0^{cd}$ | $3.1^{b}$ | $1.9^{cd}$ | $1.8^{cd}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $1164.3^{b}$ | $959.8^{b}$ | $764.5^{d}$ | $3.6^{a}$ | $2.2^{bc}$ | $2.6^{a}$ |
| CD (0.05) | 204.48 | 83.04 | 52.77 | 0.33 | 0.41 | 0.20 |

### 4.5 Plant analysis

Plant samples were collected at four stages of crop growth *viz*, 20 DAT, 40 DAT, flowering and at harvest. Collected samples were analyzed for all the primary and secondary nutrients, sodium and boron.

#### 4.5.1 Nitrogen

Data on 20 DAT (Table 14) revealed that treatments did not show any significant variation in the nitrogen content in plants. At 40 days after transplanting, $T_8$ recorded significantly higher value (1.81 %) and was on par with $T_2$, $T_4$, $T_5$ and $T_6$. But at flowering, control and $T_8$ (1.57 %) showed significantly higher values which were on par with $T_4$ and $T_6$, as compared to other treatments. Lowest N content (1.07 %) was observed in treatment $T_9$. Grains registered greater nitrogen content in treatments having foliar spray of SOP with lime or dolomite. But in the case of nitrogen content in straw, lime treated plots $T_2$, $T_3$ and $T_7$ showed higher values.

#### 4.5.2 Phosphorus

Data furnished in the Table 15 shows that treatments did not show significant effect on the phosphorus content at 20 DAT. During active tillering stage (40 DAT), it is clear that the treatments had significant influence on the phosphorus content in plant. Higher values were recorded by treatments $T_5$ and $T_{10}$ having application of dolomite @1600 kg $ha^{-1}$. At flowering stage, higher value of phosphorus content were shown by treatment $T_8$ (0.80) having combination of lime application @ 1000 kg $ha^{-1}$ and foliar spray of SOP at 20 DAT and 40 DAT. Lowest value was noted for the treatment $T_2$ (lime @ 500 kg $ha^{-1}$). In the case of grain, treatments showed significant variation in phosphorus content. $T_8$ recorded the highest value with $T_4$, $T_6$ and $T_{10}$ on par. In straw, $T_5$, $T_7$ and $T_{10}$ exhibited a positive influence on the P content.

**Table 14. Effect of amelioration and foliar spray of SOP on nitrogen content (%) in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | Flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | 2.86 | $1.05^{cd}$ | $1.57^{a}$ | $1.23^{bc}$ | $0.76^{bcde}$ |
| $T_2$ - Lime 500 | 2.16 | $1.58^{ab}$ | $1.30^{bcd}$ | $1.05^{c}$ | $1.05^{ab}$ |
| $T_3$ - Lime 1000 | 2.74 | $1.28^{bcd}$ | $1.30^{bcd}$ | $1.28^{bc}$ | $0.99^{abc}$ |
| $T_4$ - Dolomite 800 | 1.52 | $1.81^{a}$ | $1.50^{ab}$ | $1.05^{c}$ | $0.64^{def}$ |
| $T_5$ - Dolomite 1600 | 2.51 | $1.46^{abc}$ | $1.10^{d}$ | $1.34^{bc}$ | $0.47^{ef}$ |
| $T_6$ – SOP | 2.68 | $1.40^{abcd}$ | $1.37^{abc}$ | $1.34^{bc}$ | $0.99^{abc}$ |
| $T_7$ - Lime 500 +SOP | 2.28 | $1.11^{cd}$ | $1.13^{cd}$ | $1.28^{bc}$ | $1.17^{a}$ |
| $T_8$ - Lime 1000 + SOP | 3.33 | $1.81^{a}$ | $1.57^{a}$ | $1.52^{ab}$ | $0.70^{cde}$ |
| $T_9$ - Dolomite 800 + SOP | 3.09 | $0.99^{d}$ | $1.07^{d}$ | $1.69^{a}$ | $0.82^{bcd}$ |
| $T_{10}$ - Dolomite 1600 + SOP | 2.57 | $1.11^{cd}$ | $1.23^{cd}$ | $1.40^{ab}$ | $0.35^{f}$ |
| CD (0.05) | NS | 0.46 | 0.25 | 0.33 | 0.30 |

**Table 15. Effect of amelioration and foliar spray of SOP on phosphorus content (%) in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | Flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | 0.26 | $0.75^{c}$ | $0.54^{bc}$ | $0.13^{bc}$ | $0.12^{c}$ |
| $T_2$ - Lime 500 | 0.22 | $0.75^{c}$ | $0.49^{c}$ | $0.13^{bc}$ | $0.16^{b}$ |
| $T_3$ - Lime 1000 | 0.25 | $0.75^{c}$ | $0.56^{bc}$ | $0.15^{abc}$ | $0.11^{c}$ |
| $T_4$ - Dolomite 800 | 0.20 | $0.78^{bc}$ | $0.57^{bc}$ | $0.16^{ab}$ | $0.16^{b}$ |
| $T_5$ - Dolomite 1600 | 0.22 | $0.86^{a}$ | $0.61^{b}$ | $0.10^{de}$ | $0.19^{a}$ |
| $T_6$ – SOP | 0.24 | $0.76^{c}$ | $0.50^{c}$ | $0.15^{abc}$ | $0.16^{b}$ |
| $T_7$ - Lime 500 +SOP | 0.27 | $0.77^{bc}$ | $0.55^{bc}$ | $0.09^{e}$ | $0.18^{ab}$ |
| $T_8$ - Lime 1000 + SOP | 0.29 | $0.74^{c}$ | $0.80^{a}$ | $0.16^{a}$ | $0.16^{b}$ |
| $T_9$ - Dolomite 800 + SOP | 0.23 | $0.73^{c}$ | $0.57^{bc}$ | $0.13^{cd}$ | $0.16^{b}$ |
| $T_{10}$ - Dolomite 1600 + SOP | 0.25 | $0.84^{ab}$ | $0.63^{b}$ | $0.14^{abc}$ | $0.17^{ab}$ |
| CD (0.05) | NS | 0.07 | 0.10 | 0.03 | 0.02 |

### 4.5.3 Potassium

The data pertaining to potassium content at different stages of rice growth are given in Table 16. $T_3$ (lime @1000 kg $ha^{-1}$) treatment recorded highest potassium content (1.21%) at 20 days after transplanting and was on par with treatments $T_5$, $T_7$ and $T_8$. Treatments with combination of soil amelioration and foliar spray of SOP except $T_9$ recorded higher potassium content during 40 days after transplanting. At flowering, highest value was observed in treatment $T_8$ (2.21%) with a combination of lime @1000 kg $ha^{-1}$ and foliar spray of SOP. In grain, highest potassium content was observed for the treatment $T_2$ (lime @ 500 kg $ha^{-1}$) and was on par with the treatments $T_3$, $T_4$, $T_6$, $T_8$ and $T_{10.}$ But in straw, higher K content was observed for the treatment $T_8$ which was on par with $T_3$ and $T_{6.}$

### 4.5.4 Calcium

Calcium content in the plant at 20 days after transplanting was significantly influenced by the treatments (Table 17). Higher values were recorded by treatments $T_5$ and $T_{10}$. The lowest value was noted for $T_7$. But treatments did not show significant influence on calcium content at 40 DAT. During flowering stage, $T_5$ gave highest calcium content of 0.96 per cent and was on par with treatments $T_3$, $T_8$ and $T_{10}$. At harvest, grain recorded higher value in the treatment $T_2$ and straw recorded higher value in treatment $T_8$.

### 4.5.5 Magnesium

Various treatments had significantly influenced the magnesium content in plant at different crop growth stages (Table 18). The treatment $T_{10}$ [combination of dolomite@ 1600 kg $ha^{-1}$and foliar spray of SOP at 20 and 40 DAT] showed highest magnesium content of 0.31 per cent at 20 days after transplanting. And lowest value was recorded by $T_3$ (0.16 %). $T_{10}$ recorded higher magnesium content at 40 DAT also. At flowering, highest value was recorded for treatment $T_8$ [combination of lime

@ 1000 kg $ha^{-1}$and foliar spray of SOP at 20 and 40 DAT] and was on par with treatment $T_3$ (lime @1000 kg $ha^{-1}$). The lowest was observed in treatment $T_4$ (0.184%). At harvest, Mg content in grain was high for the treatments $T_7$ and $T_8$. But in case of magnesium content in straw, treatments $T_4$ and $T_6$ recorded higher values and lowest value was observed in the treatment $T_3$.

### 4.5.6 Sulphur

Data in Table 19 shows the influence of different treatments on the sulphur content in plant. This showed that treatments did not exhibit much positive influence on enhancing the sulphur content in plant. The treatment $T_3$ showed the highest value (0.61%) of sulphur content at 20 days after transplanting and was on par with the treatment $T_{10}$. The lowest value was observed in the treatment $T_4$ with 0.19 %. At 40 days after transplanting, the treatment $T_{10}$ gave the highest value among treatments. The treatments $T_3$, $T_8$ and $T_9$ were found to be on par with $T_{10}$. And the least value was recorded by the treatment $T_4$ (lime @ 1000 kg $ha^{-1}$). During flowering stage, highest value observed for the treatment $T_{10}$ and was on par with $T_3$ as well as treatments $T_1$, $T_4$, $T_7$ and $T_9$. Lowest value was noted for the treatment $T_5$. In the case of plant sulphur content at harvest stage, highest sulphur content in grain was recorded with the treatment $T_{10}$. But in straw, treatments did not significantly influence sulphur content.

### 4.5.7 Sodium

In *Pokkali* soils, most important element which influences the uptake of other mineral nutrients is sodium. Its content in plant indirectly determines the growth and performance of *Pokkali* rice. Table 20 depicts the influence of various treatments on sodium content in plant. All treatments could produce positive effect on minimizing the sodium content. Also control plot recorded highest sodium content in all stages of sampling except at 20 DAT. At 20 days after transplanting, all the treatments except $T_2$ could produce a significant positive effect in reducing sodium content. At 40 DAT, treatment $T_6$ recorded the lowest sodium content in *Pokkali* rice. At flowering,

$T_8$ recorded least value followed by $T_{10}$, $T_5$ and $T_4$. In the case of grain, lowest values were observed for the treatments having combination of foliar spray of SOP with lime or dolomite *i.e.,* $T_8$ and $T_9$ In straw, least value of sodium content was noted for the treatment $T_2$ followed by $T_8$.

### 4.5.8 Boron

Treatments significantly influenced the boron content in plant at 20 days after transplanting (Table 21). Treatment $T_8$ showed highest boron content of 22.49 (mg $kg^{-1}$) and was on par with treatment $T_6$. There was no significant variation among various treatments at 40 days after transplanting. During flowering stage, some treatments showed significant influence on boron content and it includes $T_8$, $T_1$, $T_2$, $T_5$ and $T_{10}$. Significant variation in boron content in grain could not be observed. The treatment $T_2$ recorded highest value in straw.

**Table 16. Effect of amelioration and foliar spray of SOP on potassium content (%) in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | 1.03$^{d}$ | 1.23$^{d}$ | 1.98$^{de}$ | 0.29$^{cd}$ | 1.71$^{de}$ |
| $T_2$ - Lime 500 | 1.12$^{c}$ | 1.23$^{d}$ | 2.07$^{bcd}$ | 0.32$^{a}$ | 1.73$^{de}$ |
| $T_3$ - Lime 1000 | 1.21$^{a}$ | 1.30$^{cd}$ | 2.08$^{bcd}$ | 0.31$^{ab}$ | 2.00$^{ab}$ |
| $T_4$ - Dolomite 800 | 1.07$^{cd}$ | 1.28$^{cd}$ | 1.83$^{f}$ | 0.30$^{abcd}$ | 1.70$^{e}$ |
| $T_5$ - Dolomite 1600 | 1.15$^{abc}$ | 1.33$^{bcd}$ | 2.10$^{b}$ | 0.28$^{d}$ | 1.83$^{cd}$ |
| $T_6$ – SOP | 1.09$^{cd}$ | 1.36$^{bcd}$ | 1.89$^{ef}$ | 0.30$^{abcd}$ | 2.08$^{a}$ |
| $T_7$ - Lime 500 +SOP | 1.15$^{abc}$ | 1.45$^{ab}$ | 1.90$^{ef}$ | 0.29$^{cd}$ | 1.94$^{bc}$ |
| $T_8$ - Lime 1000 + SOP | 1.21$^{a}$ | 1.54$^{a}$ | 2.21$^{a}$ | 0.31$^{ab}$ | 2.11$^{a}$ |
| $T_9$ - Dolomite 800 + SOP | 1.07$^{cd}$ | 1.37$^{bc}$ | 1.99$^{cde}$ | 0.29$^{cd}$ | 1.94$^{bc}$ |
| $T_{10}$ - Dolomite 1600 + SOP | 1.12$^{bc}$ | 1.46$^{ab}$ | 2.10$^{b}$ | 0.31$^{ab}$ | 1.95$^{bc}$ |
| CD (0.05) | 0.09 | 0.14 | 0.10 | 0.02 | 0.13 |

**Table 17. Effect of amelioration and foliar spray of SOP on calcium content (%) in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | 0.71$^{e}$ | 0.88 | 0.68$^{d}$ | 0.26$^{e}$ | 0.85$^{bc}$ |
| $T_2$ - Lime 500 | 0.76$^{d}$ | 0.92 | 0.84$^{bc}$ | 0.29$^{a}$ | 0.75$^{d}$ |
| $T_3$ - Lime 1000 | 0.79$^{c}$ | 0.94 | 0.86$^{abc}$ | 0.28$^{abc}$ | 0.81$^{cd}$ |
| $T_4$ - Dolomite 800 | 0.82$^{b}$ | 0.95 | 0.75$^{cd}$ | 0.28$^{abc}$ | 0.87$^{abc}$ |
| $T_5$ - Dolomite 1600 | 0.86$^{a}$ | 0.98 | 0.96$^{a}$ | 0.28$^{abc}$ | 0.87$^{abc}$ |
| $T_6$ – SOP | 0.78$^{cd}$ | 0.92 | 0.69$^{d}$ | 0.27$^{cde}$ | 0.90$^{ab}$ |
| $T_7$ - Lime 500 +SOP | 0.70$^{e}$ | 0.98 | 0.81$^{bc}$ | 0.28$^{abc}$ | 0.80$^{cd}$ |
| $T_8$ - Lime 1000 + SOP | 0.82$^{b}$ | 0.95 | 0.87$^{ab}$ | 0.27$^{cde}$ | 0.94$^{a}$ |
| $T_9$ - Dolomite 800 + SOP | 0.80$^{c}$ | 0.97 | 0.83$^{bc}$ | 0.28$^{abc}$ | 0.88$^{abc}$ |
| $T_{10}$ - Dolomite 1600 + SOP | 0.87$^{a}$ | 1.02 | 0.89$^{ab}$ | 0.27$^{cde}$ | 0.90$^{ab}$ |
| CD (0.05) | 0.02 | NS | 0.11 | 0.02 | 0.07 |

**Table 18. Effect of amelioration and foliar spray of SOP on magnesium content (%) in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | $0.19^{f}$ | $0.23^{f}$ | $0.23^{e}$ | $0.08^{d}$ | $0.23^{c}$ |
| $T_2$ - Lime 500 | $0.25^{c}$ | $0.26^{d}$ | $0.24^{d}$ | $0.11^{b}$ | $0.23^{c}$ |
| $T_3$ - Lime 1000 | $0.16^{g}$ | $0.29^{b}$ | $0.31^{a}$ | $0.08^{d}$ | $0.17^{f}$ |
| $T_4$ - Dolomite 800 | $0.23^{d}$ | $0.24^{e}$ | $0.18^{f}$ | $0.06^{e}$ | $0.28^{a}$ |
| $T_5$ - Dolomite 1600 | $0.23^{d}$ | $0.24^{e}$ | $0.26^{c}$ | $0.10^{c}$ | $0.20^{e}$ |
| $T_6$ – SOP | $0.27^{b}$ | $0.22^{f}$ | $0.29^{b}$ | $0.11^{b}$ | $0.27^{a}$ |
| $T_7$ - Lime 500 +SOP | $0.23^{d}$ | $0.27^{c}$ | $0.27^{c}$ | $0.14^{a}$ | $0.25^{b}$ |
| $T_8$ - Lime 1000 + SOP | $0.22^{e}$ | $0.23^{f}$ | $0.31^{a}$ | $0.14^{a}$ | $0.20^{e}$ |
| $T_9$ - Dolomite 800 + SOP | $0.28^{b}$ | $0.28^{bc}$ | $0.23^{e}$ | $0.08^{d}$ | $0.23^{c}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $0.31^{a}$ | $0.31^{a}$ | $0.24^{d}$ | $0.08^{d}$ | $0.22^{d}$ |
| CD (0.05) | 0.01 | 0.01 | 0.02 | 0.01 | 0.09 |

**Table 19. Effect of amelioration and foliar spray of SOP on sulphur (%) content in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | $0.38^{def}$ | $0.29^{bcd}$ | $0.34^{ab}$ | $0.18^{bc}$ | 0.21 |
| $T_2$ - Lime 500 | $0.41^{cde}$ | $0.22^{d}$ | $0.24^{cd}$ | $0.15^{d}$ | 0.19 |
| $T_3$ - Lime 1000 | $0.61^{a}$ | $0.39^{ab}$ | $0.37^{a}$ | $0.17^{bc}$ | 0.12 |
| $T_4$ - Dolomite 800 | $0.19^{g}$ | $0.20^{d}$ | $0.36^{ab}$ | $0.19^{ab}$ | 0.20 |
| $T_5$ - Dolomite 1600 | $0.50^{bc}$ | $0.34^{bc}$ | $0.17^{d}$ | $0.18^{bc}$ | 0.16 |
| $T_6$ – SOP | $0.33^{ef}$ | $0.28^{cd}$ | $0.29^{bc}$ | $0.16^{cd}$ | 0.17 |
| $T_7$ - Lime 500 +SOP | $0.39^{def}$ | $0.33^{bc}$ | $0.33^{ab}$ | $0.18^{bc}$ | 0.16 |
| $T_8$ - Lime 1000 + SOP | $0.30^{f}$ | $0.38^{abc}$ | $0.24^{cd}$ | $0.15^{d}$ | 0.18 |
| $T_9$ - Dolomite 800 + SOP | $0.47^{bcd}$ | $0.39^{ab}$ | $0.34^{ab}$ | $0.17^{bc}$ | 0.16 |
| $T_{10}$ - Dolomite 1600 + SOP | $0.52^{ab}$ | $0.46^{a}$ | $0.37^{a}$ | $0.20^{a}$ | 0.10 |
| CD (0.05) | 0.10 | 0.11 | 0.07 | 0.03 | NS |

**Table 20. Effect of amelioration and foliar spray of SOP on sodium (%) in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | $0.83^{ab}$ | $0.87^{a}$ | $0.84^{a}$ | $0.16^{a}$ | $1.32^{a}$ |
| $T_2$ - Lime 500 | $0.92^{a}$ | $0.81^{abcd}$ | $0.70^{b}$ | $0.16^{a}$ | $0.94^{f}$ |
| $T_3$ - Lime 1000 | $0.73^{bc}$ | $0.80^{cd}$ | $0.68^{bc}$ | $0.15^{abc}$ | $1.12^{d}$ |
| $T_4$ - Dolomite 800 | $0.56^{c}$ | $0.85^{abc}$ | $0.59^{cd}$ | $0.16^{a}$ | $1.23^{abc}$ |
| $T_5$ - Dolomite 1600 | $0.60^{c}$ | $0.87^{a}$ | $0.59^{cd}$ | $0.15^{abc}$ | $1.15^{cd}$ |
| $T_6$ – SOP | $0.70^{bc}$ | $0.78^{d}$ | $0.64^{bcd}$ | $0.14^{cde}$ | $1.26^{ab}$ |
| $T_7$ - Lime 500 +SOP | $0.70^{bc}$ | $0.80^{cd}$ | $0.71^{b}$ | $0.14^{cde}$ | $1.02^{ef}$ |
| $T_8$ - Lime 1000 + SOP | $0.73^{bc}$ | $0.80^{cd}$ | $0.57^{d}$ | $0.13^{e}$ | $1.09^{de}$ |
| $T_9$ - Dolomite 800 + SOP | $0.72^{bc}$ | $0.86^{abc}$ | $0.71^{b}$ | $0.13^{e}$ | $1.15^{cd}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $0.72^{bc}$ | $0.85^{abc}$ | $0.58^{cd}$ | $0.13^{e}$ | $1.17^{bcd}$ |
| CD (0.05) | 0.18 | 0.06 | 0.10 | 0.02 | 0.10 |

**Table 21. Effect of amelioration and foliar spray of SOP on boron (mg $kg^{-1}$) content in *Pokkali* rice**

| Treatments | 20 DAT | 40 DAT | flowering | Grain | Straw |
|---|---|---|---|---|---|
| $T_1$ - Control | $15.17^{bc}$ | 13.82 | $14.63^{abc}$ | 10.57 | $5.15^{c}$ |
| $T_2$ - Lime 500 | $6.23^{f}$ | 13.55 | $14.36^{abcd}$ | 12.73 | $17.88^{a}$ |
| $T_3$ - Lime 1000 | $14.36^{bcd}$ | 14.09 | $9.21^{cd}$ | 12.46 | $12.19^{b}$ |
| $T_4$ - Dolomite 800 | $10.84^{e}$ | 13.82 | $8.67^{d}$ | 9.21 | $11.11^{b}$ |
| $T_5$ - Dolomite 1600 | $14.09^{bcd}$ | 15.17 | $15.44^{ab}$ | 14.36 | $10.84^{b}$ |
| $T_6$ – SOP | $20.05^{a}$ | 18.97 | $11.11^{bcd}$ | 14.63 | $10.30^{b}$ |
| $T_7$ - Lime 500 +SOP | $15.71^{b}$ | 16.53 | $8.94^{cd}$ | 11.11 | $13.28^{b}$ |
| $T_8$ - Lime 1000 + SOP | $22.49^{a}$ | 16.26 | $17.34^{a}$ | 12.46 | $11.92^{b}$ |
| $T_9$ - Dolomite 800 + SOP | $12.46^{cde}$ | 13.82 | $10.30^{bcd}$ | 14.36 | $13.01^{b}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $11.38^{de}$ | 18.70 | $14.09^{abcd}$ | 15.71 | $12.74^{b}$ |
| CD (0.05) | 3.03 | NS | 5.84 | NS | 3.83 |

## 4.6 Na/K and Na/Ca ratios in *Pokkali* rice

Na/K ratio is one of the yield determining criteria especially in saline soils. Treatments significantly influenced the plant Na/ K ratio at different stages of plant growth. As the crop growth progressed the Na/K ratio showed a decreasing trend up to flowering. At harvest, the ratio was less in grains than in straw. Control treatment recorded highest ratio at all crop growth stages. In 20 DAT, $T_2$ and $T_9$ were on par with the control (Table 22). Lowest Na/K ratio was observed for the treatment $T_8$ (combination of lime @ 1000 kg $ha^{-1}$and foliar spray of SOP) during 40 DAT, flowering and harvest stage. But at 20 DAT, lowest Na/K ratio was observed for treatments $T_4$ and $T_5$, and was on par with $T_3$, $T_6$, $T_7$, $T_8$, $T_9$ and $T_{10.}$

Na/Ca ratio was higher than Na/K ratio at all stages and in grains. Na/Ca ratio also exhibited a trend similar to Na/K ratio as control treatment recorded higher values in all stages. In 20 DAT and 40 DAT, all the treatments significantly influenced the Na/Ca ratio in plant except $T_2$ at 20 DAT. But in flowering, treatments $T_5$, $T_8$ and $T_{10}$ recorded lowest values. Treatments $T_7$, $T_8$, $T_9$ and $T_{10}$ recorded lowest values in grain also. In straw too, $T_8$ recorded the least value for Na/ Ca ratio.

**Table 22. Effect of amelioration and foliar spray of SOP on plant Na/K and Na/Ca ratios in *Pokkali* rice**

| Treatments | Na/K ratio | | | | | Na/ Ca ratio | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 DAT | 40 DAT | flowering | Grain | Straw | 20 DAT | 40 DAT | flowering | Grain | Straw |
| $T_1$ - Control | $0.807^{ab}$ | $0.720^{a}$ | $0.430^{a}$ | $0.547^{a}$ | $0.777^{a}$ | $1.173^{a}$ | $0.990^{a}$ | $1.253^{a}$ | $0.597^{a}$ | $1.553^{a}$ |
| $T_2$ - Lime 500 | $0.823^{a}$ | $0.663^{ab}$ | $0.333^{bc}$ | $0.503^{abc}$ | $0.543^{cd}$ | $1.207^{a}$ | $0.880^{b}$ | $0.837^{b}$ | $0.550^{abc}$ | $1.247^{de}$ |
| $T_3$ - Lime 1000 | $0.603^{c}$ | $0.620^{bc}$ | $0.327^{bcd}$ | $0.493^{abcd}$ | $0.560^{cd}$ | $0.927^{b}$ | $0.857^{b}$ | $0.787^{bcd}$ | $0.537^{bcd}$ | $1.390^{bc}$ |
| $T_4$ - Dolomite 800 | $0.523^{c}$ | $0.667^{ab}$ | $0.323^{bcd}$ | $0.523^{ab}$ | $0.723^{a}$ | $0.690^{c}$ | $0.897^{b}$ | $0.790^{bc}$ | $0.560^{ab}$ | $1.413^{b}$ |
| $T_5$ - Dolomite 1600 | $0.523^{c}$ | $0.650^{ab}$ | $0.283^{cde}$ | $0.530^{ab}$ | $0.627^{b}$ | $0.700^{c}$ | $0.893^{b}$ | $0.617^{d}$ | $0.533^{bcd}$ | $1.320^{bcd}$ |
| $T_6$ – SOP | $0.640^{bc}$ | $0.573^{bcd}$ | $0.333^{bc}$ | $0.473^{bcde}$ | $0.603^{bc}$ | $0.897^{bc}$ | $0.850^{b}$ | $0.933^{b}$ | $0.530^{bcd}$ | $1.403^{b}$ |
| $T_7$ - Lime 500 +SOP | $0.603^{c}$ | $0.553^{cd}$ | $0.373^{b}$ | $0.497^{abcd}$ | $0.527^{d}$ | $0.987^{ab}$ | $0.817^{b}$ | $0.877^{b}$ | $0.490^{cde}$ | $1.273^{cde}$ |
| $T_8$ - Lime 1000 + SOP | $0.620^{c}$ | $0.513^{d}$ | $0.257^{e}$ | $0.413^{e}$ | $0.520^{d}$ | $0.887^{bc}$ | $0.840^{b}$ | $0.653^{cd}$ | $0.477^{de}$ | $1.157^{e}$ |
| $T_9$ - Dolomite 800 + SOP | $0.673^{abc}$ | $0.623^{bc}$ | $0.357^{b}$ | $0.437^{cde}$ | $0.593^{bc}$ | $0.903^{bc}$ | $0.883^{b}$ | $0.863^{b}$ | $0.453^{e}$ | $1.317^{bcd}$ |
| $T_{10}$ - Dolomite 1600 + SOP | $0.637^{bc}$ | $0.587^{bcd}$ | $0.277^{de}$ | $0.430^{de}$ | $0.597^{bc}$ | $0.823^{bc}$ | $0.840^{b}$ | $0.653^{cd}$ | $0.477^{de}$ | $1.297^{bcd}$ |
| CD (0.05) | 0.175 | 0.096 | 0.053 | 0.07 | 0.066 | 0.225 | 0.081 | 0.171 | 0.06 | 0.12 |

### 4.7 Nutrient uptake

Nitrogen uptake was highest for $T_8$ [lime @1000 kg ha$^{-1}$+ K (2% spray) at 20 and 40 DAT] with 67 kg ha$^{-1}$. It is clear from the Table 23 that treatments $T_9$, $T_6$ and $T_3$ were on par with $T_8$. And the lowest was observed in the control. Significant difference was recorded in phosphorus content due to various treatments. Treatment $T_8$ recorded highest value (9.82 kg ha$^{-1}$) and was on par with treatments $T_{10}$ and $T_5$. But in the case of potassium uptake, highest value was noted for the treatment $T_{10}$ (combination of dolomite @1600 kg ha$^{-1}$and foliar spray of SOP at 20 and 40 DAT). And the lowest value was showed by the control treatment. Calcium uptake was high for treatment $T_5$ followed by $T_{10}$ and were on par with treatments $T_4$, $T_6$, $T_8$ and $T_9$. On the other hand, uptake of magnesium, sulphur and sodium did not vary significantly among different treatments.

**Table 23. Effect of amelioration and foliar spray of SOP on nutrient uptake (kg ha$^{-1}$) in *Pokkali* rice**

| Treatments | N | P | K | Ca | Mg | S | Na |
|---|---|---|---|---|---|---|---|
| $T_1$ - Control | $33.64^{d}$ | $4.43^{e}$ | $39.16^{d}$ | $21.19^{d}$ | 6.85 | 6.62 | 29.08 |
| $T_2$ - Lime 500 | $47.22^{bcd}$ | $6.73^{cd}$ | $57.64^{bcd}$ | $27.25^{cd}$ | 8.76 | 7.95 | 31.20 |
| $T_3$ - Lime 1000 | $52.69^{abc}$ | $6.05^{cde}$ | $66.53^{abc}$ | $29.60^{bcd}$ | 6.58 | 6.72 | 36.91 |
| $T_4$ - Dolomite 800 | $36.80^{cd}$ | $7.52^{bcd}$ | $57.07^{bcd}$ | $31.45^{abc}$ | 9.41 | 9.40 | 40.57 |
| $T_5$ - Dolomite 1600 | $49.20^{bcd}$ | $9.45^{ab}$ | $76.38^{ab}$ | $39.79^{a}$ | 9.95 | 10.30 | 47.48 |
| $T_6$ – SOP | $56.29^{ab}$ | $7.78^{bc}$ | $67.52^{abc}$ | $32.17^{abc}$ | 10.19 | 8.24 | 40.25 |
| $T_7$ - Lime 500 +SOP | $47.44^{bcd}$ | $5.67^{de}$ | $51.87^{cd}$ | $23.85^{cd}$ | 8.13 | 6.44 | 27.13 |
| $T_8$ - Lime 1000 + SOP | $67.07^{a}$ | $9.82^{a}$ | $75.79^{ab}$ | $37.59^{ab}$ | 10.39 | 10.17 | 38.17 |
| $T_9$ - Dolomite 800 + SOP | $53.26^{abc}$ | $7.17^{cd}$ | $67.63^{abc}$ | $32.65^{abc}$ | 8.92 | 7.75 | 39.55 |
| $T_{10}$ - Dolomite 1600 + SOP | $44.67^{bcd}$ | $9.30^{ab}$ | $79.01^{a}$ | $39.59^{a}$ | 9.92 | 8.29 | 46.30 |
| CD (0.05) | 17.55 | 2.00 | 19.46 | 8.82 | NS | NS | NS |

# Discussion

# 5. DISCUSSION

Salinity, acidity and submergence are the major issues found in *Pokkali* ecosystem. The experiment entitled "Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice" was conducted with an aim to narrow the Na/K ratio inside the plant by liming and foliar application of potassium in *Pokkali* rice. The results of this research work are discussed in this chapter with supporting research works from literature.

## 5.1 Growth parameters

Due to heavy floods occurred twice during the cropping season, the crop was completely submerged for a period of 5 days and 8 days each and this affected the crop growth and yield in general.

In rice, the growth is mainly assessed in terms of plant height, number tillers/m$^2$, leaf area index *etc.* The results on growth parameters indicated that there was considerable improvement in growth with soil amelioration and foliar nutrition with sulphate of potash. The combination of lime @1000 kg ha$^{-1}$ and SOP foliar nutrition produced greater number of tillers per m$^2$ at flowering and at harvest. Amelioration with dolomite @1600 kg ha$^{-1}$ with or without foliar spray could significantly enhance leaf area index. At flowering stage, higher leaf area index (Figure 4) was observed for treatments with higher doses of liming along with foliar spray of SOP. Bohra and Doerffling (1993) reported that under saline conditions potassium application enhanced the plant height, number of tillers and shoot dry weight. In addition to this, application of lime also significantly increased the plant height in a quadratic manner according to Fageria and Knupp (2014).

## 5.2. Yield parameters

A positive influence of various treatments could be seen on yield and yield attributes also. Treatments having a combination of lime application and potassium foliar spray recorded higher values for grain yield, percentage of filled grains and number of panicles per $m^2$ (Figure 3). This may be due to the positive impact of lime in ameliorating the issues of salinity and acidity in *Pokkali* soil. In a study conducted to assess the ameliorating effect of different levels of lime, sawdust and gypsum in *Pokkali* soils, it was found that there was an enhancement in yield by 21 per cent with the application of lime @ 1000 kg $ha^{-1}$ (Shylaraj *et al.,* 2013). In addition to this, studies have shown that the foliar spray of KCl in rice generated a positive response in rice yield, which was almost double than that of untreated control (Nair *et al*., 1993). Ali *et al.* (2005) reported that application of potassium sulphate produced more tillers, straw and paddy yield. However a lower dose of lime or dolomite resulted in low yield compared to that of a higher dose. Hence, lime @ 1000 kg $ha^{-1}$ or dolomite @ 1600 kg $ha^{-1}$ is needed for amelioration in *Pokkali* soils.

Plots treated with dolomite @ 1600 kg $ha^{-1}$ recorded highest dry matter production. The results obtained were in accordance with the findings of Suriyagoda *et al.* (2017) who reported that enhanced shoot and root dry weight in rice with dolomite application was due to increased biomass of stems, dead leaves and grains. Highest number of filled grains per panicle was seen in treatment plots applied with 1000 kg $ha^{-1}$ lime and with 1600 kg $ha^{-1}$ dolomite. This result was in accordance with the findings of Bhindu (2017), who reported that considerable improvement in number of grains per panicle could be obtained with the application of dolomite. In the present study also it was seen that liming enhanced number of grains per panicle, but percentage of filled grains was more when supplemented with foliar spray of SOP.

Net returns were found to be high for the treatment with lime @1000 kg $ha^{-1}$+ foliar spray of SOP at 20 and 40 DAT. It was found to be more profitable and viable among all treatments.

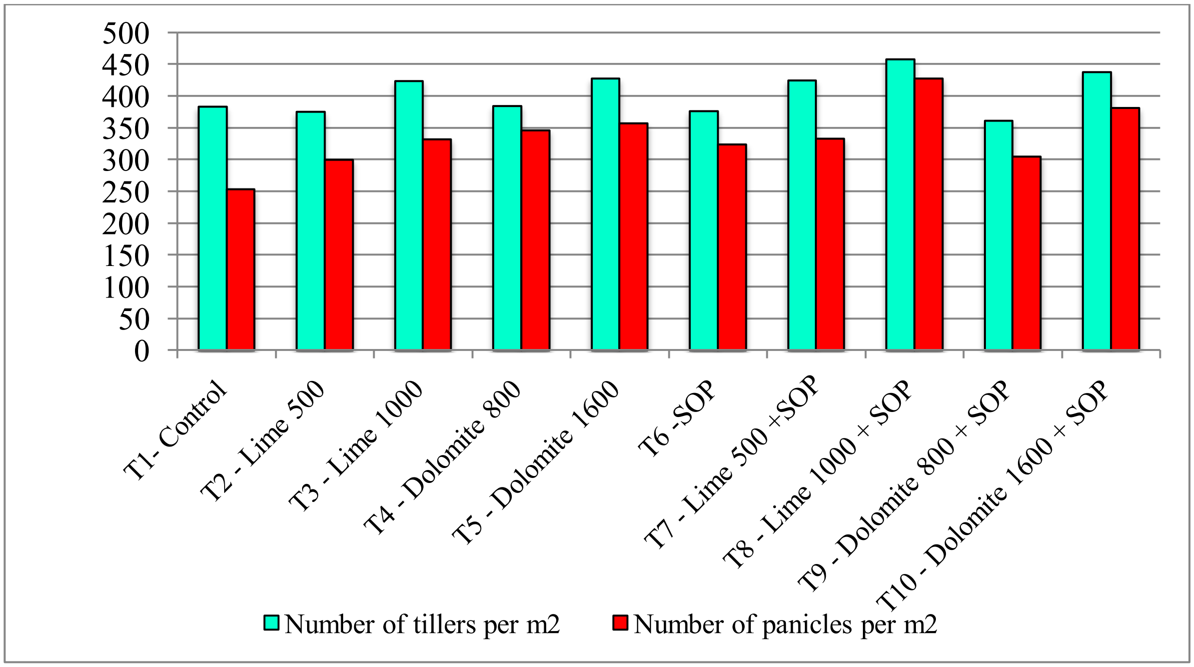



**Fig. 3 Effect of amelioration and SOP foliar spray on number of tillers at flowering stage and number of panicles**

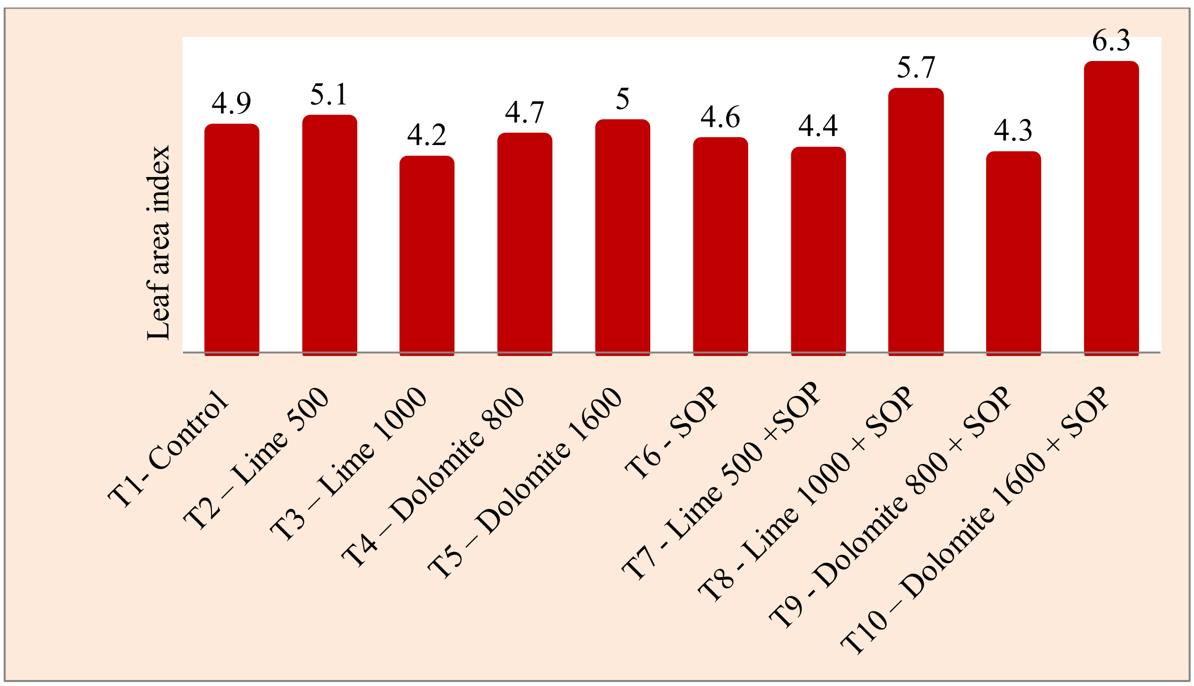



**Fig. 4 Effect of amelioration and foliar spray of SOP on leaf area index at flowering stage**

### 5.2. Soil analysis

#### 5.2.1. Effect of amelioration and foliar spray of SOP on pH and EC of soil

Soil acidity is one of the major abiotic stresses in acid saline *Pokkali* soils. Many studies suggested that liming is the foremost and most relevant method to overcome constraints and improve rice production in acid soils. Liming helps to raise the pH of soil to the range of 5 - 6.5, which is ideal for most crops. Amendments used for this purpose in this experiment were lime and dolomite at two different concentrations. Results showed that except control all the other treatments could produce a significant change in pH of the soil during flowering stage of rice (Table 8). At harvest, treatments with lime and dolomite application could enhance the soil pH values.

Electrical conductivity (EC) is the most commonly used indicator of soil salinity. Presence of excess salts or exchangeable sodium in soil may cause detrimental effects on both growth and physiology of plants. At 20 days after transplanting, control treatment recorded higher EC values. This indicated that soil amelioration has significant positive effect in reducing the electrical conductivity. Razzaque *et al*. (2010) reported that calcium supplementation had a great role in the salt tolerance of rice grown in saline soils. They continued that there was an enhanced absorption of $K^+$ and reduced percent $Na^+$ content in rice shoots with the addition of calcium. But at 90 days after transplanting and at harvest, treatments did not produce significant variation in electrical conductivity, and its range in the soil of a tolerable limit. This might be because of the leaching and drainage which occurred due to repeated flooding.

#### 5.2.2 Effect of amelioration and foliar spray of SOP on organic carbon and primary nutrients

*Pokkali* soil under study was organic matter rich soil having an organic carbon content of 2.33 per cent initially, and organic carbon was maintained in the sufficiency range throughout the crop growth period which ranged from 1.5 to 2.4. Lowlands like *Pokkali* tract were rich in organic carbon may be due to the incomplete decomposition of organic matter, intermittent submergence, continuous addition of organic residues and deltaic deposition (Bhindu, 2017). Treatments differed significantly with respect to the organic carbon content at 20 DAT, flowering and at harvest, but no definite pattern was observed due to flooding.

Higher values of available nitrogen were noted in almost all treatment plots during the harvest period. Treatments including dolomite gave best results of available nitrogen in soil during harvest. Srivastava *et al.* (1972) reported that application of lime enhanced the microbial activity in soil and resulted in the mineralization of organic nitrogen, thereby increasing the availability of nitrogen.

Sufficient phosphorus was found in acid saline soils during the initial set of soil analysis at 20 days after transplanting. During flowering and harvest, available phosphorus was highest for the treatment $T_8$ having a combination of application of lime @ 1000 kg $ha^{-1}$ and foliar spray of 2 per cent potassium spray. In a study conducted to evaluate the effect of liming on phosphate availability, it is reported that the persistence of Al toxicity in acidic soil inhibits the uptake, translocation and utilization of phosphate by plants. Liming increased the availability of soil phosphorus by the amelioration of Al toxicity and mineralization of soil organic phosphorus (Haynes, 1982).

*Pokkali* soils are generally rich in potassium. Soil analysis at 20 days after transplanting showed that the available potassium content in the entire field maintained a medium to high status. Even then, $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] and $T_8$ [lime @1000 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] recorded highest value among treatment plots. Significant increase in the available potassium might be due to the replacement of potassium from the exchange sites with the calcium from the liming materials, hence enhancing the potassium content in the labile pool. As compared to acid soils, limed soils retained more potassium in the available form (Mehlich, 1943; Thomas and Coleman, 1959). At flowering, treatment $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$+ SOP (2% spray) at 20 and 40 DAT] recorded high available potassium in soil. During harvest, a slight increase in the potassium content in the entire field was observed. This might be due to the intermittent submergence of crop during flooding. All lime treatments except treatments with half dose of dolomite showed good values of available potassium at harvest. An increase in available potassium, calcium, magnesium, sodium, iron and manganese in soils subjected to flooding has been reported by Bhaskaran and Varghese (2009).

**5.2.3 Effect of amelioration and foliar spray of SOP on availability of secondary nutrients**

Available calcium content did not show any variation among different treatments at 20 days after transplanting. But at flowering, treatment $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] showed better results regarding available calcium content in soil. But at the time of harvest, application of lime followed by foliar spray showed higher levels of calcium. Soil amelioration by liming improved the physiological balance of various nutrients (Ca, K, Mg, S and microelements) in the soil. They incorporated and made available several nutrients in the soil in large quantities (Loide, 2004).

Highest values of available magnesium was observed in the treatment $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] during 20 DAT, 40 DAT and at harvest. However, liming also favoured improved the available magnesium content. In addition to the correction of soil acidity, application of dolomite could maintain a balance between the calcium and magnesium content in soil as well as enhance the uptake of magnesium by the crop (Bhindu *et al.,* 2018). As compared to calcium, chances of leaching were higher for magnesium. This might have been due to the weak bonding of magnesium with soil colloids due to its larger hydrated ionic radii.

Available sulphur content in the field under experiment was found to be higher during 20 days after transplanting. Santhosh (2013) reported that *Pokkali* lands were high in sulphur content due to the acid sulphate nature of the soil. Lime was added to these acid sulphate soils with an aim to enhance the productivity of crops by ensuring the availability of native and applied plant nutrients. The experiment conducted to assess the effects of lime on the availability of nutrients in soils and their uptake by plants, concluded that the application of lime improved the available nitrogen, phosphorus, calcium, magnesium, sulphur and zinc content in soils (Barman *et al*., 2014).

**5.2.4. Effect of amelioration and foliar spray of SOP on available sodium and boron in soil**

During 20 DAT and flowering, control treatment recorded higher sodium content in soil. It is clear from the Table 13 that liming the field had significant influence in reducing the sodium content. The result was in accordance with the findings of an experiment done by Higgins *et al*. (2012), who reported that there would be an increase in the exchangeable calcium content in soil with the addition of lime. Exchangeable K and Na had largely been replaced by the Ca and Mg in the liming materials. As compared to 20 DAT and flowering, lowest sodium content was observed in the whole field during the harvest stage. This might have been due to the intermittent flooding which occurred during different phases of crop growth.

Widespread deficiency of boron has become an emerging issue in regions with acidic, alluvial and light textured soils. This might be due to the leaching effect prevalent in these soils. Treatment $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] and $T_4$ (dolomite @ 800 kg $ha^{-1}$) recorded highest available boron content in soil during 20 days after transplanting. At harvest in addition to these two treatments, treatment $T_8$ [lime @ 1000 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] also showed a significant positive variation on available boron content in soil. Similar results of supporting studies were obtained from literature. Lalljee and Facknath (2002) conducted an experiment to assess the effect of lime application on the micronutrient content of soil and yield in *Solanum tuberosum* and they concluded that available soil zinc, copper, iron and manganese decreased and available boron increased with lime application.

Another study established a positive relation of lime and organic matter application on the recovery of available boron in soil. This might have been due to the release of greater amounts of soluble organic compounds from the decomposition of added organic matter at favorable soil pH produced by liming (Mandai *et al.,* 1993).

**5.3. Effect of treatments on plant nutrient content**

In the initial stage (20 DAT), treatments did not show significant effect on the nitrogen and phosphorus content in the plant. However in later stages, there was significant variation among treatments as compared to control. In grain, highest nitrogen content was observed in treatments with combination of lime or dolomite application and foliar spray of SOP at 20 and 40 DAT. Treatments $T_5$ and $T_{10}$ recorded high values of phosphorus content at 40 days after transplanting. At flowering, treatment $T_8$ recorded higher values in grain. This might have been due to the acceleration of additional P and K absorption facilitated by the calcium sufficiency in the soil (Kawasaki, 1995).

Potassium content was higher for the treatments which included lime @1000 kg $ha^{-1}$ at 20 days after transplanting. Application of dolomite @1600 kg $ha^{-1}$ was also comparable. At 40 DAT, the treatment $T_8$ recorded the highest potassium content among all the other treatments due to foliar application. Treatments $T_7$ and $T_{10}$ were also comparable with $T_8$. This showed that foliar application of SOP resulted in enhanced K absorption. At flowering, $T_8$ was followed by $T_{10}$ during which $T_3$ and $T_5$ also were comparable. Application of lime alone, or combination of lime and foliar spray of SOP resulted in more K in grain and straw.

At 20 days after transplanting, calcium content was higher for the treatments $T_5$ and $T_{10}$ which were applied with dolomite @1600 kg $ha^{-1}$. At 40 days after transplanting, treatments did not show significant difference in the calcium content in plant. At flowering, treatments $T_3$, $T_5$, $T_8$ and $T_{10}$ (amelioration at 100% with or without foliar spray) were found to be having better content than others. In grain, calcium content of all the treatments was in the range of 0.263 to 0.286 per cent. Control treatment recorded the least calcium content in plant. Magnesium content was higher for the treatment $T_{10}$ [dolomite @ 1600 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] and $T_4$ (dolomite @ 800 kg $ha^{-1}$) during 20 and 40 DAT. This might have been due to the addition of magnesium through dolomite application. But at flowering and at harvest stage, liming recorded high magnesium content. But dolomite treated plots registered higher magnesium content in straw.

Sodium content was higher for the control treatment during all stages of crop growth. This indicated the positive influence of treatments in reducing the plant sodium content. But at 20 days after transplanting, treatment $T_2$ (lime (CaO) @ 500 kg $ha^{-1}$) recorded highest sodium content than control treatment. Studies in *Pokkali* soils reported that amelioration may increase Na content in the plant tissues even exceeding the levels of the actual metabolic requirement and turn harmful to growth (Sasidharan, 2004). During the critical flowering stage, the lowest sodium content was observed for $T_8$ [lime @1000 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] followed by $T_{10}$, $T_4$ and $T_5$. Foliar spray of sulphate of potash also exhibited some positive influence in reducing the deleterious effects of sodium in plant. Under saline environment, the toxic ions $Na^+$ and $Cl^-$ might have interfere with the phloem loading, uptake of nutrients from roots to shoot etc. But when nutrients were supplied through leaves, the nutrient elements might have entered the system through the leaves and restricted the inhibition put forward by these toxic ions and reduced the salinity induced nutrient deficiencies in plants (Sultana *et al.,* 2001). In addition to this, plants also tried to reduce the salinity stress by adopting several mechanisms. From the results obtained, it was clear that at harvest stage sodium content was high in straw as compared to grain sodium content. This might have been due to the plant mechanism for keeping safe the progeny for next generation.

This type of mechanism for alleviating the soil salinity stress in plants is compartmentalization. The result obtained was in accordance with the findings of Reddy *et al.* (2017). He reported that salt tolerant varieties could maintain comparatively lower concentrations of salts in panicle and flag leaves. In the case of panicle, substantially lower salt concentration was found in grain as compared to rice husks and rachis. Sodium chloride was the most decisive salt that restricts the crop production in saline areas. Plant restricted the movement of these salts to young meristematic tissues and instead moved them to older leaves and leaf sheaths for alleviating the salinity damage to plants (Munns, 2002). Rice was also able to compartmentalize these toxic ions in older leaves and structural tissues. This enhanced the senescence of older leaves and maintained the younger leaves at low Na concentrations. The presence of large vacuole helped the older leaves to sequestrate higher concentrations of $Na^+$, $Cl^-$ and $NO^{3-}$ than young leaves (Wang *et al.*, 2012).

**5.4. Total nutrient uptake**

Nutrient uptake is the movement of nutrients from external environments such as soil or air in to the plant (Figure 5 and 6). Soil application and foliar application of different nutrient sources had some positive influence on uptake of N, P, K and Ca. Highest nitrogen uptake was observed for the treatment $T_8$ [lime @ 1000 kg $ha^{-1}$ + SOP (2% spray) at 20 and 40 DAT] with 67.07 kg $ha^{-1}$. Nutrients were absorbed from the root zone of crop in ionic forms, which was indirectly influenced by the soil acidity and nutrient concentration in the soil. Application of lime increased the soil pH and facilitated the uptake of more nitrogen by the crop (Kihanda *et al.,* 1999). Highest phosphorus uptake was observed for treatment $T_8$ followed by $T_5$ and $T_{10}$. In the case of potassium uptake also, these three treatments recorded the best results, which were on par with treatments $T_3$, $T_6$ and the above results are in agreement with the findings of Chang and Sung (2004), who reported that by reducing the toxic effects of Al in soil, liming enhanced the uptake of P and K. Similar trend was seen in case of calcium also. Higher calcium uptake was observed for the treatments $T_5$ and $T_{10}$ followed by $T_8$. The increased calcium content in the soil resulting from the lime application might have been the reason for its higher uptake from these treatments. Treatments did not show significant influence on the uptake of magnesium, sulphur and sodium.

**5.5. Productivity and nutrient interrelation**

Plant nutrient ratios were considered as indicators of salinity tolerance under saline environment. Among these ratios (Figure 7), Na/K and Na/Ca ratio were most important ones under such situations. From the results shown in Table 22, it was clear that control treatment acquired higher values for both these ratios during all crop growth stages. Treatments $T_8$ [lime @ 1000 kg $ha^{-1}$ + SOP (2% spray) at 20 DAT and

40 DAT] and $T_{10}$ [dolomite @1600 kg $ha^{-1}$ + SOP (2% spray) at 20 DAT and 40 DAT] registered lower values for both ratios during the critical stage of flowering. Results on yield and nutrient content indicated that these ratios played a great role in maintaining high yield. Therefore, it was essential to maintain a high K/Na ratio in plant tissues for better tolerance to salt stress (Maathuis and Amtmann 1999). Zhang *et al*. (2010) observed that application of supplemental calcium had a role in mitigating the toxic effects of sodium in saline soils by the replacement of displaced $Ca^{2+}$, thereby regaining the cell wall stability and plasma membrane integrity, maintaining higher K/Na ratio in plant tissues. This led to the enhanced salt tolerance in plants. An experiment conducted by Wu and Wang (2012) indicated that application of Calcium at low saline conditions reduced the $Na^{+}$ accumulation in roots and increased the $K^{+}$ accumulation in shoots. However, there was no effect on sodium and potassium accumulation in plant tissues under high saline conditions. Therefore, it was suggested to apply Ca under low salinity for regulating the K/Na homeostasis in plants. Ashraf *et al*. (2017) reported that addition of K as potassium sulfate nutrition in cotton plant at different levels of salinity reduced the Na accumulation in plant tissues, increased shoot $K^{+}$, $K^{+}$: $Na^{+}$ ratio and $Ca^{2+}$ and ultimately enhanced the yield attributes and fiber quality.

A critical and detailed evaluation of the direct and indirect effect of nutrients would help to explain the yield forming and yield negating processes inside the plant. A perusal of the data on correlation of Na/K ratio at different growth stages (20 DAT, 40 DAT, flowering and harvest) with yield showed that Na/K ratio at the flowering stage was the most critical one. So narrowing the ratio at this stage was found essential. For rice, early seedling growth and flowering were the most sensitive stages to salinity in rice. In *Pokkali*, early seedling stage is on the top of the mounds - a special method by which soil salinity is washed off and seedlings are protected from salinity. After transplanting, the ratio at flowering stage would be more critical.

At flowering, potassium (0.648*) phosphorus (0.864**) and calcium (0.482) content in rice were positively correlated with the grain yield (Table 24), while sodium content (-0.726*), Na/K ratio (-0.816**) and Na/Ca ratio (-0.640*) at flowering were negatively correlated with the grain yield. Among these ratios, higher Na/K ratio exhibited much more negative influence on the grain yield. This also showed that it was not the direct effect of plant nutrient content, but the effect of one element on the activity of other element which influenced the yield. Potassium and calcium by themselves had direct positive effects and sodium had direct negative effect, but more than that the ratio between Na and other cations like K and Ca influenced the crop yield significantly. And there existed a significantly positive correlation between Na/K ratio, Na/Ca ratio and sodium content in the plant. The significantly positive correlation between the calcium and potassium (0.716*) was found to be higher than the positive correlation between potassium and phosphorus (0.658*). Calcium content in rice had a significantly negative correlation with the Na/Ca ratio at flowering.

The correlation coefficients between Na/K ratio, yield attributes and grain yield are presented in the Table 25. Grain yield had significant positive correlation with number of panicles per $m^2$ (0.862**) and significant negative correlation with Na/K ratio at flowering (0.816**). Thousand grain weight was positively correlated to number of panicles per $m^2$ (0.646*). Na/K ratios at 40 DAT (-0.736*) and flowering (-0.903**) were negatively correlated with number of panicles per $m^2$. Out of these Na/K ratio at flowering was more negatively correlated with number of panicles per $m^2$. Thus the importance of Na/K ratio at flowering stage is understood from the results. So maintaining a low ratio at flowering could enhance the yield and productivity in *Pokkali* rice. .

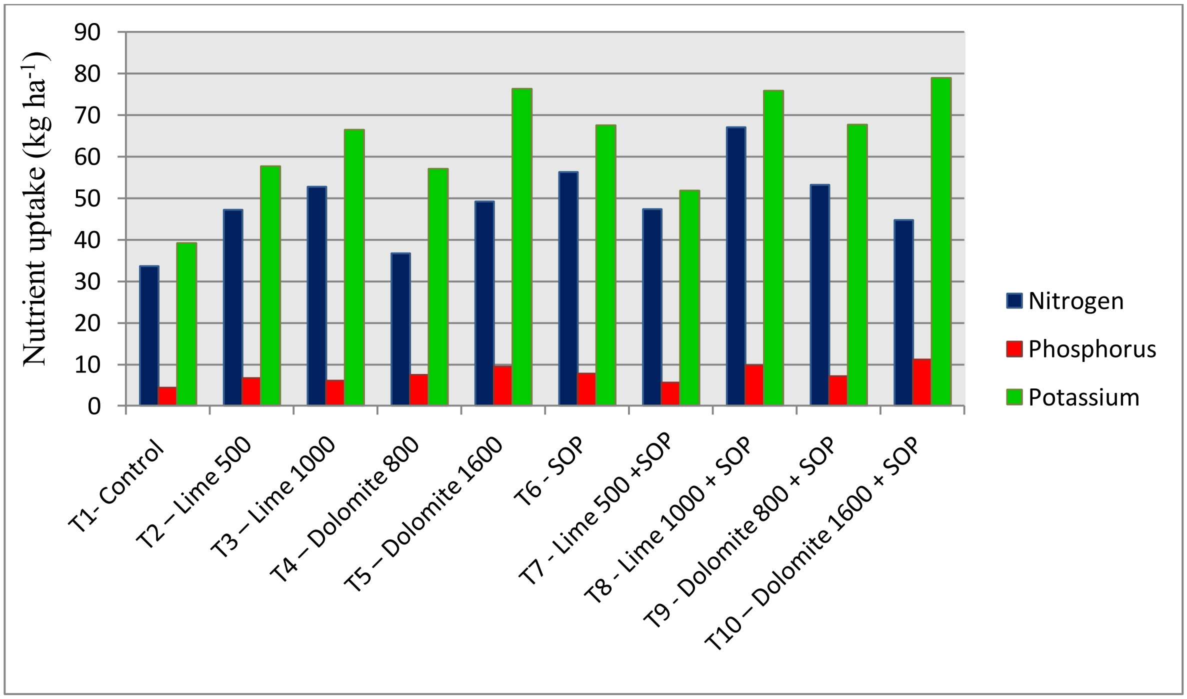



**Fig. 5 Effect of amelioration and foliar spray of SOP on uptake of N, P and K**

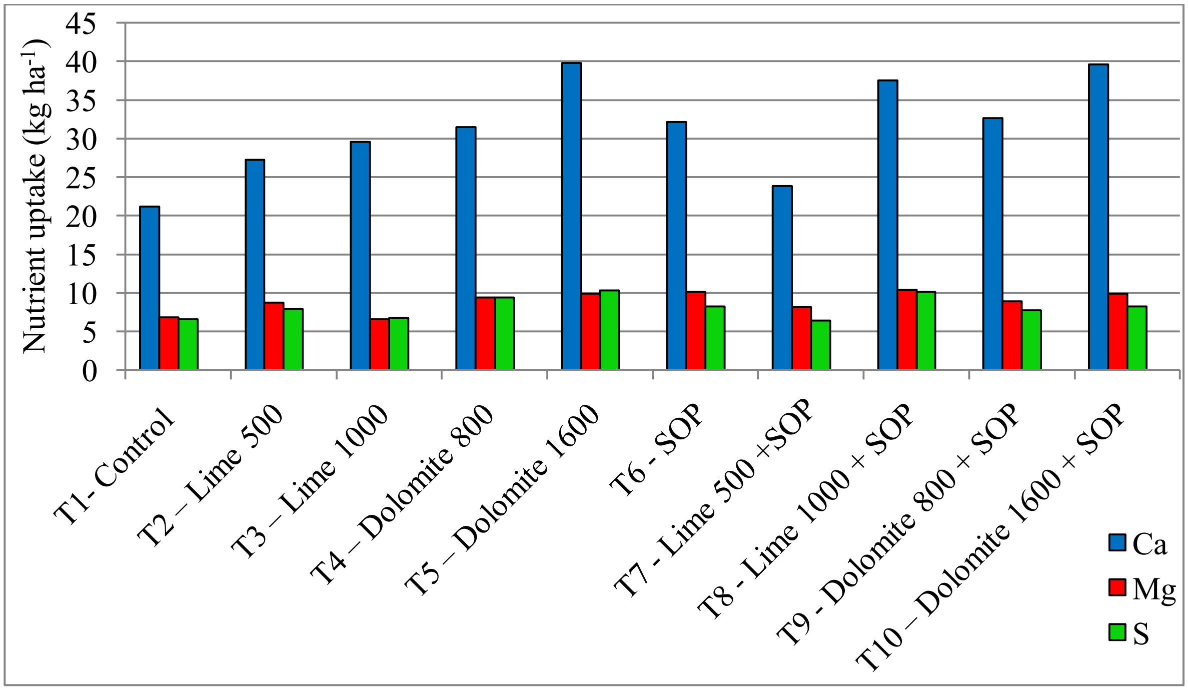



**Fig. 6 Effect of amelioration and foliar spray of SOP on uptake of Ca, Mg and S**

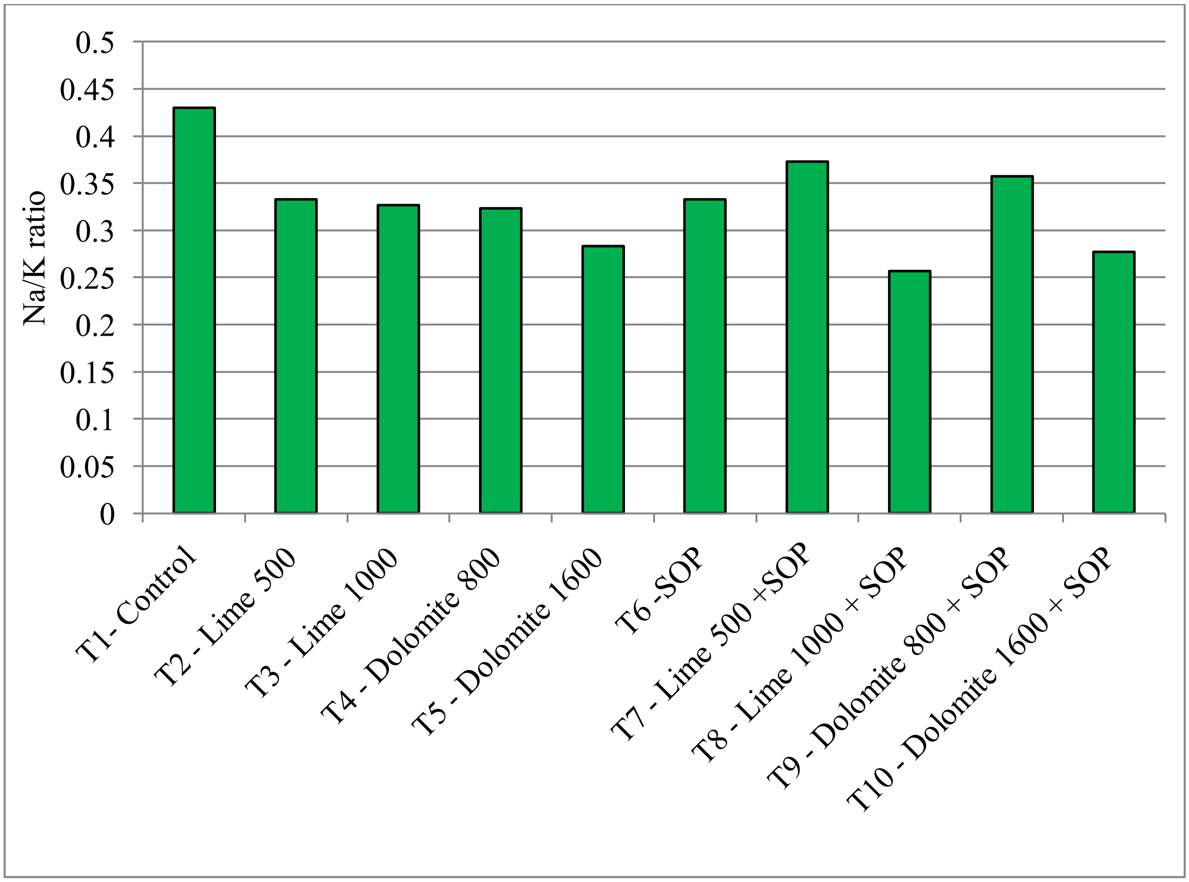



**Fig. 7 Effect of amelioration and foliar spray of SOP on Na/K ratio at flowering stage**

**Table 24. Correlation between plant nutrient content, Grain yield, Na/ K and Na/Ca ratios**

| | Yield | Na/K ratio at flowering | Na/Ca ratio at flowering | Nitrogen | Phosphorus | Potassium | Calcium | Magnesium | Sulphur | Sodium |
|---|---|---|---|---|---|---|---|---|---|---|
| **Yield** | 1.000 | | | | | | | | | |
| **Na/K ratio at flowering** | -0.816** | 1.000 | | | | | | | | |
| **Na/Ca at flowering** | -0.640* | 0.935** | 1.000 | | | | | | | |
| **Nitrogen** | 0.225 | 0.066 | 0.338 | 1.000 | | | | | | |
| **Phosphorus** | 0.864** | -0.665* | -0.566 | 0.245 | 1.000 | | | | | |
| **Potassium** | 0.648* | -0.574 | -0.492 | 0.001 | 0.658* | 1.000 | | | | |
| **Calcium** | 0.482 | -0.705* | -0.839** | -0.522 | 0.496 | 0.716* | 1.000 | | | |
| **Magnesium** | 0.494 | -0.331 | -0.243 | -0.021 | 0.327 | 0.494 | 0.253 | 1.000 | | |
| **Sulphur** | -0.449 | 0.416 | 0.368 | 0.116 | -0.249 | -0.435 | -0.451 | -0.275 | 1.000 | |
| **Sodium** | -0.726* | 0.943** | 0.899** | 0.061 | -0.554 | -0.276 | -0.539 | -0.191 | 0.302 | 1.000 |

**Table 25. Correlation between yield attributes, Na/K ratio and grain yield**

| | Yield | Na/K at 20 DAT | Na/K at 40 DAT | Na/K at flowering | Na/K ratio at harvest | Thousand grain weight | Grains per panicle | Percentage of filled grains | Number of panicles per $m^2$ |
|---|---|---|---|---|---|---|---|---|---|
| **Yield** | 1.000 | | | | | | | | |
| **Na/K at 20 DAT** | -0.427 | 1.000 | | | | | | | |
| **Na/K at 40 DAT** | -0.571 | 0.365 | 1.000 | | | | | | |
| **Na/K at flowering** | -0.816** | 0.533 | 0.535 | 1.000 | | | | | |
| **Na/K ratio at harvest** | -0.514 | 0.078 | 0.766** | 0.543 | 1.000 | | | | |
| **Thousand grain weight** | 0.611 | -0.171 | -0.488 | -0.577 | -0.598 | 1.000 | | | |
| **Grains per panicle** | 0.140 | -0.565 | -0.237 | -0.277 | -0.015 | 0.119 | 1.000 | | |
| **Percentage of filled grains** | -0.332 | -0.151 | -0.243 | 0.301 | -0.217 | -0.027 | -0.251 | 1.000 | |
| **Number of panicles per $m^2$** | 0.862** | -0.616 | -0.736* | -0.903** | -0.618 | 0.646* | 0.203 | -0.032 | 1.000 |

# *Summary*

# 6. SUMMARY

The research work entitled "Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice" was conducted at Rice Research Station, Vyttila with an objective to study the effect of narrowing the Na/K ratio by liming and foliar application of potassium in *Pokkali* rice. Field experiment was conducted with 10 treatments and three replications. Treatments included soil application of different levels of lime (500, 1000 kg $ha^{-1}$) or dolomite (800, 1600 kg $ha^{-1}$) alone, these treatments followed by foliar spray of sulphate of potash (SOP 2% at 20 and 40 DAT), foliar spray of SOP alone and a control (no amelioration, no foliar spray). Observations on biometric parameters were recorded periodically and soil and plant samples were analysed for primary and secondary nutrients. Major findings of experiment are furnished below:

1. Significant influence of treatments on the plant growth was evident from the results of the experiment. Application of higher dose of lime or dolomite followed by foliar spray of SOP resulted in taller plants with more number of tillers.
2. More number of panicles per $m^2$ and grain yield were observed in the treatment lime @ 1000 kg $ha^{-1}$ and 2 per cent foliar spray of sulphate of potash. Liming improved grains per panicle, but percentage of filled grains was more when supplemented with foliar spray.
3. The individual effect of dolomite on yield was higher than the individual effect of lime or foliar spray of SOP. The individual effect of foliar spray of K on yield was comparable with the individual application of lime @ 1000 kg $ha^{-1}$.
4. Economic returns were also found to be higher for treatment lime @ 1000 kg $ha^{-1}$ and 2 per cent foliar spray of SOP. Highest B: C ratio recorded in the field experiment was 1.84.

5. Soil amelioration with dolomite @1600 kg $ha^{-1}$ with or without foliar spray of K could significantly enhance the dry matter production and leaf area index and could result in a yield next to the best treatment.
6. In addition to the correction of soil acidity, application of lime and dolomite could improve the availability of calcium and magnesium in soil as well as enhance their uptake by the crop.
7. The correlation analysis of nutrient content during different growth stages showed that it was not the direct effect of plant nutrient content, but the effect of one element on the activity of other element which influenced the yield. Potassium and calcium by themselves had direct positive effects and sodium had direct negative effect, but more than that the ratio between Na and other cations like K and Ca influenced the crop yield significantly.
8. At flowering, potassium (0.648*) and calcium (0.482) content in rice were positively correlated with the grain yield, while sodium content (-0.726*), Na/K ratio (-0.816**) and Na/Ca ratio (-0.640*) were negatively correlated with the grain yield. Among these ratios, higher Na/K ratio exhibited much more negative influence on the grain yield.
9. In acid saline soils, higher Na/K ratio is considered as the major yield limiting factor. Treatments significantly influenced the plant Na/ K ratio at different stages of crop growth. Control treatment recorded highest Na/ K ratio at all the stages. This indicated that amelioration and foliar spray of SOP in the field had significant influence in reducing the plant Na/ K ratio.
10. A perusal of the data on correlation of Na/K ratio at different growth stages (20 DAT, 40 DAT, flowering and harvest) with yield showed that Na/K ratio at the flowering stage was the most critical one. So narrowing the ratio at this stage was found to be critical. Therefore, maintaining a low Na/K ratio during flowering stage benefitted the crop significantly.
11. Application of lime @ 1000 kg $ha^{-1}$ or dolomite @ 1600 kg $ha^{-1}$ + K (2% spray) at 20 and 40 DAT could narrow down the Na/K ratio at flowering stage and thereby increased the yield significantly.

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**REGULATION OF PLANT Na/K RATIO FOR PRODUCTIVITY ENHANCEMENT IN *POKKALI* RICE**

**By**

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# ABSTRACT OF THE THESIS

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## (AGRONOMY)

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**"Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice"**


## Abstract

*Pokkali* is a sustainable and unique rice farming system in coastal saline soils of Kerala. Salinity, submergence and high inherent acidity are the major issues underlying this special system of rice cultivation. In saline soils, higher Na content and the resultant high ratio between Na and other cations like K, Ca and Mg within the plant becomes detrimental for crop. Maintaining a low ratio of Na with other cations especially with K, is considered to be an yield determining and salt tolerance criterion in crops. Ameliorants containing sufficient amount of calcium inhibits the effect of soil acidity as well as soil salinity. As no response to soil application of nutrients is observed in *Pokkali* rice, foliar nutrition of K is expected to maintain nutritional balance within the plant. Hence the study was conducted with the objective to study the effect of the narrowing down of Na/K ratio in *Pokkali* rice by liming and foliar application of K.

The study entitled "Regulation of plant Na/K ratio for productivity enhancement in *Pokkali* rice" was conducted at Rice Research Station, Vyttila. VTL-8 was the variety used for the field experiment. Treatments included soil application of different levels of lime (500, 1000 kg $ha^{-1}$) or dolomite (800, 1600 kg $ha^{-1}$) alone and these treatments followed by foliar spray of sulphate of potash (2% SOP at 20 and 40 DAT). These treatments were compared with foliar spray of SOP alone and a control (no amelioration, no foliar spray). Various biometric observations, soil chemical characteristics and plant nutrient content were assessed during and after the field experiment. Crop duration was 137 days.

Both growth and yield parameters exhibited significant variation among treatments. Number of tillers per sq. m, number of panicles per sq. m, percentage of filled grains and grain yield (2975 kg $ha^{-1}$) were found to be higher for soil application of lime along with foliar spray of SOP at 20 and 40 DAT. Effect of dolomite @1600 kg $ha^{-1}$ on yield was higher than the effect of lime @ 500 or 1000 kg

$ha^{-1}$. Foliar spray of K resulted in comparable yield to that of lime @ 1000 kg $ha^{-1}$. Amelioration with dolomite @1600 kg $ha^{-1}$ with or without foliar spray could significantly enhance the dry matter production and leaf area index and could result in a yield next to the best treatment.

Liming influenced the plant nutrient content in *Pokkali* rice at various stages. Higher potassium, phosphorus and magnesium content were observed when applied with lime @1000 kg $ha^{-1}$+ K (2% spray) at 20 and 40 DAT. Higher calcium content was observed in plots treated with dolomite @ 1600 kg $ha^{-1}$.

In acid saline soils, higher Na/K ratio is considered as the major yield limiting factor. Treatments significantly influenced the plant Na/K ratio at different stages of crop growth. Control treatment recorded highest Na/K ratio at all the stages. This indicated that amelioration and foliar spray of SOP had significant influence in reducing the plant Na/ K ratio. Correlation analysis also showed that grain yield had significant negative correlation with Na/K ratio at 90 days after transplanting. This indicates that Na/K ratio at flowering stage is most critical. Application of lime @1000 kg $ha^{-1}$ or dolomite @ 1600 kg $ha^{-1}$ along with SOP (2% spray) at 20 and 40 DAT could narrow down the Na/K ratio at flowering stage and thereby increase the yield significantly. A reduction in soil pH was observed in these treatments at flowering stage.

In addition to the correction of soil acidity, application of lime and dolomite could improve the availability of calcium and magnesium content in soil as well as enhance their uptake by the crop. Economic returns were also found to be higher on application of lime @1000 kg $ha^{-1}$ and 2% foliar spray of SOP. Hence application of lime @1000kg $ha^{-1}$ and 2% foliar spray of SOP at 20 and 40 DAT can be recommended to increase the yield of *Pokkali* rice.