ACIDITY AMELIORATION AND NUTRIENT MANAGEMENT PRACTICES FOR MITIGATING YIELD CONSTRAINTS OF RICE IN VAIKOM KARI

by

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DECLARATION

I, hereby declare that this thesis entitled "**ACIDITY AMELIORATION AND NUTRIENT MANAGEMENT PRACTICES FOR MITIGATING YIELD CONSTRAINTS OF RICE IN VAIKOM KARI**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "**ACIDITY AMELIORATION AND NUTRIENT MANAGEMENT PRACTICES FOR MITIGATING YIELD CONSTRAINTS OF RICE IN VAIKOM KARI**" is a record of research work done independently by Mrs. Devi V.S. 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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LIST OF ABBREVIATIONS

a.i.	Active ingredient
Al	Aluminium
BCR	Benefit cost ratio
B	Boron
Cu	Copper
Ca	Calcium
CD	Critical difference
cm	Centimetre
DAS	Days after sowing
EC	Electrical conductivity
et al.	Co-workers/ Co-authers
FAO	Food and Agriculture Organization
Fe	Iron
Fig.	Figure
g	Gram
ha	Hectare
HI	Harvest index
K	Potassium
KAU	Kerala Agricultural University
Kg	Kilogram
Kg ha^{-1}	Kilogram per hectare
LAI	Leaf Area Index
MAP	Months after planning
m^{-2}	per square metre
mg kg^{-1}	Milligram per kilo gram
Mg	Magnesium
Mn	Manganese
MT	Maximum tillering
N	Nitrogen

Na	Sodium
NS	Not significant
P	Phosphorus
PI	Panicle Initiation
POP	Package of practices
RHA	Rice husk ash
S	Sulphur
SEm	Standard error of mean
t ha^{-1}	Tonnes per hectare
TDMP	Total dry matter production
TPF	Triphenylformazan
var.	Variety
viz.	Namely
Zn	Zinc

LIST OF SYMBOLS

@	At the rate of
$^{\circ}$C	Degree Celsius
%	Per cent
µg	microgram

Introduction

1. INTRODUCTION

Rice (*Oryza sativa* L.) is a widely grown crop the world over. It constitutes the staple food of about two-third of the global population. About 90% of the rice is cultivated and consumed in its homeland, Asia (Khush and Baenziger, 1996). In India, rice is the staple food for more than 50% of population with a production of 103.04 million tonnes from an area of 43.86 million ha (GoI, 2014). It is projected to have a demand – supply gap of 5 millon tonnes by the year 2016 and the only solution to overcome this is to increase productivity. In Kerala, where rice is the staple food, it is grown in an area of only 1.99 lakh ha with a production of 5.64 lakh tonnes which is less than $1/5^{th}$ of our demand emphasizing the need for increasing productivity.

Kuttanad is considered to be the rice bowl of Kerala with 16% of the total rice area and 30% of production in Kerala (GoK, 2014). Kuttanad has acquired the status of Globally Important Agricultural Heritage System (GIAHS) of Food and Agriculture Organization (FAO) in 2013. The farmers of Kuttanad have developed and mastered the marvellous system of below sea level cultivation over 150 years ago on lands that were 2.5 to 3 m below the sea level (Nair, 2015).The high productivity of Kuttanad soils is the major attraction for farmers to take up rice cultivation in the region. The average rice productivity in Kerala is only 2.5 t ha^{-1} whereas the farmers of Kuttanad can reap a productivity of 5 to 7 t ha^{-1}.

The geographical area of Kuttanad is distributed in and around Vembanad lake in Alappuzha, Kottayam and Pathanamthitta districts. It is a special agro-ecological unit delineated to represent the water logged land which lies 1-2 m below mean sea level. The climate is tropical humid monsoon (mean annual temperature 26.5°C and rainfall 26 cm). Millions of years ago, these lands were covered with forests with abundant marshy vegetation. In succeeding geological ages, Arabian Sea advanced and engulfed these lands. The areas remained submerged below the ground level and got silted up to varying heights both by alluvium from the rivers and by the marine sediments. The sediments and soils in these areas have vast organic deposits along with fossils of timber and shellfish at different depths. Hydromorphic soils, often underlain by potential acid sulphate sediments and unique hydrological conditions characterize the unit. The natural blending of land and water coupled with high fertility status of soil make this land–water system ideal for agricultural purpose, the most important one of which has been rice cultivation.

The land area of Kuttanad is divided into a large number of *padasekharams* each extending about 1000 ha surrounded by broad man-made bunds of mud and in some places, rubbles. The different *padasekharams* are separated from one another by canals and rivers. Rice is grown in *padasekharams* after pumping out water into the adjoining water ways. Coconut is grown in the earthen bunds in several places. For intensive rice cultivation, flooding and saline water intrusion have to be controlled for which Thottappally spillway was constructed in 1955 to control flooding and Thanneermukkam barrage in 1976 to prevent sea water intrusion during summer.

In Kuttanad, the major rice growing season is known as *puncha* season which is from September-October to December-January. When the monsoon subsides by September- October, the level of water drops and cultural operations for rice cultivation begin with strengthening of the bunds and pumping out water from individual *padasekharams.* Drainage of water after heavy monsoon showers helps in washing out of toxic elements in the field and then rice cultivation is undertaken in these fields.

Kuttanad soils are sub divided and named according to morphological conditions into *kayal, karappadam* and *kari*. Unlike *kayal* and *karappadam* soils of Kuttanad, *kari* soils extending to 9000 ha have a different genesis making it difficult for reaching high productivity. *Kari* soils are deep black in colour, heavy in texture, poorly aerated and ill drained. The name *kari* is derived from the deep black colour of soil where large mass of woody matter at various stages of decomposition occur embedded in these soils. The soils are affected by severe acidity and periodic saline water inundation with consequent accumulation of soluble salts. In these soils, free sulphuric acid is formed by oxidation of sulphur (S) compounds of organic residues or that accumulated in the soil from sea water by repeated inundation. The soils are low in available nutrient status. Besides, they contain toxic concentrations of iron (Fe), aluminium (Al) and unidentified toxic organic compounds (Chattopadhyay and Sidharthan, 1985).

The *kari* soils are located in the taluks of Vaikom and Kottayam of Kottayam district (Vaikom Kari) and Cherthala and Ambalapuzha of Alappuzha district (Purakad Kari). Vaikom Kari is facing severe yield limiting factors than Purakad Kari. They are black, peaty, heavy textured and acid sulphate soils. High acidity and nutrient disequilibria throughout the year and high salinity especially during the low rainfall condition constitute major limiting factors for successful rice cultivation in these soils.

In *kari* soils, the shallow water table with poor drainage enhances the problem of Fe and Al toxicity damaging the roots and hampering the nutrient uptake by plants which necessitates foliar nutrition at critical growth stages. The low pH combined with low aeration reduces the microbial activity in this soil affecting the availability of nutrients. The saline water intrusion during the summer causes high sodium (Na) in the soil which further aggravates the problem. Recently, poor grain filling and grain discolouration are found to be associated with high Na content in the soil. Besides, heavy chemical fertilizer application by farmers is causing nutrient imbalance in the soil. Wide spread deficiencies of magnesium (Mg) and boron (B) are reported.

To ameliorate soil acidity, liming is an important practice adopted in many parts of the world. Liming enhances the physical, chemical and biological properties of acid soils (Bolan, *et al.*, 2003). Burnt lime shell (calcium oxide) is the most common liming material used in Kerala. However, due to ecological constraints, its collection and extraction are restricted in many places and its availability is also limited leading to high cost. Dolomite (calcium magnesium carbonate), which is comparatively a cheaper liming material, imported from the neighbouring states, is also being used. Another potential liming material is rice husk ash (RHA), a waste product from rice mills, which is cheap and environment friendly. Hence it is necessitated to evaluate lime, dolomite and RHA as soil acidity ameliorants in *kari* soils for enhancing rice yield. Judicious application of NPK, foliar nutrition of N and K at critical stage through water soluble KNO_3 and alleviation of Mg and B deficiencies are to be experimented for improving the productivity of rice in k*ari* soils. Amelioration of soil acidity by liming, adoption of balanced nutrition and proper water management can substantially improve and sustain rice yield in the acid sulphate soils of Vaikom Kari. Hence the present study was undertaken with the following objectives:

- To standardize acidity amelioration practices for addressing yield constraints in Vaikom Kari
- To standardize nutrient management practices for addressing yield constraints in Vaikom Kari
- To work out the economics of cultivation.

Review of Literature

2. REVIEW OF LITERATURE

The present investigation entitled "Acidity amelioration and nutrient management practices for mitigating yield constraints of rice in Vaikom Kari" was undertaken to standardize acidity amelioration and nutrient management practices for rice to overcome yield constraints in Vaikom Kari and to work out the economics of cultivation. Hence relevant literature on nutrient stress for rice in acid soil, effect of acidity ameliorants such as lime, dolomite and RHA on soil properties and growth and yield characters of rice, effect of salinity on rice and nutrient management of rice in acid soil are reviewed in this chapter.

2.1 NUTRIENT STRESS FOR RICE IN ACID SOIL

Soil acidity causes nutrient stress to rice and is a main barrier to rice production (Mandal *et al*., 2004). Acidity causes nutrient stress since availability of most of the nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), Sulphur (S), Copper (Cu) and Boron (B) is optimized between pH 5.5 and 7. Some of the nutrients such as Al, Fe, Manganese (Mn) and Zinc (Zn) are more available at a lower pH and when the pH goes below 5.0, these nutrients become more soluble and accumulate in toxic concentrations in the rhizosphere. Nutrients such as Ca and Mo are available at pH above 7.0 (Rajput, 2012). Hence nutrient stress for rice in acid soils includes toxicities of Fe, Al and H_2S and deficiencies of N, P, K, Ca, Mg, Zn and B. Low soil pH and resultant problems like Fe toxicity and low availability of other nutrients are the most important soil related yield limiting factors in rice soils of Kerala (Moossa *et al*., 2012).

Mineralization of soil organic N is generally dependent on the pH of the environment (Harmsen and Van Schreven, 1955; Alexander, 1977). Padmaja *et al.* (1994) reported that low pH and anaerobic soil conditions were not congenial for the existence and multiplication of beneficial microorganisms resulting in low availability of nutrients to plants.

In acid soils, P becomes immobile and unavailable to plants due to low pH and dominance of active forms of Al and Fe (Dixit, 2006). Fixation of P by Fe and Al sesquioxides is a consequence of extreme soil acidity (Audebert and Sahrawat, 2000). When pH is increased, the proportion of the divalent phosphate ion (HPO_4^{2-}) is also increased (Barrow, 1984).

In acid sulphate soils, K deficiency is associated with the formation of the sulphide mineral oxidation product jarosite, which acts as an infinite sink for K in the upper sulphuric horizon, and reduces available K for plant growth (Keene *et al.*, 2004).

Soil acidity leads to the decline in basic cations, such as Ca and Mg, causing their deficiency for plant growth. In acid soils, most of the Ca exists in soluble form, but both soluble and exchangeable Ca decreases with decreasing soil pH. Furthermore at low pH, the bioavailability of Ca is reduced by high concentration of Al (Haynes and Ludecke, 1981). The uptake of Mg is strongly influenced by the availability of other cations like NH_4, Ca and K (Fageria, 2001; Romheld and Kirkby, 2007). Ca, Mg, and K compete with each other and the addition of any one of them will reduce the uptake of the other two (Malvi, 2011).

High S content can lead to the production of sulphides and organic acids in submerged rice soils that may cause toxicity to rice plants as substantiated by Yoshida (1981) and Sahrawat (2005). Bell and Dell (2008) found that in submerged soil, the availability of S was limited by the slower mineralization of organically bound S and shallow root system. Low redox potential of submerged soil also caused reduction of sulphates to sulphides, some of which were toxic (H_2S) and others low in solubility (FeS and ZnS). Accumulation of excess hydrogen sulphide on root surface decreased root respiration and caused reduced nutrient uptake and deficiencies of K, P, Ca or Mg in the soil. According to Ramasamy (2014), toxicity of sulphide occurs in well-drained sandy soils with low active Fe, degraded paddy soils with low active Fe, poorly drained organic soils and acid sulphate soils. Concentration of S in rice plant after 60 days of growth period as well as in straw and grain at harvest were significantly reduced due to liming (Karan *et al.*, 2014).

The critical Fe concentration in the soil varied with the pH and was about 100 ppm at pH 3.7 and 300 ppm or higher at pH 5.0 (Takagi, 1960; Tanaka and Park, 1966). Usually Fe is present in soil as oxidised Fe^{3+} and reduced Fe^{2+} forms. Under aerated condition, Fe^{3+} predominates and under reduced or submerged condition, Fe^{2+} is the dominant one. As reported by Romheld and Marschner (1983), Fe^{2+} is the favourite species taken up by plants and Fe that is present as Fe^{3+} has to be reduced at root surface to Fe^{2+} for uptake by the plant.

Iron toxicity is a yield-limiting factor in wetland rice. Fe toxicity occurs in soils derived from acidic parent material like acid igneous rocks in Kerala soil which are high in Fe and Al sesquioxides. It occurs when the rice plant accumulates Fe in its leaves resulting from high concentration of Fe^{2+}iron in the soil solution (Ponnamperuma, 1972). The Fe content of the rice root of the order of 50,000 ppm under submerged conditions was found to inhibit morphological and physiological development of rice as evidenced by very few long roots, low root weight, root damage, fewer tillers and low dry matter leading to low yield (Bridgit *et al.*, 1993; Bridgit, 1999; Bridgit and Potty, 2002). Majumder *et al.* (1995) also reported stunted growth, extremely limited tillering, extended vegetative period, increased spikelet sterility and reduced grain yield in rice due to Fe toxicity.

Iron toxicity is related to multiple-nutritional stress which leads to reduced root oxidation power. High concentration of Fe in the soil solution decreases the absorption of other nutrients such as P and K (Yoshida, 1981). Fe toxicity creates a range of nutrient disorders and deficiencies of P, K, Ca, Mg, Mn and Zn in plants (Ottow *et al.*, 1983; Yamauchi, 1989; Sahrawat *et al.*, 1996). High Fe in the soil suppresses Cu absorption by rice (Tisdale *et al.*, 1993; Das, 2014).

In acid soils below pH 5, Al^{3+} is dominant and is solubilized into a phytotoxic form (Matsumoto, 2000). According to Rout *et al.*, (2001), Al toxicity is an important growth-limiting factor for plants in many acid soils, particularly at pH < 5. In highly acidic organic soils (pH <4), the major yield limiting constraint is considered to be Al toxicity or P deficiency (Kidd and Proctor, 2001). In soils poor in base saturation and Ca and Mg, Al toxicity is most severe (Vitorello *et al.*, 2005), thereby leading to a reduction in rice yield. Severe inhibition of root growth is the major direct effect of Al toxicity on plants which generally restricts water and nutrient uptake leading to poor growth. Al toxicity also inhibits shoot growth by inducing nutrient (Mg, Ca and P) deficiencies, drought stress and hormonal imbalances. Aluminium stress caused an increase in root and shoot Al content being greater in Al sensitive rice varieties than in Al resistant cultivars at high Al doses of 1000 and 1500 μM (Macedo and Jan, 2008). The Ca and P contents were found to be low in rice shoot in Al sensitive cultivars. Aluminium decreased Ca, P, K, Mg and Mn concentrations in shoot and K, Mg and Mn concentrations in root. Famoso *et al.* (2010) studied the effect of Al on the root growth of emerging rice seedling of rice cultivar NSF_4 and found that under normal as well as toxic Al concentrations, the root length was similar but the total root volume was less under toxic concentration. Toxic levels of Al in nutrient solution significantly decreased seedling root growth, number of primary roots, seedling shoot length, number of leaves seedling^{-1}, seedling fresh weight, and seedling dry weight (Roy and Bhadra, 2014).

Among cereals, rice 6 to 10 times more tolerant to Al toxicity (Foy, 1988; Famoso *et al.*, 2010). The tolerance mechanism includes Al stress avoidance and tolerance. Al toxicity is avoided by exclusion of Al from sensitive sites or reduced Al^{3+} activity in the rhizosphere by organic acids excreted by rice roots that chelate Al^{3+} into non - toxic immobile forms. Of the organic acids, citrate has the highest binding activity for Al followed by oxalate, malate and succinate. Aluminium stress tolerance is due to high tissue tolerance of Al where Al is immobilized into non- toxic forms followed by sequestration of Al into the vacuoles in the plant tissue (Shamshuddin *et al.,* 2013).

2.1.1 Nutrient Stress in *Kari* Soil

Kari soils are acid sulphate soils with high organic matter (10 to 30%), deep black in colour and extremely acidic (pH of 3 to 4.5) with toxicities of Fe, Al and S (Thampatti, 1997). Earlier workers (Kabeerathumma and Nair, 1973; Marykutty and Aiyer, 1987) have reported a much higher content of exchangeable Al^{3+}, exchangeable H^+ and exchangeable acidity in *kari* soils. The increase in acidity, on exposure of soils to air, is a character exhibited by most of the soils of Kuttanad and the toxic subsoil layer is a source of acid salts that can enter the permeable layer with the rise of ground water.

Though *kari* soils are rich in organic carbon content, the available N is usually deficient due to the poor microbial activity (Koruth *et al.*, 2013). *Kari* soils are generally low in P. This is mainly due to the fixation of P by hydroxides of Fe and Al. The available K content in *kari* soils was found to be deficient (Nair and Money, 1972; Money and Sukumaran, 1973). High acidity in spite of large accumulation of lime shells are some of the peculiar characteristics of the *kari* soils (Nair and Iyer, 1948; Subramoney, 1958 and 1959; Money, 1961; Money and Sukumaran, 1973; Chattopadhyay and Sidharthan, 1985). According to Koruth *et al.* (2013), S is adequate in 96% of Kuttanad soils as most of these soils being high in S content. *Kari* soils contain more total S than the other two types *viz. kayal* and *karappadam* soils of Kuttanad. The available S content of *karappadarm, kayal* and *kari* soils were in the range of 20 to 208, 233 to 481 and 571 to 1500 ppm respectively as observed by Hegde *et al.* (1980). According to Mathew (1989), the S content varied from 4950 to 30000 ppm. The high sulphate content of Kuttanad soils is not reduced markedly due to submergence and hence, it does not exhibit S toxicity (Kuruvila and Patnaik, 1994). The high organic matter content of *kari* soils lead to chelation of Cu, restricting its availability. The deficiency of B in *kari* soils was reported by Sasidharan and Ambikadevi (2013). Koruth *et al.* (2013) also reported widespread B deficiency in Kuttanad soils (AEU 4) which needs application of B on soil test basis.

2.2 EFFECT OF ACIDITY AMELIORANTS ON RICE

Liming is the most common practice for amelioration of acid soils. The commonly used liming materials are lime stone - $CaCO_3$, and dolomite -$CaMg(CO_3)_2$. Agricultural by-products like RHA can also be used for ameliorating soil acidity.

2.2.1 Lime

2.2.1.1 Effect on Soil Physico-Chemical Properties

Lime increased soil pH and improved crop growth in direct seeded rice systems (Moschler *et al.*, 1973; Arshad and Gill, 1996). Marykutty (1986) reported that application of lime increased soil pH in four major soil types *viz.* lateritic alluvium, *kole*, *pokkali* and *kari* soils. Lime application can enhance soil biological processes and subsequent release of organically derived CO_2 by decomposition of organic matter in acid soils (Biasi *et al.*, 2008; Tamir *et al.*, 2011). Ono (2012) opined that application of $CaCO_3$ was not able to release the organic matter in soil when the soil pH was < 7.

Liming with CaO or Ca $(OH)_2$ was reported to promote N mineralization in flooded soil much more than $CaCO_3$ (Harada 1959). Borthakur and Mazumder (1968) observed that N mineralization in flooded soils was not influenced by the application of $CaCO_3$ but was enhanced in non flooded soils. Available N and P were found to increase while K decreased upon application of lime in lateritic alluvium, *kole*, *pokkali* and *kari* soils as reported by Marykutty (1986).

Condron and Goh (1989) attributed decline in organic P in the top 7.5 cm soil layer between 1971 and 1974 to increased mineralization as a result of liming in 1972. Liming may caused the precipitation of P as calcium phosphate and increased P retention as pH approaches 7.0 (Naidu *et al.*, 1990). Liming might accelerate the rate of organic P mineralization due to increased rates of microbial activity. It is generally known that liming and reduction in soil acidity increase P availability, but too high lime can lead to P fixation (Rahman *et al.*, 2002). Bolan *et al.* (2003) suggested that, once pH is high enough (>5) to eliminate Al or Mn toxicity, liming will neither have a large nor consistent effect on the efficiency of utilization of soil or applied P. Rastija *et al.* (2014) found that the available P content in the acid soil was considerably improved by liming, significantly lower concentrations of P was observed in grains of plants suffering from P deficiency because grain P levels in rice typically reflect soil P status (Rose, *et al.*, 2016; Vandamme *et al.*, 2016).

The increased concentration of Ca in soil solution affects the adsorption of cations, such as K, as found by Goedert *et al.* (1975) and Galindo and Bingham (1977). In laboratory studies, the concentration of K in soil solution decreased after liming due to increased K adsorption (Curtin and Smillie, 1983). Increase in CEC due to liming could alter the equilibrium between soil solution K and exchangeable K and remove Al from exchange sites as there is competition of Ca from lime for exchange sites with Al. Adequate levels of Ca also assist in K or Na selectivity or may also directly suppress Na. Marykutty (1986) found an increase in exchangeable Ca and Mg and decrease in exchangeable H and Al in lateritic alluvium, *kole, pokkali* and *kari* soils of rice due to lime application. The ratio of Ca to K in soil solution can increase substantially when soil is limed (Curtin and Smillie, 1995). Since liming increases the concentration of Ca in soil solution, the adsorption of cations, such as K, can be affected (Bolan, 2003).

Lime application decreases extractable Al^{3+} in direct seeded rice systems (Moschler *et al.*, 1973; Wildey, 2003). Deficiency of Ca triggers Al toxicity in plants whereas addition of Ca alleviates Al toxicity (Rout *et al.,* 2001; Rengel and Zhang, 2003). The Ca uptake and translocation in plants in acid soils (pH < 5.5) are affected by Ca-Al interactions (Mossor-Pietraszewska, 2001). Watanabe and Osaki (2002) and Silva *et al.* (2005) have shown that excess Al in soil competes or inhibits Ca and/or Mg absorption capacity and affects normal plant development. The Ca-Al relation is strongly associated with growth and development in a wide variety of plants (Schaberg *et al.,* 2006). Merino *et al.* (2010) reported that Ca plays a fundamental role in the amelioration of pH and Al toxicity and improving physiological and biochemical processes in plants through Al-Ca interactions.

Magnesium plays a major role in activating a large number of enzymes and thus has an important role in numerous physiological and biochemical processes affecting plant growth and development (Bose *et al.*, 2011). The uptake of Mg is strongly influenced by the availability of other cations like NH_4, Ca and K (Fageria, 2001; Romheld and Kirkby, 2007). Generally, the binding strengths of K and Ca are much stronger than Mg and they easily out-compete Mg at exchange sites (Malvi, 2011). High K and Ca result in lower Mg availability to plant roots (Chao *et al.*, 2011; Sun *et al.*, 2013). Excess Al also inhibits Mg absorption by plants (Kinraide *et al.*, 2004; Chen and Ma, 2013). Mg can also ameliorate Al phytotoxicity possibly through over-expression of Mg-dependent mechanisms that alleviate Al toxicity in plants. Inhibition of plant growth and development by many toxic heavy metal ions and Al can be reduced by addition of Mg (Guoa *et al.*, 2016).

Karan *et al.* (2014) reported that liming at the rate of 2 t ha^{-1} significantly decreased S concentration in alluvial soil. Concentration of S in rice plant after 60 days of growth period as well as in straw and grain at harvest were also significantly reduced due to liming.

2.2.1.2 Effect on Growth and Yield of Rice

Marykutty (1986) observed significant increase in the growth and yield characters of rice due to lime application. Rice yields may benefit from low to moderate rates of lime application to soils with pH < 5.0 (Ntamatungiro *et al.*, 1999). Aslam *et al.* (2002) reported improved growth characteristics (tillering capacity, shoot and root lengths, shoot and root weights) in rice because of external supply of Ca as $Ca(NO3)_2$ @ 20 to 40 μg Ca mL^{-1} in solution culture in the presence of NaCl salinity. Field application of 200 kg Ca ha^{-1} as $Ca(NO_3)_2$ also resulted in higher rice yield in salt affected field. Seed setting was also improved in rice by external Ca supply to saline and saline sodic soils. According to Santhosh (2013), the amelioration of soil acidity and multi nutritional deficiencies with the application of lime ($CaCO_3$) @600 kg ha^{-1} resulted in increased rice yield.

2.2.2 Dolomite

2.2.2.1 Effect on Soil Physico-Chemical Properties

Application of dolomite (56% CaO and 40% MgO) raised pH values and available P in rice soils (Rahman *et al.*, 2002). Sukristiyonubowo *et al.* (2011) reported that the addition of 2 t ha^{-1} of dolomite, 2 t ha^{-1} of compost made from rice straw and NPK fertilizer reduced high content of Fe and Mn in the newly opened wetland rice soil and improved total N, available P, potential P and potential K and also had a positive residual effect. Shamshuddin *et al.* (2013) recommended the application of ground Mg lime stone for rice in acid sulphate soil to reduce soil acidity and Al^{3+} and Fe^{2+} toxicity. According to Rastija *et al.* (2014), liming with dolomite considerably affected soil chemical properties and raised pH value. Application of dolomite raised the P availability by 8% in the P rich soils and 45% in low P soils. Suriyagoda *et al.* (2016) found that in lowland rice fields affected by Fe^{2+} toxicity, the application of dolomite reduced the negative impacts of Fe^{2+} toxicity with a greater response by the Fe^{2+} susceptible rice variety than by the tolerant variety.

2.2.2.2 Effect on Growth and Yield of Rice

Application of dolomite improved grain yield in rice (Rahman *et al.*, 2002). Biswas *et al.* (2013) also reported a significant increase in grain and straw yield of rice in Mg deficient soils by Mg application in the form of $MgSO_4$, magnesite or dolomite. Application of dolomite to lowland rice fields affected by Fe^{2+} toxicity increased grain yield, plant height and shoot and root dry weight (Suriyagoda *et al.*, 2016).

2.2.3 Rice Husk Ash

Rice husk is an agricultural residue which accounts for 20% of the 649.7 million tonnes of rice produced annually worldwide. On an average, 50% of the rice hull obtained is used as fuel in rice mills, hotels, and brick-making industries in south

India. Okon *et al.* (2005) opined that RHA could be recommended as an invaluable, environment friendly, cheap and low-input material for amending soil acidity. The nutrient content in RHA from various sources found to vary and they ranged from 0.72 to 3.84% K_2O and 0.23 to 1.59% MgO (Muthadhi *et al.*, 2007) whereas 0.01 to 2.69% P_2O_5 and 0.1 to 2.54% K_2O and pH from 8.1 to 11 (Bronzeoak Ltd., 2003). Priyadharshini and Seran (2009) established the presence of reasonable quantities of Ca, Mg, K, Na and other essential elements including P in RHA. They found 1.31% K_2O and 0.66% P_2O_5 in RHA upon nutrient analysis. According to Milla, *et al.* (2013), RHA contains a high content of Si and K which have great potential for amending soil. Moghadam and Heidarzadeh (2014) noticed 80% Si content in RHA. According to Subrahmanyam *et al.* (2015), RHA is a great environment threat causing damage to the land and the surrounding area in which it is dumped. Utilization of RHA for ameliorating soil acidity will reduce the environmental pollution caused by it.

2.2.3.1 Effect on Soil Physico-Chemical Properties

Improved aeration in crop root zone and enhanced exchangeable K and Mg were reported due to RHA application (AICOAF, 2001). A study on response of RHA application on groundnut in acid soil by Nottidge *et al.* (2009) showed an increase in soil pH from initial value of 5.16 to 6.2 while levels of exchangeable acidity correspondingly decreased from initial value of 0.8 to 0.26 c mol kg^{-1}. Their analysis showed alkaline nature of the RHA with a pH of 10.86. Ogbe *et al.* (2015) reported that the application of RHA @ 6 t ha^{-1} improved the physical and chemical properties *viz.* increased soil pH, total porosity, organic matter, exchangeable bases and cation exchange capacity of the soil and decreased bulk density and electrical conductivity.

2.2.3.2 Effect on Growth and Yield of Rice

According to Amarasiri (1978), application of 740 kg RHA ha^{-1} gave an additional rice yield of 1.0–1.4 t ha^{-1}. Application of RHA @ 2 t ha^{-1} resulted in higher grain and straw yield of paddy in acid soils (Prakash *et al.*, 2007). Gypsum and rice-husk-charcoal increased grain yield in tsunami-affected rice fields whereas dolomite and cinnamon ash had no significant effect (Reichenauer *et al*., 2009). Growth and biomass production in rice was found to be improved by addition of 2 t ha^{-1} dolomite, 2 t ha^{-1} compost made from rice straw and NPK fertilizer (Sukristiyonubowo *et al*., 2011).

Since rice has high requirement of Si for growth, its deficiency leads to yield reductions (Ma *et al*., 1989). Removal of plant-available Si in the soil, where rice is grown, may contribute to declining or stagnating yield (Savant *et al.,* 1997). Addition of Si, though not considered as essential for growth and development, can enhance the growth and yield of rice (Savant *et al.,* 1997). They also observed a decrease in disease incidence as well as inhibition of Fe, Al, and Mn toxicities by adequate supply of Si to the rice crop. Asch *et al*., (1999) found that though rice-husk-charcoal, which contains no Ca but high amounts of Si, led to a significant increase in straw biomass and a significant decrease of unfilled ears in salt affected rice crop. Desplanques *et al*. (2006) reported that substantial amounts of Si are removed by each harvest, thus reducing the amount of bio-available Si. So application of RHA, which is rich in Si will not only ameliorate soil acidity but also supplies Si to the rice crop.

2.3 EFFECT OF SALINITY ON RICE

Soil salinity due to sea water intrusion is a recurring problem in Kuttanad soil. According to Maas and Hoffman (1977), rice is moderately sensitive to salinity. In saline environment, plants take up excessive amounts of Na at the cost of K and Ca (Kuiper, 1984). But it was also reported that Ca reduces the permeability of root cell membrane to Na, resulting in decreased Na uptake by rice. Swarup (1985) explained that while Cl^- ions are very mobile in soils and plants, Na^+ adhere to cation binding sites of the soil expressed by the exchangeable sodium percentage and can lead to an imbalance of nutrient uptake and a decrease in yield. Elevated salt concentrations were shown to lead to a reduction in the yield of irrigated rice plants (Marschner 1995; Asch *et al*., 2000). In salt affected rice field, Si deficiency can increase transpiration losses (Dobermann and Fairhurst, 2000) which potentially could increase salt stress by increasing Na uptake via the transpiration stream (Asch *et al*., 1995;

Asch and Wopereis, 2001). Salt stress affected irrigated rice plants by decreasing germination rate, biomass production and seed set and by increasing sterility (Asch and Wopereis 2001; Sultana *et al.*, 2001).

According to Maathuis and Amtmann (1999), the similar physic - chemical structures of Na and K leads to competition of Na at transport sites for K that may result in K deficiency. Asch *et al.* (2000) reported a highly significant correlation between K/Na_{Leaves} and salinity-induced grain yield reduction. Kuttanad soils recorded high Na content in the surface samples and the values ranged from 288 to 4188 mg kg^{-1} (Beena, 2005). Hence K/Na_{Leaves} can be taken as an indicator of yield reduction due to salinity.Plants will preferentially take up Na in place of K at higher levels of Na. Plants use both low and high affinity systems for K uptake. Under Na stress, plants operate the more selective high-affinity K uptake system to ensure adequate K nutrition. K deficiency inevitably leads to growth inhibition because it plays a critical role in maintaining cell turgor, membrane potential and enzyme activities. The activities of many enzymes in the cytoplasm are inhibited by Na depending on how much K is present and higher Na/K ratio, more the damage (Malvi, 2011).

Increased Ca supply has a protective effect on plants under Na stress. Dobermann and Fairhurst (2000) suggested that Na can be displaced by addition of soil amendments containing large quantities of Ca not only from cation exchange sites in the soil but also at binding sites in biomolecules followed by flushing the soil to remove the Na^+ ions. Aslam *et al.* (2002) reported that shoot Na^+ and Cl^- decreased whereas, K^+ concentration and K^+ / Na^+ ratio improved because of Ca supply in saline soil conditions. The ameliorative effect of Ca was due to reduced shoot Na^+ and Cl^- concentration and better ratio of K^+ / Na^+ in shoot.

2.4 NUTRIENT MANAGEMENT OF RICE IN ACID SOILS

Even though Kuttanad soils have a high organic carbon status, available N is not adequate which necessitates application of 100% of the recommended dose of N (Koruth *et al.*, 2013). High P content in 61% of soil samples analysed and medium in 22% samples indicated the necessity for soil test based P application in Kuttanad soils to avoid nutrient imbalance (Koruth *et al.,* 2013). The content of K is medium to high because of continuous straw recycling due to the use of combined harvester resulting in enrichment of K in rice fields in Kuttanad. Hence under such situation, Koruth (2007) suggested to apply K @ 15 kg ha^{-1} instead of the general recommendation of 45 kg ha^{-1}.

Available Ca and Mg is deficient in Kuttanad soils where application of liming material will provide Ca and deficiency of Mg can be corrected by basal application of Mg as magnesium sulphate (16% MgO) or magnesite (40% MgO) or dolomite (10% MgO) (Koruth *et al.*, 2013). Biswas *et al.* (2013) also reported a significant increase in grain and straw yield of rice in Mg deficient soils by Mg application.

Ottow *et al.* (1991) and Benckiser *et al.* (1984) suggested that Fe toxicity is a result of multiple nutrient stresses and that the application of nutrients can reduce Fe toxicity. According to Benckiser *et al.* (1984), application of K and Ca and Mg alone or in combination decreased the uptake of Fe compared to the control. Addition of lime alone decreased Fe and Mn uptake at all growth stages. The application of lime + K followed by NPK + lime and NPK + Mn reduced the Fe content more effectively. The straw Fe content decreased with plant growth and was almost half of that of the straw. Though the Fe content in plant and soil was low, higher dry matter production resulted in higher Fe uptake with NPK application at all growth stages. They also reported a decrease in Mn content with crop growth and addition of Mn to the soil increased Mn content in the plant at all growth stages. The application of other nutrient amendments, however, decreased the plant Mn, including the grain. The maximum decrease in Mn was observed with the application of lime alone, followed by NPK + lime, NPK or K alone. The grain content of Mn was much smaller than the straw content and varied between 42 and 60 mg kg^{-1}.

Chelation of micronutrients with insoluble organic matter reduces the nutrient availability. In peat soils, acute Cu deficiency is due to formation of complexes of Cu with insoluble humic acids (Sanyal and Majumdar, 2009). The high organic matter content of *kari* soils leads to chelation of Cu restricting its availability. Application of

$CuSO_4.5H_2O$ @ 2 kg ha^{-1} or seedling dip in 1% $CuSO_4$ solution or soaking of seeds in 0.25% $CuSO_4$ solution is recommended for correcting the deficiency of Cu in Kuttanad soil (KAU, 2011).

Mukhopadhyay *et al.* (2008) reported the superiority of soil test based fertilizer application over the existing POP in respect of yield, quality and economic parameters of rice. Santhosh (2013) has observed that application of lime @ 600 kg ha^{-1}, full dose of NPK and $MgSO_4$, improved rice yield (7 t ha^{-1}) substantially.

2.4.1 Boron Nutrition in Rice

Improvement in growth and yield of rice due to B nutrition was reported by Rerkasem *et al.* (1993) and Rashid *et al.* (2009). According to Mottonen *et al.* (2001), an increase in number of root tips and mycorrhiza induced by B leads to improved water uptake in plants. Adequate B supply may also help maintain the assimilate supply to the developing grains (Dixit *et al.*, 2002). B is responsible for better pollination, seed setting and grain formation in different rice varieties (Aslam *et al.*, 2002; Rehman *et al.*, 2012), making it more important during the reproductive stage as compared to the vegetative stage of the crop. Like K, B is also involved in some aspects of flowering and fruiting processes, pollen germination, cell division, nitrogen metabolism, carbohydrate metabolism, active salt absorption, hormone movement and action, water metabolism and the water relations in plants. It has been shown that an optimal level of B increases K permeability in the cell membrane (Malvi, 2011). Increases in B concentration in limed soils are attributed to the increase in pH on liming.

Boron deficiency is spreading in most of rice growing soils. Though rice is considered to be tolerant to B deficiency it is found to cause substantial yield loss in many cases (Cakmak and Romheld, 1997; Rashid *et al.*, 2009). According to Longbin *et al.* (2000), reproductive stage of plants is more sensitive to B deficiency than the vegetative stage. According to Sasidharan and Ambikadevi (2013), *kari* soils were deficient in B (0.21 to 0.3 mg kg^{-1}). Koruth *et al.* (2013) also reported widespread B deficiency in Kuttanad soils which needs application of B on soil test basis.

Boron deficiency decreases the growth of pollen tube and fertilization thus causing failure of grain setting (Rerkasem *et al.*, 1993). B application at the rate of 0.5 to 2.5 kg/ha in B deficient soils of eastern and northern India showed better responses of cereals including rice (Savithri *et al.*, 1999). Application of B, to soils low in B, increased rice growth and yield (Rashid *et al.*, 2009; Hussain *et al.*, 2012) by ensuring grain setting as indicated by decrease in panicle sterility. As a result of B deficiency, low water status of panicle during anthesis as one of the reasons of panicle sterility in rice (Farooq *et al.*, 2011) and poor water status in leaves (Dell and Huang, 1997; Rehman *et al.*, 2012) have been reported. Hussain *et al.*, (2012) found that B application at the transplanting, tillering, flowering and grain formation stages of rice by foliar as well as soil applied, substantially improved the rice growth and yield. However, soil application was better in improving the number of grains per panicle, 1000-grain weight, grain yield, harvest index, net economic income and benefit cost ratio. Application of B along with lime, NPK and $MgSO_4$ increased rice yield by 1 t ha^{-1} clearly showing the benefit of B application as reported by Santhosh (2013).

When there are factors like low soil pH, calcareous nature of soil, drought and leaching and fixation causing B deficiency (Goldberg, 1997; Shorrocks, 1997), foliar nutrition is found to be more effective and economical in improving grain yield. However, enhanced yield of rice with soil applied B than foliar nutrition was substantiated in a similar study by Dunn *et al.* (2005). An increase in leaf and grain B contents with increase in B concentration in the foliar spray was observed (Rehman *et al.*, 2014).

The uptake of mineral nutrients and production of carbohydrates by paddy studied by Ramanathan and Krishnamoorthy (1973) showed that from 59 to 84% of the nutrients present in the mature plants were absorbed between tillering and flowering. More than 90% of the N and K, 80% of the P and Ca, and 65% of the Mg were absorbed before flowering and the remaining after heading. More than 60% of the carbohydrates present in the mature stage was synthesised after flowering. Rice absorbs the majority of its K during the vegetative and early reproductive growth stages. Hirata (1995) reported that 75% of the total K uptake at maturity is absorbed prior to the booting stage and almost no absorption occurs between flowering and maturity. The literature emphasizes the significance of split application of nutrients and optimum nutrient application at critical stages of the crop. According to Fageria *et al.* (2009), foliar fertilization of crops can complement soil fertilization and it not only increases the efficiency of nutrient uptake but also decreases cost of production. Rice yield and net income were improved when a portion of the basal KCl was replaced with three foliar sprays of potassium nitrate which produced 15% increase in yield and 13% increase in net income (Son *et al.*, 2012). Not only the quantity of nutrient application, but also the time and method of application are crucial for ensuring higher nutrient use efficiency.

Realization of high rice productivity in Vaikom Kari soil is impeded due to high acidity and high salinity causing nutrient stress in rice. A scan of literature revealed that amelioration of acidity can alleviate nutrient stress for rice in acid sulphate soils. Different liming materials such as lime, dolomite or RHA can be utilized for ameliorating acidity in acid soils, the efficiency of which has to be tested in Vaikom Kari soil, which is strongly or extremely acidic. Also, the efficiency of foliar application of nutrients at critical stages of the crop has to be test verified for realizing higher productivity and profitability of rice in Vaikom Kari soil. With this background, the present investigation was carried out in order to evolve appropriate acidity amelioration practices and to standardize nutrient management practices for addressing yield constraints and for maximizing rice productivity in Vaikom Kari.

Materials and Methods

3. MATERIALS AND METHODS

The investigation entitled "Acidity amelioration and nutrient management practices for mitigating yield constraints of rice in Vaikom Kari" was carried out with the objective of standardizing acidity amelioration and nutrient management practices for rice to overcome yield constraints in Vaikom Kari and to work out the economics of cultivation. The study was conducted as two field experiments: (1) Evaluation of acidity amelioration practices for rice in Vaikom Kari and (2) Standardization of nutrient management practices for rice in Vaikom Kari. The materials used and the methods followed for the study are detailed below.

3.1. MATERIALS

3.1.1 Experimental Site

The first experiment was carried out in farmer's field at Kallara panchayat in Kottayam district during 2014. The field was situated at 9° 41' 33.6" N latitude and 76° 28' 30.2" E longitude and at an altitude of 3 m above mean sea level. The second experiment was conducted in farmers' fields in Thalayazham panchayat in Kottayam district. The fields were situated at 9° 43' 35.9" N latitude and 76° 25' 23.5" E longitude during 2015 and 9° 43' 77.4" N latitude and 76° 25'25.2" E longitude during 2016. The location map is given in Plate 1.

3.1.2 Climate

The experimental site has a humid tropical climate. Data on weather parameters *viz.* temperature, rainfall, relative humidity and bright sunshine (BSS) hours were obtained from the Class B Agromet Observatory at Regional Agricultural Research Station, Kumarakom, Kottayam. The mean values of weather parameters recorded during the cropping periods are given in Appendix Ia, Ib and Ic and graphically presented in Fig. 1a, 1b and 1c.

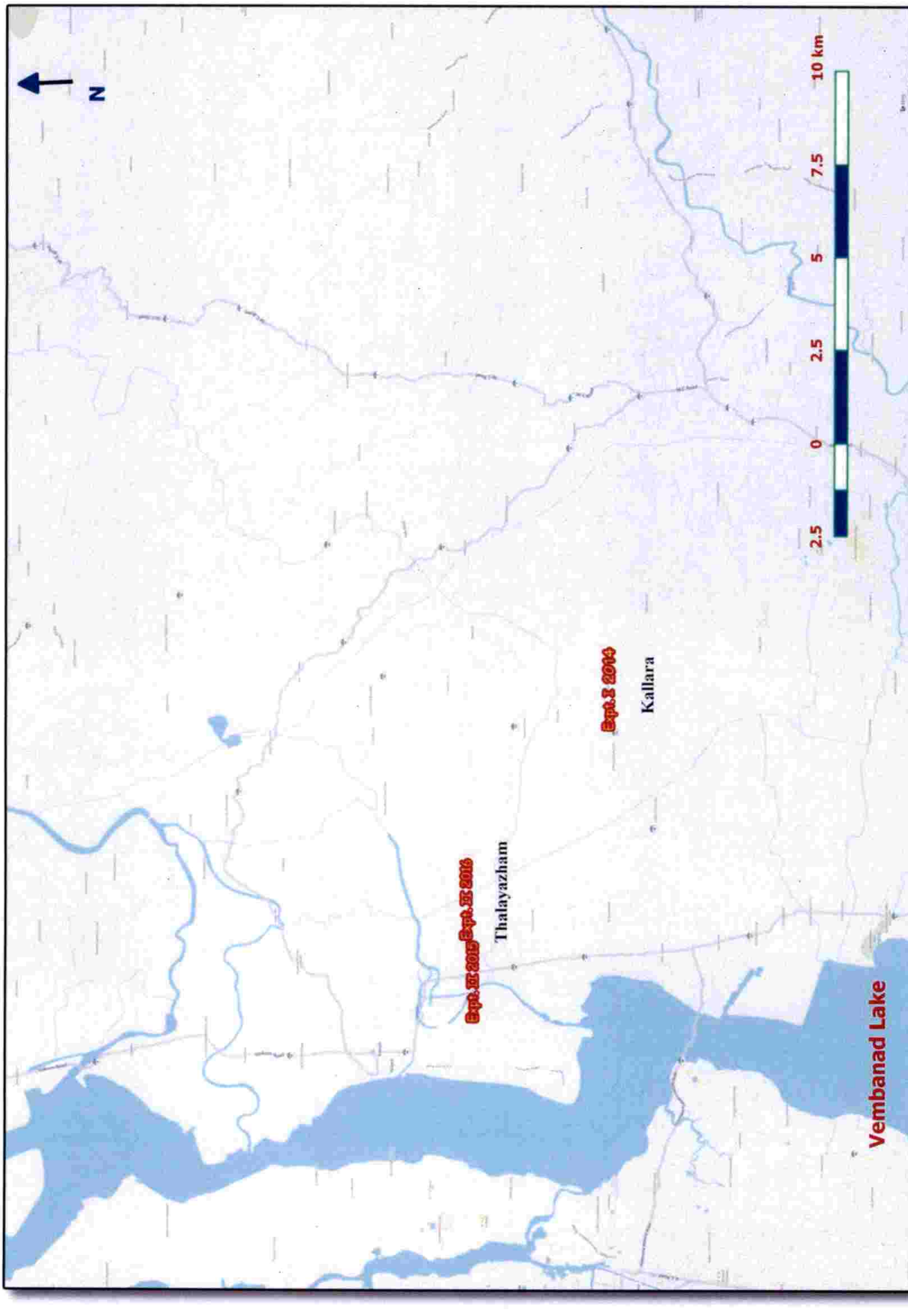

Plate 1. Location map of the experimental field

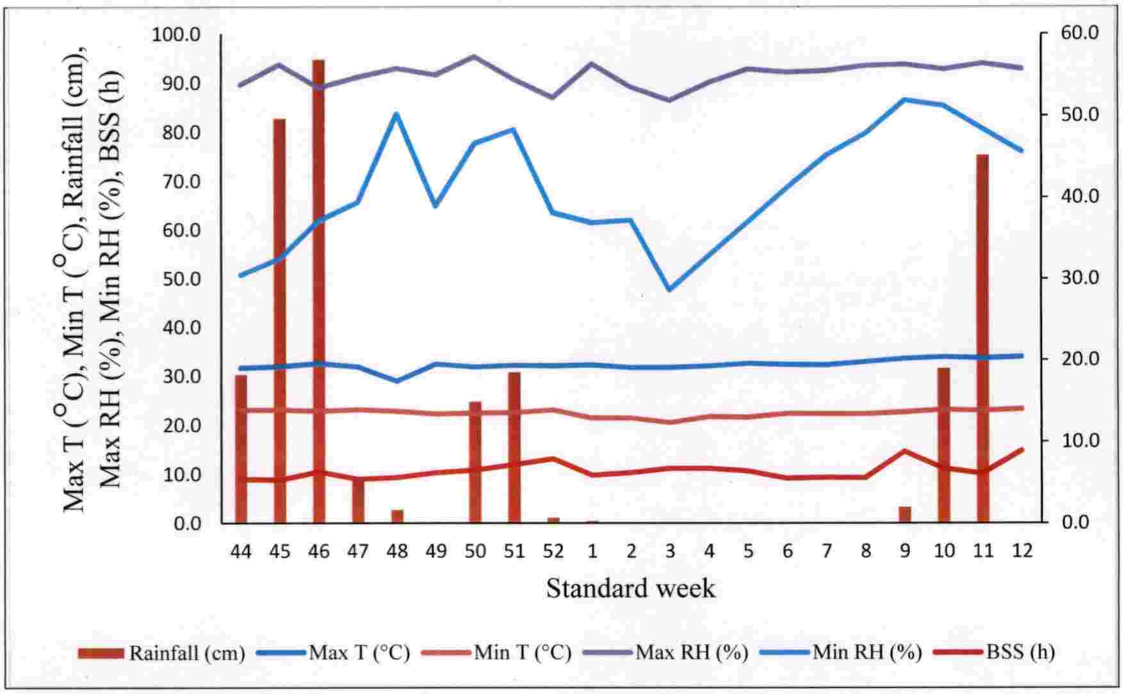

Fig.1a Weather data during the cropping period (October 2014 to March 2015) of Experiment I

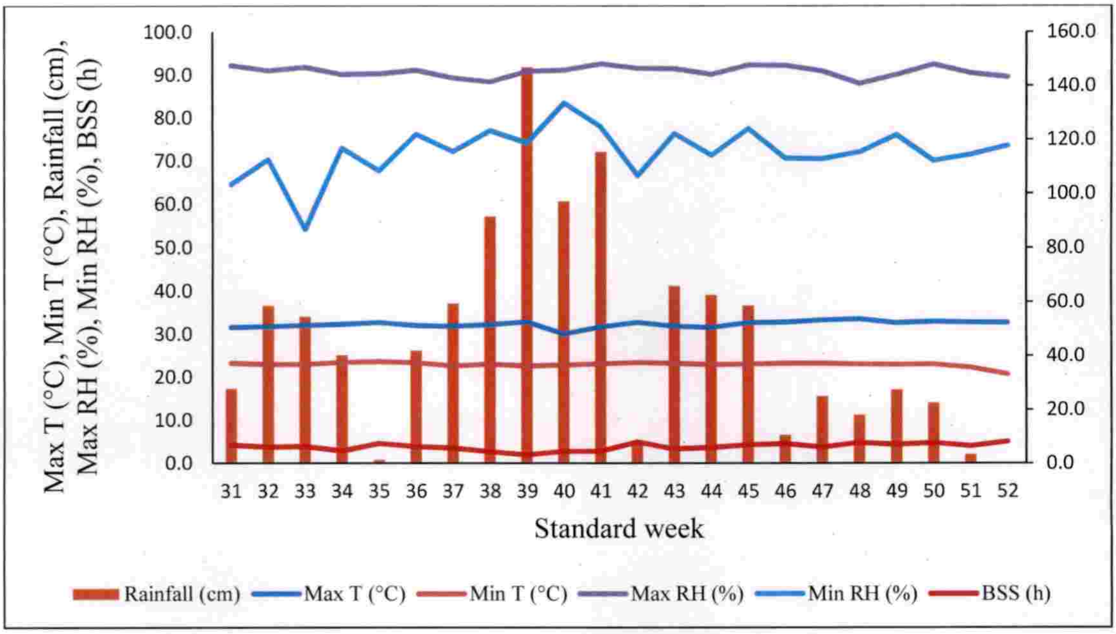

Fig. 1b Weather data during the cropping period (July 2015 to December 2015) of Experiment II

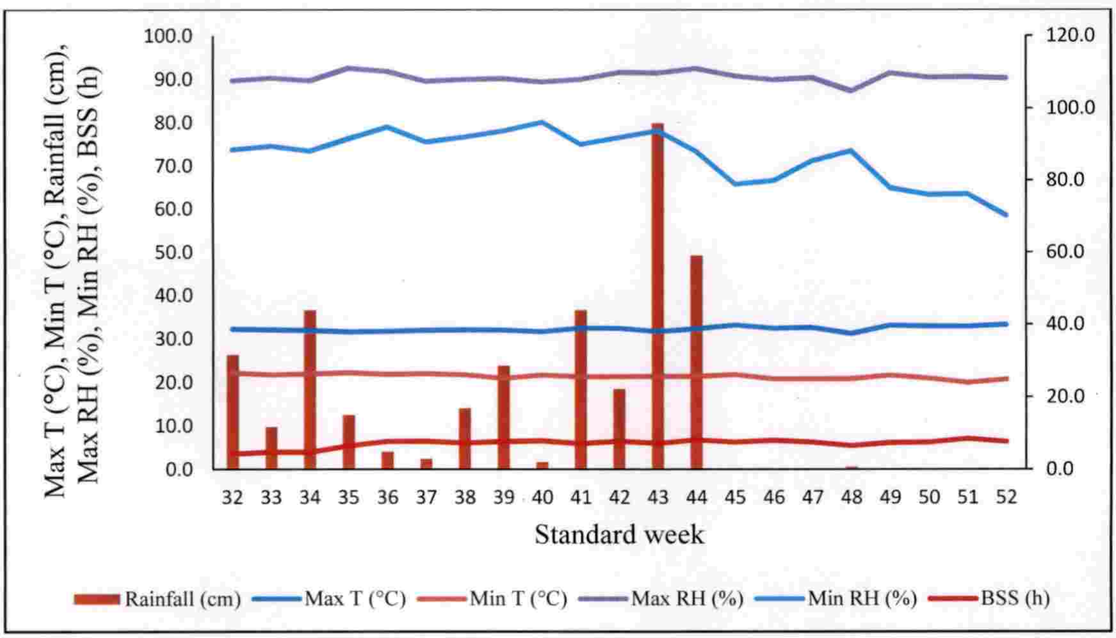

Fig. 1c Weather data during the cropping period (July 2016 to December 2016) of Experiment II

3.1.3 Cropping Season

The first experiment was conducted during November 2014 to February 2015 (*puncha* in Kuttanad). The second experiment was conducted during *virippu* season from August to November in 2015 and 2016 (additional crop in Kuttanad).

3.1.4 Soil

The soil in the experimental field of Experiment I was silty clay loam of Manjoor series and that of Experiment II was sandy clay loam of Vechoor series belonging to the order Entisol (GoK, 1999). The procedures followed for soil analysis are furnished in Table 1 and the data on mechanical composition and physico-chemical properties are presented in Table 2 and 3 respectively.

3.1.5 Cropping History of the Field

After the rice crop during *puncha* of 2013, the experimental field at Kallara was kept under water fallow. At Thalayazham, the farmers used to cultivate only one rice crop during *virippu* season (additional crop of Kuttanad) and the field was kept under water fallow for rest of the period.

3.1.6 Crop Variety

The rice variety used was Uma (MO-16) which was released from Rice Research Station, Moncompu, Kerala Agricultural University. It is a red, medium bold and medium duration variety with duration of 115 to120 days during *puncha* and 120 to135 days during virippu season. It is non-lodging and resistant to brown plant hopper. It is suited for all the three seasons and is best suited for the additional crop season of Kuttanad (KAU, 2011).

Table 1. Procedures followed for soil analysis

Soil parameter	Procedure of analysis	Instrument used	Reference
Mechanical composition	International pipette method	-	Piper (1967)
pH	Soil water suspension (1:1)	pH meter	Jackson (1973)
EC	Soil water suspension (1:1)	Conductivity meter	Jackson (1973)
Organic carbon	Chromic acid wet oxidation method	Titration	Walkley and Black (1934)
Available N	Alkaline permanganate method	Titration	Subbiah and Asija (1956)
Available P	Bray No.1 extraction	Spectrophotometer	Bray and Kurtz (1945) and Jackson (1973)
Available K, Ca and Na	Neutral normal ammonium acetate extraction	Flame photometer	Hanway and Heidal (1952)
Available Mg	Neutral normal ammonium acetate extraction	Atomic absorption spectrophotometer	Hanway and Heidal (1952)
Available S	Calcium chloride extraction and turbidimetry	Spectrophotometer	Tabatabai (1982)
Available Fe, Mn, Zn and Cu and exchangeable Al	HCl extraction	Atomic absorption spectrophotometer	Lindsay and Norvell (1978)
Available B	Hot water extraction and azomethine yellow colour method	Spectrophotometer	Berger and Troug (1939)
Dehydrogenase enzyme activity	TPF method	Spectrophotometer	Cassida *et al.* (1964)

Table 2. Mechanical composition of the soil of the experimental site

Soil fractions	Content in soil, %		
	Kallara	Thalayazham 2015	Thalayazham 2016
Sand	27.10	50.20	52.30
Silt	43.75	18.15	17.20
Clay	29.15	31.65	30.50
Soil texture	Silty clay loam	Sandy clay loam	Sandy clay loam

Table 3. Physico - chemical properties of the soil of the experimental site

Soil parameters	Unit	Kallara - 2014		Thalayazham - 2015		Thalayazham - 2016	
		Content	Rating	Content	Rating	Content	Rating
pH	-	4.68	Strongly acidic	4.23	Extremely acidic	4.29	Extremely acidic
EC	dS m^{-1}	0.22	Low	0.66	Low	0.39	Low
Organic carbon	%	4.33	High	5.69	High	4.85	High
Available N	kg ha^{-1}	275.97	Low	125.44	Low	172.48	Low
Available P	kg ha^{-1}	4.20	Low	5.47	Low	6.10	Low
Available K	kg ha^{-1}	168.67	Medium	138.88	Medium	226.24	Medium
Available Ca	mg kg^{-1}	110.00	Low	382.50	High	605.50	High
Available Mg	mg kg^{-1}	47.10	Low	87.50	Low	49.53	Low
Available S	mg kg^{-1}	973.90	High	673.90	High	620.04	High
Available Fe	mg kg^{-1}	509.20	High	1432	Above toxic limit	1630	Above toxic limit
Available Mn	mg kg^{-1}	9.26	High	1.41	High	8.01	High
Available Zn	mg kg^{-1}	3.71	High	1.79	High	6.21	High
Available Cu	mg kg^{-1}	5.41	High	0.64	Low	0.13	Low
Available B	mg kg^{-1}	0.32	Low	0.24	Low	0.21	Low
Available Na	mg kg^{-1}	53.10	Low	152.30	High	230.10	Above toxic limit
Available Al	mg kg^{-1}	49.30	Below toxic limit	71.00	Below toxic limit	78.08	Below toxic limit
Dehydrogenase activity	µg TPF g^{-1} soil 24 h^{-1}	54.88	-	88.75	-	103.6	-

3.1.7 Soil ameliorants

Lime, dolomite and RHA were used as soil ameliorants for correcting soil acidity. The results of chemical analysis of the liming materials are furnished in Table 4.

Table 4. Chemical analysis of the liming materials

Liming materials	Nutrient content, %				
	P	K	Ca	Mg	Si
Lime	-	-	31.35	-	-
Dolomite	-	-	17.16	12.15	-
RHA	0.24	0.42	0.86	0.76	83

3.1.8 Manures and Fertilizers

Urea, rajphos and muriate of potash containing 46% N, 20% P_2O_5 and 60% K_2O respectively were used as the sources of N, P, and K for soil application. Magnesium sulphate ($MgSO_4$) containing 9.1% Mg, water soluble potassium nitrate (13:0:45) and borax containing 11% B were also used as per treatments in Experiment II.

3.2 METHODS

3.2.1 Design, Treatments and Layout

3.2.1.1 Experiment I - Evaluation of acidity amelioration practices for rice in Vaikom kari

Design : Randomized Block Design (RBD)

Number of treatments : 7

Number of replications : 3

Plot size : 5 m x 2 m

Spacing : 20 cm x 10 cm

Treatments

T_1 - Lime in two splits as basal and at 30 DAS (KAU, 2011)

T_2 - Lime in two splits as basal and one week before third dose of fertilizer application

T_3 - Dolomite in two splits as basal and at 30 DAS

T_4 - Dolomite in two splits as basal and one week before third dose of fertilizer application

T_5 - Rice husk ash in two splits as basal and at 30 DAS

T_6 - Rice husk ash in two splits as basal and one week before third dose of fertilizer application

T_7 - Control

The lay out plan of Experiment I is given in Fig. 2. General view of the experimental field is presented in Plate 2.

3.2.1.2 Experiment II - Standardization of nutrient management practices for rice in Vaikom kari

Design : Randomised Block Design (RBD)

Number of treatments : 16

Number of replications : 3

Plot size : 5 m x 4 m

Spacing : 20 cm x 10 cm

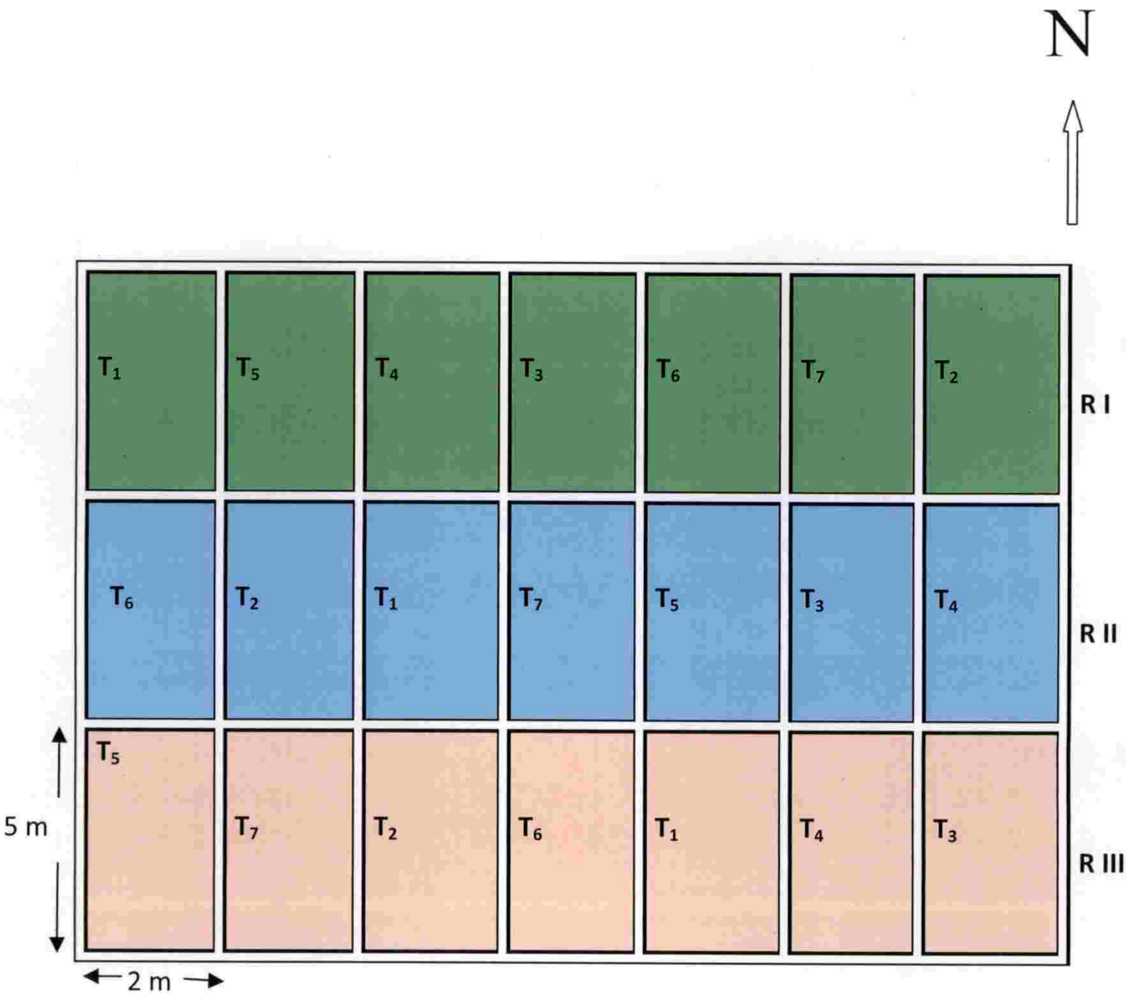

Fig. 2 Layout of the field of Experiment I

Plate 2. General field view of Experiment I

Treatments

Since all the three soil ameliorants were found equally effective in correcting soil acidity in Experiment I, they were included in Experiment II and treatments formulated accordingly.

T_1 - Dolomite + POP*

T_2 - Dolomite + POP + 13:0:45 as foliar spray (1%) at panicle initiation (PI) stage

T_3 - Dolomite + POP + Borax as foliar spray (0.5%) at PI stage

T_4 - Dolomite + POP + 13:0:45 as foliar spray + Borax as foliar spray

T_5 - Lime + POP + $MgSO_4$ (soil application 80 kg ha^{-1})

T_6 - Lime + POP + $MgSO_4$ + 13:0:45 as foliar spray (1%) at PI stage

T_7 - Lime+ POP + $MgSO_4$ + Borax as foliar spray (0.5%) at PI stage

T_8 - Lime + POP + $MgSO_4$+ 13:0:45 as foliar spray + Borax as foliar spray

T_9 - Rice Husk Ash (RHA) + POP + $MgSO_4$ (soil application 80 kg ha^{-1})

T_{10} -RHA + POP + $MgSO_4$ +13:0:45 as foliar spray (1%) at PI stage

T_{11} - RHA + POP + $MgSO_4$ + Borax as foliar spray (0.5%) at PI stage

T_{12} - RHA + POP + $MgSO_4$ + 13:0:45 as foliar spray + Borax as foliar spray

T_{13} -75% POP + Lime + $MgSO_4$ + 13:0:45 as foliar spray + Borax as foliar spray

T_{14} - Lime + POP + 13:0:45 as foliar spray (1%) at PI stage

T_{15} - Lime + POP + Borax as foliar spray (0.5%) at PI stage

T_{16} - Lime + POP +13:0:45 as foliar spray + Borax as foliar spray

*POP recommendation - 90:45:45 kg NPK ha^{-1} (KAU, 2011)

Layout plan of Experiment II is given in Fig 3. General view of the experimental field during 2015 and 2016 is presented in Plate 3 and 4.

3.2.2 Details of Cultivation

3.2.2.1 Land Preparation

The experimental field was tilled, puddled and laid out as per the design for Experiment I and Experiment II. Bunds of 50 cm width were provided on outer sides of the field. The plots were separated with bunds of 30 cm width. Proper irrigation facilities and drainage channels were provided.

3.2.2.2 Application of Soil Ameliorants

Lime ($CaCO_3$) @ 600 kg ha^{-1} was applied in two splits of 350 kg as basal dose and 250 kg at 30 DAS or one week before third dose of fertilizer application (before PI) as per treatments in Experiment I and mixed with soil. Dolomite and RHA were applied @ 500 kg ha^{-1} in two splits of 300 kg and 200 kg as above.

In Experiment II, lime @ 600 kg ha^{-1}, dolomite and RHA each @ 500 kg ha^{-1} were applied in two splits as above as basal dose and at 30 DAS only.

3.2.2.3 Application of Fertilizers

For Experiment I, fertilizers @ 90:45:45 kg N P K ha^{-1} recommended for the medium duration rice var. Uma (KAU, 2011) were applied uniformly in all plots. Full dose of P as rajphos was applied as basal dose. N and K were applied through urea and muriate of potash respectively in three equal splits at 20 DAS, 35 DAS and PI stage.

For Experiment II, fertilizers @ 90:45:45 kg NPK ha^{-1} were applied as above in all the treatments except T_{13}, where 75% of the recommended dose was applied. $MgSO_4$ @ 80 kg ha^{-1} was applied in soil as basal dose in respective treatments.

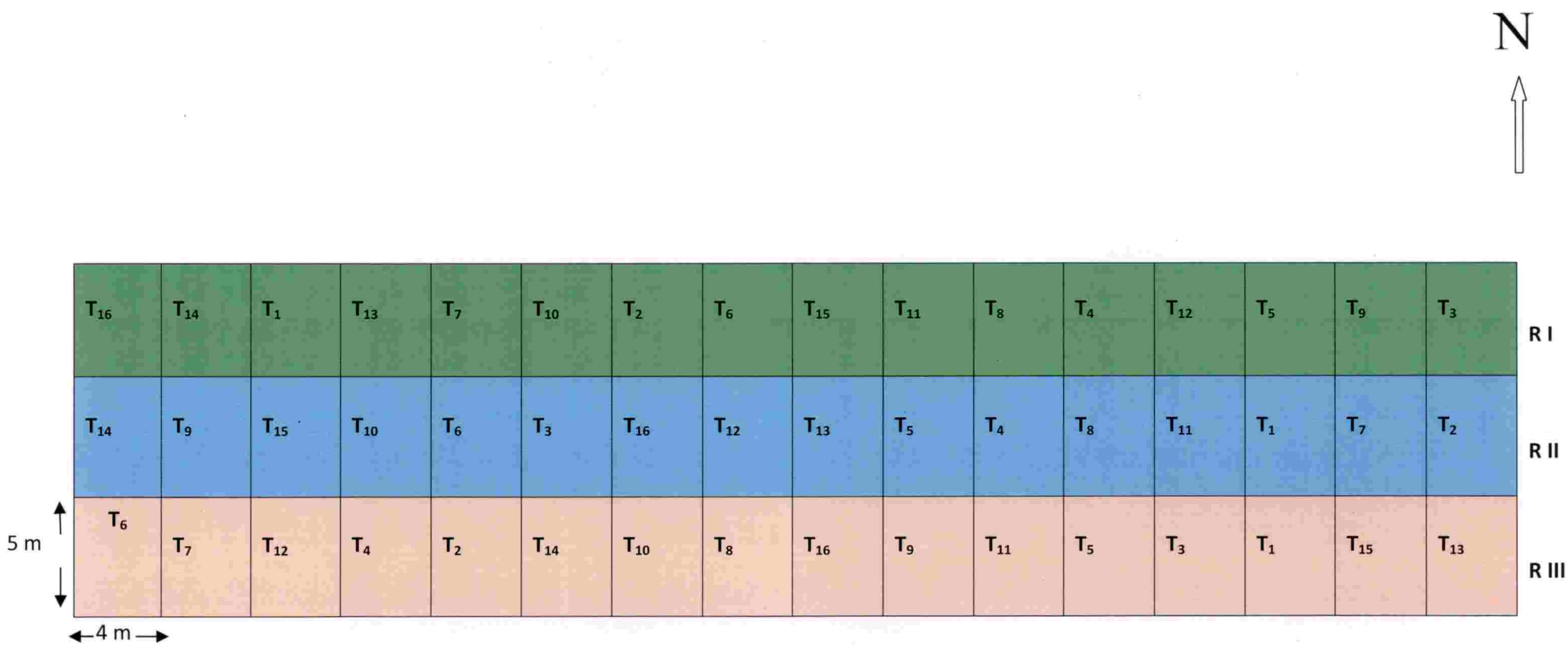

Fig. 3 Layout of the field of Experiment II

Plate 3. General field view of Experiment II during 2015

Plate 4. General field view of Experiment II during 2016

Potassium nitrate (13:0:45) and borax were given as 1% and 0.5% foliar spray respectively, at PI stage as per treatments.

3.2.2.4 Seeds and Sowing

Seeds of rice var. Uma were obtained from Regional Agricultural Research Station, Kumarakom, Kottayam. Seeds were soaked in 0.25% $CuSO_4$ solution overnight, the excess water was drained and kept for sprouting (KAU, 2011). The pre-germinated seeds were dibbled using seed drum at a spacing of 20 cm x 10 cm (Plate 5). The crop of Experiment I was sown on 15.11.2014. The first crop of Experiment II was sown on 13.08.2015 and second crop was sown on 14.08.2016.

3.2.2.5 Aftercultivation

Post emergent herbicide Almix 20WP (chlorimuron ethyl 10% + metsulfuron methyl 10% @ 4g *a.i.* ha^{-1} + 0.2% surfactant) was sprayed at 20 DAS and gap filling, thinning and hand weeding were done at 30 DAS, before the application of first split of N and K fertilizers. Water management was done as per KAU (2011) by providing *kachals* and *vachals*.

3.2.2.6 Plant Protection

The incidence of stem borer was noticed at tillering stage of the crop in all the field experiments which was controlled by soil application of Fertera (chorantraniliprole 0.4% GR) along with the first split application of of N and K fertilizers.

3.2.2.7 Harvest

The crop of Experiment I was harvested on 08.03.2015. The first crop of Experiment II was harvested on 24.12.2015 and the second crop on 25.12.2016. The border and observation plants were harvested separately. Each net plot was harvested and threshed separately. The grains and straw were dried and weighed to record plot wise yield data.

Dibbling sprouted seeds using seed drum

Early seedling stage

Tillering stage

Plate 5. Direct sowing of rice and growth stages

3.3 OBSERVATIONS

Two rows of plants were left as border on all the sides of each plot. Ten hills were selected at random from the net plot area of each plot and tagged as observation plants for recording biometric observations.

3.3.1 Growth Characters

3.3.1.1 Plant Height

Observations on plant height were recorded at maximum tillering (MT), PI and harvest stages from observation plants tagged using the method described by Gomez (1972). The height was measured from the base of the plant to the tip of the longest leaf or tip of the longest ear head whichever was longer and the average was worked out in cm.

3.3.1.2 Leaf Area Index

Leaf area index was computed at MT, PI and harvest stages using the method described by Gomez (1972). The maximum width 'w' and length 'l' of all the leaves of central tiller of observation hills were recorded, mean values were worked out and LAI was computed using the formula

Leaf area = l x w x k

where k - Adjustment factor (0.75 at MT and PI stages and 0.67 at harvest stage)

$$\text{LAI} = \frac{\text{Total leaf area tiller}^{-1} \times \text{Number of tillers plant}^{-1}}{\text{Land area occupied by the plant}}$$

3.3.1.3 Number of Tillers m^{-2}

Tiller number was recorded from observation plants at MT, PI and harvest stages, mean was worked out and expressed as number of tillers m^{-2}.

3.3.1.4 Total Dry Matter Production (TDMP)

The observation plants were uprooted at harvest, washed, separated into grain and straw, initially air dried and later oven dried at 65 ± 5°C to a constant weight. The mean values were recorded and TDMP was computed and expressed in t ha^{-1}.

3.3.2 Yield and Yield Attributes

3.3.2.1 Number of Productive Tillers m^{-2}

At harvest, number of productive tillers in observation plants was counted and expressed as number of productive tillers m^{-2}.

3.3.2.2 Thousand Grain Weight

Thousand grains were counted from the cleaned and dried produce from the observation plants and the weight was recorded in g.

3.3.2.3 Sterility Percentage

Sterility percentage was worked out using the following formula.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.3.2.4 Grain Yield

The net plot area was harvested separately, threshed, grains cleaned and dried to 14 per cent moisture level and the weight was recorded. Grain yield was expressed in t ha^{-1}.

3.3.2.5 Straw Yield

Straw harvested from the net plot of each treatment was dried to a constant weight and the weight was expressed as t ha^{-1}.

3.3.2.6 Harvest Index (HI)

From grain and straw yield values, HI was worked out using the following equation as suggested by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.3.3 Soil Analysis

Composite soil samples were collected from 0-15 cm depth from the experimental field prior to the experiment. Soil samples were also collected before each fertilizer application at 20 DAS, 35 DAS, PI stage and harvest. Wet samples were analysed for mechanical composition (of the initial composite sample) and physico-chemical properties adopting the procedures cited in Table 1. Moisture percentage in soil samples was determined and the analytical values were expressed on dry weight basis.

3.3.4 Plant analysis

The youngest three leaves one week before PI stage and flag leaves were collected from five plants randomly from the net plot area for nutrient analysis. At harvest, samples of grain and straw were collected from observation plants. All the collected samples were dried in hot air oven at 65 ± 5°C to a constant weight and powdered for nutrient analysis adopting the procedures as outlined in Table 5.

3.3.4.1 K/Na_{Leaves} Ratio

Samples of the youngest leaves collected were analysed for K and Na contents and K/Na_{Leaves} ratio was worked out.

Table 5. Procedures followed for plant analysis

Plant parameters	Procedure of analysis	Instrument used	Reference
Total N	Single acid (H_2SO_4) digestion followed by distillation	Micro kjeldahl digestion and distillation units	Jackson (1973)
Total P	Di-acid (nitric and perchloric acids in 9:4 ratio) digestion followed by vanado-molybdo- phosphoric yellow colour method	Spectrophotometer	Jackson (1973)
Total K, Ca and Na	Di-acid (nitric and perchloric acids in 9:4 ratio) digestion followed by flame photometry	Flame photometer	Piper (1967)
Total S	Di-acid (nitric and perchloric acids in 9:4 ratio) digestion followed by $CaCl_2$ turbidimetry	Spectrophotometer	Tabatabai (1982)
Total Mg, Fe, Mn, Zn, Cu, Al	Di-acid digestion followed by direct reading	Atomic Absorption Spectrophotometer	Lindsay and Norvell (1978)
Total B	Dry ashing and azomethine yellow colour method	Spectrophotometer	Gaines and Mitchel (1979) and Bingham (1982)

3.3.4.2 Nutrient Content of Flag *Leaf*

Samples of flag leaves were analysed for macronutrients *viz.* N, P, K, Ca, Mg and S, micronutrients *viz.* Fe, Mn, Zn, Cu and B, Na and Al.

3.3.4.3 Nutrient Content of Grain and Straw

Samples of grain and straw at harvest were analysed for macronutrients *viz.* N, P, K, Ca, Mg and S, micro nutrients *viz.* Fe, Mn, Zn, Cu and B, Na and Al.

3.3.5 Uptake of Nutrients

Uptake of macronutrients, micronutrients, Na and Al was computed by multiplying nutrient content of each part with respective dry weight expressed in kg ha^{-1}. The total uptake was also worked out and expressed in kg ha^{-1}.

3.4 PEST AND DISEASE INCIDENCE

Incidence of pest and disease was monitored throughout the cropping period.

3.5 ECONOMIC ANALYSIS

Economics of cultivation was calculated considering the cost of inputs and minimum support price of paddy during the cropping periods (Appendix V). Net income (₹ ha^{-1}) and BCR were calculated as given below.

Net income (₹ ha^{-1}) = Gross income - Cost of cultivation

BCR = Gross income ÷ Cost of cultivation

3.6 STATISTICAL ANALYSIS

The data collected from the field experiments were analysed by applying the technique of analysis of variance (ANOVA) for RBD (Cochran and Cox, 1965). Critical difference has been provided wherever F test was significant. Pooled analysis of grain yield during two years for Experiment II was also carried out. Suitable correlations were also worked out.

Results

4. RESULT

Two field experiments were conducted for the investigation entitled "Acidity amelioration and nutrient management practices for mitigating yield constraints of rice in Vaikom Kari". The first experiment was conducted in farmer's field in Kallara panchayat in Kottayam district from November 2014 to March 2015 to evaluate acidity amelioration practices for rice in Vaikom Kari. The experiment was laid out in RBD with seven treatments and three replications. The second experiment was conducted in farmers' fields in Thalayazham panchayat of Kottayam district from August to December 2015 and repeated during August to December 2016 to standardize nutrient management practices for rice to overcome yield constraints in Vaikom Kari. The second experiment was laid out in RBD with 16 treatments and three replications. The data collected were statistically analysed and the results are presented in this chapter.

4.1. Experiment I - Evaluation of acidity amelioration practices for rice in Vaikom kari

4.1.1 Growth Characters

Growth characters like plant height, number of tillers m^{-2} and LAI were recorded at MT, PI and harvest stages. The data on growth characters as influenced by acidity amelioration practices are presented in Table 6.

4.1.1.1 Plant Height

The plant height was significantly influenced by the treatments (Table 6). Application of RHA as basal + 30 DAS (T_5) recorded the highest value during MT stage (76.07 cm) and it was on par with RHA as basal + PI (T_6) and dolomite treatments (T_3 and T_4). During PI and harvest stages, application of T_6 showed the highest value (78.93 and 88.8 cm respectively) but was on par with all treatments except control (T_7).

4.1.1.2 Number of Tillers m^{-2}

Significant influence of treatments on number of tillers m^{-2} is evident from Table 6. Dolomite application as basal + 30 DAS (T_3) recorded the highest tiller number (586.67) at MT stage but was on par with lime or RHA as basal + 30 DAS (T_1 and T_5 respectively). At PI stage, tiller number was the highest (600) with RHA as basal + PI (T_6) but was on par with T_3, T_1 and T_5. At harvest, lime as basal + 30 DAS (T_2) registered the highest value (301.67) and was on par with all treatments except control (T_7).

4.1.1.3 Leaf Area Index

The data on LAI in Table 6 revealed significant influence of acidity amelioration practices. At MT and PI stages, dolomite as basal + 30 DAS (T_3) registered the highest LAI of 6.92 and 8.12 respectively. However, it was on par with lime or RHA as basal + 30 DAS (T_5 or T_1) at MT stage and with all other treatments except lime as basal + PI (T_2) and control (T_7) at PI stage. At harvest, significantly higher LAI of 3.82 was recorded by RHA as basal + 30 DAS (T_5).

4.1.2 Yield attributes and yield

The data on yield attributes of rice such as number of panicle m^{-2}, 1000 grain weight and grain sterility percentage as influenced by acidity amelioration practices are given in Table 7. The average grain yield, straw yield and harvest index recorded by the treatments are also furnished in Table 7.

4.1.2.1 Number of Panicles m^{-2}

Number of panicles m^{-2} was found to be the highest (293.33) with lime as basal + 30 DAS (T_1) and was on par with all other treatments except control (Table7).

Table 6. Effect of acidity amelioration practices on growth characters

Treatments	Plant height (cm)			No. of tillers m^{-2}			Leaf area index		
	MT	PI	Harvest	MT	PI	Harvest	MT	PI	Harvest
T_1	72.93	75.33	84.93	578.33	583.33	296.67	6.48	7.86	2.91
T_2	71.80	75.33	83.00	531.67	566.67	301.67	6.10	7.51	1.94
T_3	75.13	77.87	84.87	586.67	590.00	298.33	6.92	8.12	3.14
T_4	74.20	77.60	87.07	545.00	563.33	268.33	6.00	7.77	2.59
T_5	76.07	77.20	87.53	583.33	581.67	276.67	6.91	7.92	3.82
T_6	75.43	78.93	88.80	545.00	600.00	268.33	5.95	7.87	2.95
T_7	68.93	70.13	76.53	438.33	491.67	206.67	4.55	5.81	0.94
SEm (±)	0.86	1.51	2.16	11.26	8.69	11.61	0.18	0.14	0.21
CD(0.05)	2.656	4.643	6.654	34.704	26.767	35.765	0.541	0.415	0.647

Table 7. Effect of acidity amelioration practices on yield attributes and yield

Treatments	Yield attributes			Yield and harvest index		
	Panicle no. m^{-2}	Sterility (%)	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index
T_1	293.33	8.93	26.00	7.58	8.51	0.48
T_2	285.00	9.33	24.33	6.46	7.09	0.47
T_3	288.33	8.40	26.33	7.92	8.56	0.48
T_4	263.33	9.27	24.33	7.02	7.17	0.49
T_5	266.67	8.00	25.67	7.59	8.00	0.47
T_6	263.33	8.67	25.67	6.98	8.60	0.46
T_7	198.33	16.87	23.00	4.31	6.30	0.41
SEm (±)	10.62	0.43	0.76	0.28	0.30	0.01
CD(0.05)	32.730	1.315	2.335	0.851	0.909	-

4.1.2.2 1000 Grain Weight

Thousand grain weight was the highest (26.33g - Table 7) with dolomite as basal + 30 DAS (T_3) and was on par with all other treatments except control (T_7).

4.1.2.3 Sterility Percentage

The lowest sterility percentage (8%) was recorded by RHA as basal + 30 DAS (T_5) and was on par with all other treatments except lime as basal + PI (T_2) and control (Table 7).

4.1.2.4 Grain Yield

It can be seen from Table 7 that acidity amelioration practices significantly influenced the grain yield. The grain yield was the highest (7.92 t ha^{-1}) with dolomite as basal + 30 DAS (T_3) but was on par with RHA as basal + 30 DAS (T_5) and lime as basal + 30 DAS (T_1). The lowest yield of 4.31 t ha^{-1} was recorded by the control (without ameliorants).

4.1.2.5 Straw Yield

The highest straw yield of 8.6 t ha^{-1} (Table 7) was produced by RHA as basal + PI (T_6) but was on par with T_1, T_3 and T_5 (lime or dolomite or RHA as basal + 30 DAS respectively). The control treatment (T_7) produced the lowest straw yield of 6.3 t ha^{-1} which was on par with lime or dolomite as basal + PI (T_2 and T_4 respectively).

4.1.2.6 Harvest Index

Harvest index was not significantly influenced by acidity amelioration practices (Table 7). But the highest HI of 0.49 was recorded by dolomite as basal + PI (T_4) closely followed by dolomite as basal + 30 DAS (T_3 - 0.48) and lime as basal + 30 DAS (T_1-0.48).

4.1.3 Dry Matter Production

The influence of the acidity amelioration practices on grain dry matter yield, straw dry matter yield and total dry matter production are given in Table 8.

4.1.3.1 Grain Dry Matter Yield

The grain dry matter production was significantly influenced by the treatments (Table 8). The highest grain dry matter yield was recorded by dolomite as basal + 30 DAS (T_3) which was on par with RHA or lime as basal + 30 DAS (T_5 and T_1 respectively) (Table 8). The control (without ameliorants) plots registered the lowest value.

4.1.3.2 Straw Dry Matter Yield

There was significant influence of the treatment on straw dry matter yield. (Table 8). Dolomite as basal + 30 DAS (T_3) recorded the highest straw dry matter yield. But it was on par with RHA or lime as basal + 30 DAS (T_5 and T_1 respectively) and dolomite as basal + PI (T_4).

4.1.3.3 Total Dry Matter Production

The treatments had profound influence on TDMP (Table 8). Dolomite as basal + 30 DAS (T_3) recorded the highest dry matter yield of 15.67 t ha^{-1} which was on par with RHA or lime as basal + 30 DAS (T_5 and T_1 respectively). The lowest dry matter yield of 8.78 t ha^{-1} was registered by the control (without ameliorants).

4.1.4 Plant Analysis

4.1.4.1 K/Na_{Leaves} One Week before PI

The average values of K content, Na content and K/Na_{Leaves} of three youngest leaves one week before PI as influenced by acidity amelioration practices are furnished in Table 9. Though not significant, higher K content in three youngest leaves one week before PI was observed in the treated plots.

Table 8. Effect of acidity amelioration practices on dry matter production at harvest, t ha^{-1}

Treatments	Grain dry matter yield	Straw dry matter yield	Total dry matter production
T_1	7.15	7.92	15.06
T_2	6.58	7.24	13.82
T_3	7.65	8.03	15.67
T_4	6.94	7.52	14.45
T_5	7.32	7.82	15.14
T_6	6.80	7.41	14.21
T_7	3.99	4.79	8.78
SEm (±)	0.21	0.18	0.34
CD(0.05)	0.661	0.556	1.051

Table 9. Effect of acidity amelioration practices on K/Na_{Leaves} one week before panicle initiation

Treatments	K content of three youngest leaves mg kg^{-1}	Na content of three youngest leaves mg kg^{-1}	K/Na_{Leaves}
T_1	5203.33	443.33	48.46
T_2	6491.11	473.33	46.73
T_3	5873.33	494.44	36.56
T_4	5243.33	462.22	41.46
T_5	4587.78	456.67	37.33
T_6	4653.33	465.56	35.04
T_7	3953.33	510.00	22.38
SEm (±)	580.11	6.78	5.71
CD(0.05)	-	20.879	-

Significant influence of the treatments was observed in Na content with the highest value in the control plot. The treatments failed to produce significant variation in K/Na_{Leaves} one week before PI. However, the lowest ratio of 22.38 was registered by the control.

4.1.4.2 Nutrient Content of Flag Leaf

Flag leaf was analysed to determine the contents of macronutrients and micronutrients as well as Na and Al and the data are presented in Table 10. The critical nutrient concentration (CNC) in the flag leaf as suggested by Dobermann and Fairhurst (2000) is given in Appendix III.

The N and P contents in the flag leaf agreed with CNC but K content was lower than CNC (Appendix III). However, the treatments failed to express significant influence on N, P and K contents of the flag leaf (Table 10).

The contents of Ca and Mg were lower whereas that of S was higher than CNC in the flag leaf (Appendix III). The content of secondary nutrients in the flag leaf was significantly influenced by the treatments (Table 10). Significantly higher Ca content in the flag leaf was recorded by lime treatments (T_1 and T_2) while higher Mg content was recorded by dolomite treatments (T_3 and T_4). The lowest Ca and Mg contents in the flag leaf were observed with T_7 (control). In the case of S content, the highest value was observed with control and the lowest with lime as basal + 30 DAS (T_1).

The flag leaf content of Fe was higher and Mn, Zn, Cu and B contents were within CNC (Appendix III). The treatments had significant influence on the content of micronutrients in the flag leaf (Table 10). Lower Fe content was registered by dolomite as basal + 30 DAS (T_3) which was on par with all treatments except RHA as basal + PI (T_6) and control (T_7). The highest Mn content in the flag leaf was registered by control (T_7) which was significantly different from all other treatments. The lowest Mn content was recorded by dolomite as basal + 30 DAS (T_3) which was on par with T_6, lime or RHA as basal+ 30 DAS (T_1 and T_5).

Table 10. Effect of acidity amelioration practices on nutrient status of flag leaf

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Al (mg kg^{-1})
T_1	2.57	0.29	1.21	0.23	0.08	0.17	122.00	104.56	40.44	9.89	10.38	655.53	79.21
T_2	2.20	0.27	1.18	0.21	0.09	0.19	126.60	128.67	34.78	9.89	9.90	722.17	74.73
T_3	2.29	0.28	1.24	0.17	0.14	0.20	116.18	78.44	31.11	10.11	11.45	633.30	80.48
T_4	2.26	0.26	1.16	0.14	0.13	0.18	146.89	131.78	31.45	13.33	12.47	588.83	81.72
T_5	2.45	0.26	1.40	0.13	0.07	0.18	130.67	110.89	38.44	9.67	11.15	622.20	86.01
T_6	2.33	0.23	1.28	0.13	0.09	0.19	207.40	94.34	23.67	9.00	11.00	611.10	86.80
T_7	2.23	0.22	0.98	0.12	0.04	0.27	219.22	249.66	41.49	11.71	9.52	755.53	97.15
SEm (±)	0.09	0.02	0.17	0.01	0.01	0.02	17.80	11.73	3.38	0.77	0.22	27.96	8.13
CD(0.05)	-	-	-	0.021	0.028	0.054	54.838	36.148	10.428	2.364	0.689	86.163	-

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All treatments were on par with respect to Zn and Cu content in the flag leaf except T_6 (RHA as basal + PI) in both the cases and the highest Zn and Cu contents were shown by the control (T_7) and dolomite as basal + PI (T_4). The highest content of B in the flag leaf was shown by T_4 which was significantly superior to all other treatments and the lowest B content was registered by the control.

The Na content in the flag leaf was significantly influenced by the treatments. The control (T_7) recorded the highest value which was on par with lime as basal + PI (T_2).

Though the Al content was much above CNC, it was below the critical level of toxicity (Appendix III). The treatments had no significant influence on Al content in the flag leaf. However, the highest Al content was recorded by T_7 (control) and T4 respectively.

4.1.4.3 Nutrient Content in Grain and Straw at Harvest

The nutrient content in the grain and straw at harvest as influenced by the treatments are presented in Table 11 and 12. The CNC in the rice grain and straw as suggested by Dobermann and Fairhurst (2000) is given in Appendix III.

The contents of N, P and K in the grain and straw were near or within CNC. Among primary nutrients, the treatments had significant influence only on P content in the grain (Table 11). The highest P content was registered by dolomite as basal + 30 DAS (T_3) and the lowest by the control.

The content of Ca in the grain was slightly higher whereas that in the straw was slightly lesser than CNC. The plant was low in Mg both in the grain and straw while S content was within CNC in the grain but was slightly higher in the straw.

The treatments significantly influenced the contents of secondary nutrient in the grain (Table 11). Significantly higher Ca content in the grain was recorded by all amelioration treatments excluding dolomite as basal + 30 DAS (T_3) and RHA as basal + PI (T_6) and were on par with each other (Table 11).

Table 11. Effect of acidity amelioration practices on macronutrient content in grain and straw at harvest, %

Treatments	N		P		K		Ca		Mg		S	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.09	0.75	0.15	0.144	0.35	1.68	0.14	0.28	0.07	0.07	0.13	0.18
T_2	0.99	0.68	0.16	0.145	0.32	1.55	0.13	0.27	0.06	0.08	0.12	0.16
T_3	0.99	0.71	0.28	0.133	0.30	1.60	0.11	0.28	0.08	0.12	0.11	0.21
T_4	1.09	0.59	0.22	0.131	0.30	1.51	0.14	0.29	0.07	0.09	0.11	0.17
T_5	1.15	0.78	0.19	0.131	0.31	1.75	0.13	0.21	0.06	0.08	0.14	0.19
T_6	1.05	0.53	0.18	0.141	0.33	1.54	0.11	0.19	0.06	0.07	0.11	0.20
T_7	1.02	0.50	0.14	0.137	0.29	1.81	0.10	0.21	0.05	0.05	0.15	0.23
SEm (±)	0.05	0.08	0.02	0.004	0.01	0.10	0.01	0.01	0.01	0.01	0.01	0.01
CD(0.05)	-	-	0.053	-	-	-	0.017	0.023	0.016	0.016	0.025	-

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The lowest Ca content was registered by the control. All treatments except control were on par in their effects on Mg content in the grain. With regard to S content in the grain, all treatments were on par but registered lower values than the control. In the case of straw, significantly higher Ca content was recorded by lime and dolomite treatments (T_1, T_2, T_3 and T_4) which were on par. The treatment dolomite as basal + 30 DAS (T_3) was found superior with regard to Mg content in the straw. The lowest Mg content was recorded by T_7 (control). The content of S in the straw was not significantly influenced by the treatments.

Grain Fe content was near or within CNC while straw content was higher but below toxic limit (Appendix III). Concentration of Mn in the grain and the straw were below CNC. Grain and straw Zn and Cu contents were near or within CNC. Content of B in the grain was below CNC while that in the straw was within CNC.

The treatments had significant influence on the micronutrient content in the grain except on Cu content (Table 12). The highest contents of Fe, Mn and Zn in the grain were observed with control which was on par with RHA as basal + PI (T_6) in the case of Fe, dolomite as basal + PI (T_4) in the case of Mn and Zn. The Cu content in the grain was not significantly influenced by the treatments. In the case of B, the highest content in grain was registered by RHA as basal + 30 DAS (T_5) but was on par with lime or dolomite as basal + 30 DAS (T_1 and T_3).

The micronutrient content in the straw was significantly influenced by the treatments (Table 12). The control recorded the highest Fe content in the straw. Dolomite as basal + PI (T_4) was on par with lime treatments (T_1 and T_2) with regard to the straw Mn content but superior to other treatments. Significantly higher Zn content was recorded by lime or RHA as basal + 30 DAS (T_1 andT_5) and dolomite as basal + PI (T_4) which were on par with each other. All treatments except dolomite as basal + 30 DAS (T_3) were on par in their effect on straw Cu content. The treatments involving RHA or lime or dolomite as basal + 30 DAS (T_5, T_1 and T_3) registered significantly higher B content in the straw and were on par with the highest B content recorded by RHA as basal + PI (T_6).

There was no significant influence of the treatments on Na content in the grain or straw.

Table 12. Effect of acidity amelioration practices on micronutrients, Na and Al content in grain and straw at harvest, mg kg^{-1}

Treatments	Fe		Mn		Zn		Cu		B		Na		Al	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	153.33	157.44	26.22	157.00	29.55	66.81	10.00	11.56	11.70	11.96	255.50	1777.63	109.04	75.13
T_2	185.55	139.00	25.22	142.89	25.00	44.78	7.67	13.56	9.96	10.01	255.50	1688.70	108.92	83.77
T_3	164.56	129.44	21.11	103.00	20.22	26.89	5.89	7.22	11.63	11.68	222.20	1755.40	78.24	70.17
T_4	158.55	163.78	29.22	165.33	35.89	54.78	8.44	9.33	10.84	9.85	299.97	1644.30	122.97	58.73
T_5	169.33	153.11	23.34	125.22	19.67	60.22	7.33	15.11	12.62	11.14	222.20	1822.07	131.71	82.27
T_6	219.88	129.22	25.00	79.56	26.33	28.67	8.67	9.22	9.96	12.14	244.43	1555.40	131.52	106.23
T_7	249.22	235.11	38.55	111.56	36.00	42.89	7.89	11.45	9.78	9.39	255.50	1777.60	180.59	85.43
SEm (±)	14.46	18.70	3.03	9.26	2.23	5.20	0.80	1.54	0.38	0.40	15.61	92.19	14.36	10.08
CD(0.05)	44.565	57.617	9.334	28.524	6.880	16.036	-	4.740	1.169	1.242	-	-	44.244	31.072

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The control treatment (T_7) recorded the highest Al content in the grain and dolomite as basal + 30 DAS (T_3) recorded the lowest content. The Al content in the straw was higher than CNC and near the toxic limit. The RHA treatments (T_5 and T_6), control (T_7) and lime as basal + PI (T_2) registered significantly higher Al content in the straw but were on par with each other.

4.1.5 Uptake of Nutrients

The average values of uptake of nutrients by the crop as influenced by the amelioration practices are presented in Table 13, 14, 15 and 16.

4.1.5.1 Uptake of Primary Nutrients

Significant influence of the treatments was observed in the total uptake of N, P and K at harvest (Table 13).

The grain N uptake was significantly higher with RHA or lime or dolomite as basal + 30 DAS (T_5, T_1 and T_3) and dolomite as basal + PI (T_4) which were on par with each other. The straw N uptake was significantly higher with T_5 and was on par with all other treatments except T_6 (RHA as basal + PI) and T_7 (control). The treatment RHA as basal + 30 DAS (T_5) recorded significantly higher total N uptake but was on par with lime as basal + 30 DAS (T_1) and dolomite as basal + 30 DAS (T_3).

The highest grain P uptake was registered with T_3 and the treatments T_1, T_2, T_3 and T_6 recorded significantly higher straw P uptake which were on par. The treatment T_3 was superior with respect to total P uptake.

The grain K uptake was the highest with lime as basal + 30 DAS (T_1) and was on par with all other treatments except T_4 (dolomite as basal + PI) and (control). With respect to the straw K uptake, all treatments except lime as basal + PI (T_2) and T_7 registered significantly higher values and were on par. The highest total K uptake was recorded by T_5 (RHA as basal + 30 DAS) but was on par with lime or dolomite as basal +30 DAS (T_1 and T_3).

Table 13. Effect of acidity amelioration practices on uptake of primary nutrients, kg ha^{-1}

Treatments	N uptake			P uptake			K uptake		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	77.66	58.54	136.20	11.00	11.39	22.39	24.80	132.40	157.19
T_2	65.11	48.66	113.77	10.18	10.49	20.66	21.05	112.45	133.50
T_3	75.84	57.18	133.02	21.41	10.67	32.09	23.06	128.68	151.74
T_4	75.22	44.49	119.71	15.34	9.90	25.25	20.59	113.89	134.48
T_5	83.63	60.45	144.09	14.17	10.24	24.41	22.78	137.02	159.80
T_6	71.61	38.82	110.43	12.51	10.47	22.97	22.24	114.81	134.05
T_7	40.81	23.89	64.70	5.65	6.56	12.21	11.61	86.04	97.65
SEm (±)	2.76	6.43	6.64	1.27	0.34	1.35	1.09	7.68	8.05
CD(0.05)	8.496	19.825	20.466	3.917	1.053	4.147	3.353	23.655	24.814

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The lowest uptake of N, P and K was observed in the control. It was also observed that, in general, lime or dolomite or RHA as basal + PI (T_2, T_4 and T_6) registered lower values of N, P and K uptake compared to lime or dolomite or RHA as basal + 30 DAS (T_1, T_3 and T_5).

4.1.5.2. Uptake of Secondary Nutrients

The uptake of Ca, Mg and S was also significantly influenced by the treatments (Table 14). The grain uptake of Ca was the highest with lime as basal + 30 DAS (T_1) and was on par with all treatments except T_6 and T_7 and the treatment T_1 was superior to all other treatments in straw Ca uptake. The treatment lime as basal + 30 DAS (T_1) was found superior with respect to total Ca uptake. In the case of the grain and straw uptake as well as total Mg uptake, dolomite as basal + 30 DAS (T_3) was superior to all other treatments. With respect to S uptake, T_1 and T_3 registered significantly higher grain S uptake and T_1, T_3, T_5 and T_6 registered significantly higher straw S uptake which were on par. But T_3 (dolomite as basal + 30 DAS) registered significantly higher S uptake. The lowest uptake of Ca, Mg and S was recorded by T_7 (control).

4.1.5.3. Uptake of Micronutrients

The treatments had a significant influence on the uptake of micronutrients except Fe, grain uptake of Mn and straw uptake of Cu (Table 15).

The treatment lime as basal +30 DAS (T_1) recorded straw Mn uptake which was superior to all other treatments. The grain Zn uptake was the highest with dolomite as basal + 30 DAS (T_3) whereas RHA as basal + 30 DAS (T_5) and lime as basal + 30 DAS (T_1) registered significantly higher straw Zn uptake. The plant uptake of Mn and Zn were the highest with the treatment T_1 and it was on par with T_5 in the case of Zn uptake. Significantly higher Cu uptake in the grain was recorded by all treatments except T_6 which were on par.

Table 14. Effect of acidity amelioration practices on uptake of secondary nutrients, kg ha^{-1}

Treatments	Ca uptake			Mg uptake			S uptake		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	10.19	18.23	28.41	4.94	5.72	10.66	15.93	14.40	19.88
T_2	8.36	14.87	23.22	3.66	5.79	9.46	12.77	11.85	20.34
T_3	8.38	13.94	22.32	6.10	9.30	15.40	15.70	17.27	25.52
T_4	9.49	10.70	20.19	4.83	7.08	11.92	12.12	12.68	20.13
T_5	9.22	10.17	19.39	4.50	6.12	10.63	12.76	14.85	18.13
T_6	7.42	9.34	16.76	4.26	4.93	9.20	13.43	14.68	16.94
T_7	4.05	5.79	9.84	1.90	2.51	4.40	8.92	11.09	15.28
SEm (±)	0.52	0.47	0.67	0.37	0.40	0.64	0.63	1.02	0.60
CD(0.05)	1.587	1.453	2.064	1.151	1.218	1.981	1.954	3.147	1.853

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Table 15. Effect of acidity amelioration practices on uptake of micronutrients, kg ha^{-1}

Treatments	Fe uptake			Mn uptake			Zn uptake			Cu uptake			B uptake		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	1.10	1.24	2.34	0.19	1.24	1.43	0.21	0.53	0.74	0.05	0.09	0.16	0.08	0.09	0.18
T_2	1.21	1.01	2.23	0.17	1.03	1.20	0.16	0.31	0.48	0.06	0.08	0.15	0.07	0.07	0.14
T_3	1.26	1.03	2.29	0.16	0.83	0.99	0.28	0.22	0.37	0.06	0.06	0.10	0.09	0.09	0.18
T_4	1.10	1.23	2.33	0.17	0.84	1.45	0.14	0.41	0.66	0.05	0.07	0.13	0.08	0.07	0.15
T_5	1.24	1.20	2.43	0.17	0.98	1.15	0.14	0.47	0.61	0.06	0.07	0.17	0.09	0.09	0.18
T_6	1.49	0.95	2.44	0.20	0.59	0.76	0.18	0.21	0.39	0.03	0.07	0.13	0.07	0.09	0.16
T_7	0.99	1.13	2.13	0.15	0.80	0.69	0.14	0.21	0.35	0.05	0.06	0.09	0.04	0.05	0.08
SEm (±)	0.010	0.14	0.18	0.02	0.06	0.07	0.02	0.04	0.04	0.004	0.01	0.01	0.003	0.004	0.05
CD(0.05)	-	-	-	-	0.199	0.217	0.052	0.111	0.125	0.015	-	0.036	0.011	0.011	0.014

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All treatments except T_3 and T_7 registered higher total Cu uptake. The treatments T_1, T_3, T_4 and T_5 registered significantly higher uptake of B in the grain and the treatments T_1, T_3, T_5 and T_6 recorded significantly higher B in the straw. Similarly, the treatments lime or dolomite or RHA as basal + 30 DAS (T_1, T_3 and T_5) registered higher total B uptake which was significantly superior to other treatments. The control plots registered lower uptake of Fe, Mn, Zn and B uptake by plant.

4.1.5.2. Uptake of Na and Al

Table 16 depicts the significant influence of treatments on Na and Al uptake except on grain Al uptake.

The highest grain Na uptake was registered with dolomite as basal + PI (T_4). Meanwhile, all the treatments except lime as basal + 30 DAS, RHA as basal + PI and control (T_2, T_6 and T_7) recorded significantly higher straw Na uptake which were on par. All treatments except RHA as basal + PI (T_6) and control (T_7) recorded significantly higher Na uptake which were on par. The highest straw Al uptake was registered with T_6 which was on par with lime or RHA as basal + 30 DAS (T_1 and T_5). In the case of total Al uptake, RHA treatments (T_5 and T_6) recorded higher values than other treatments which were on par.

4.1.6 Soil Analysis

The data on soil analysis during the cropping period and after the experiment reflecting the effect of treatments are shown in Table 17 to 23.

4.1.6.1 Soil pH

It is seen from Table 17 that soil pH showed an increase over the initial value (4.68) during the cropping period upto PI stage in the treated plots while it decreased in the control plot. At harvest, pH decreased below the initial value in all the plots. During the cropping period, pH decreased from seedling to tillering stage with lime, dolomite or RHA applied as basal + PI (T_2, T_4 and T_6) and dolomite as basal + 30 DAS (T_3) but showed an increase from tillering to PI stage with T_2, T_4 and T_6.

Table 16. Effect of acidity amelioration practices on uptake of Na and Al, kg ha^{-1}

Treatments	Na uptake			Al uptake		
	Grain	Straw	Total	Grain	Straw	Total
T_1	1.82	14.07	15.89	0.78	0.53	1.31
T_2	1.69	12.06	13.75	0.71	0.49	1.19
T_3	1.70	14.11	15.81	0.60	0.44	1.04
T_4	2.08	12.35	14.43	0.85	0.37	1.22
T_5	1.63	14.23	15.86	0.96	0.74	1.70
T_6	1.66	11.51	13.17	0.89	0.77	1.66
T_7	1.02	8.45	9.48	0.72	0.47	1.19
SEm (±)	0.12	0.66	0.71	0.10	0.08	0.14
CD(0.05)	0.382	2.030	2.182	-	0.253	0.421

Acidity amelioration practices significantly influenced soil pH as evident from Table 17. At seedling stage of the crop, soil pH was the highest with lime as basal + 30 DAS (T_1) but was on par with lime as basal + PI (T_2) and dolomite treatments (T_3 and T_4). At tillering stage, lime or dolomite as basal + 30 DAS (T_1 and T_3) recorded higher soil pH. At PI stage, lime as basal + PI (T_2) recorded the highest soil pH followed by T_4 and T_1. At harvest also, the highest pH was recorded by T_2 which was on par with T_1, T_4 and T_3.

4.1.6.2 EC

The soil EC increased over the initial value during the cropping period with a sharp increase at harvest (Table 17). Perusal of the data also showed significant effect of treatments on soil EC only at seedling stage. Lime as basal + PI (T_2) had the highest soil EC at seedling stage and it was on par with all other treatments except RHA treatments (T_5 and T_6). The treatment effect on soil EC was not significant at other stages of soil sampling.

4.1.6.3 Dehydrogenase Enzyme Activity

The effect of acidity amelioration practices on dehydrogenase enzyme activity is presented in Table 18. At seedling stage, an increased dehydrogenase activity over the initial value (Table 3) was observed in the treated plots with a sharp increase in the lime and dolomite applied plots while the control plots showed lower enzyme activity. However, a decreasing trend in dehydrogenase activity was observed from seedling to harvest stage.

The treatments had significant effect on dehydrogenase activity at all stages. Higher dehydrogenase activity at seedling stage was found with dolomite treatments (T_3 and T_4). At tillering also, dolomite as basal + 30 DAS (T_3) recorded significantly superior enzyme activity. At PI stage, dolomite as basal + PI (T_4) had the highest activity which was on par with lime as basal + PI (T_2) while lime as basal + 30 DAS (T_1) had the highest activity at harvest which was on par with T_2, T_3 and T_4.

Table 17. Effect of acidity amelioration practices on soil pH and EC

Treatments	pH				EC (dSm^{-1})			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	5.80	6.13	5.40	4.17	0.77	0.60	0.57	2.00
T_2	5.63	5.07	6.07	4.37	0.80	0.60	0.77	1.93
T_3	5.63	5.47	5.13	3.97	0.67	0.67	0.63	1.83
T_4	5.43	5.07	5.53	4.17	0.67	0.70	0.53	1.77
T_5	5.00	5.03	5.03	3.57	0.47	0.43	0.63	1.77
T_6	5.10	4.70	4.80	3.87	0.33	0.40	0.67	1.90
T_7	4.50	4.53	4.60	3.63	0.73	0.87	0.77	1.97
SEm (±)	0.15	0.08	0.09	0.15	0.10	0.14	0.09	0.08
CD(0.05)	0.469	0.258	0.289	0.456	0.300	-	-	-

Table 18. Effect of acidity amelioration practices on dehydrogenase activity and organic carbon status in the soil

Treatments	Dehydrogenase activity (µg TPF g^{-1} soil 24 h^{-1})				Organic carbon (%)			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	147.98	114.58	90.02	91.07	4.26	4.30	4.20	3.48
T_2	143.75	110.81	118.88	89.50	4.20	4.89	3.83	3.81
T_3	166.31	140.10	100.37	84.70	3.78	3.89	3.72	3.43
T_4	176.23	101.81	121.85	84.69	3.38	3.98	3.88	3.18
T_5	61.30	57.01	24.85	20.29	4.34	4.58	4.33	3.50
T_6	54.94	30.87	29.11	20.83	4.24	4.18	3.53	3.42
T_7	47.43	27.28	21.24	11.13	3.83	4.26	3.29	3.19
SEm (±)	11.60	6.21	5.68	5.31	0.26	0.37	0.13	0.30
CD(0.05)	35.756	19.141	17.502	16.359	-	-	0.414	-

4.1.6.4 Organic Carbon

Table 18 depicts the effect of acidity amelioration practices on soil organic carbon. The soil organic carbon was initially high (Table 3). The OC content showed a slight increase from seedling to tillering stage and decreased towards harvest.

The effect of treatments on OC was significant only during PI stage when the highest OC content was obtained with RHA as basal + 30 DAS (T_5) but was on par with lime treatments (T_1 and T_2) and RHA as basal + PI (T_4).

4.1.6.5 Available N

Table 19 shows the effect of acidity amelioration practices on available N in the soil. The treated plots showed higher available N status compared to the initial value during the cropping period and even at harvest. The increased available N status in the control plots at seedling stage showed a reduction at harvest stage. However, the available N status in the control plots was maintained near the initial status throughout the cropping period.

Significant influence of treatments was observed at all stages except at harvest. At seedling stage, lime as basal + PI (T_2) recorded the highest soil available N and was on par with dolomite treatments (T_3 and T_4). At tillering and PI stages, all treatments except control (T_7) were on par and were superior to T_7. The control recorded lower available N status at all stages.

4.1.6.6 Available P

Available soil P status as influenced by the acidity amelioration practices is given in Table 19. The status of available P in the soil was low initially which was enhanced due to treatments. A sharp increase in available P status was observed from seedling to tillering stage in all the treatments. An increase in P availability was also noticed from tillering to PI stage but was reduced in all the treatments at harvest. Lower available P contents were recorded in the control plot at all stages.

The treatment had significant effect only at tillering and PI stages. At tillering stage, lime or dolomite or RHA as basal + 30 DAS (T_1, T_3 and T_5 respectively) recorded significantly higher status of soil available P which were on par. Lime or dolomite as basal + 30 DAS (T_1 and T_3) registered significantly higher available P at PI stage compared to other treatments.

4.1.6.7 Available K

The effect on soil available K is shown in Table 19. Compared to initial status, available K status was lowered at seedling stage which further increased at tillering but showed a drastic reduction at PI and harvest stages.

It can be seen from Table 19 that the treatments failed to express significant effect on soil available K during the cropping period and after the experiment.

4.1.6.8 Available Ca

The effect of treatments on soil available Ca is presented in Table 20. The soil was initially deficient in available Ca (Table 3) but the status could be improved by soil amelioration practices. Lower status of available Ca was observed in the control plots at all stages.

Significant effect of treatments on soil available Ca was observed from Table 20. The treatment lime as basal + 30 DAS (T_1) had the highest soil available Ca which was on par with lime as basal + PI (T_2) at seedling stage. At tillering, the highest available Ca content was registered by dolomite as basal + 30 DAS (T_3) which was on par with T_1. The highest available Ca was recorded by dolomite as basal + PI (T_4) at both PI and harvest stages but was on par with T_2 at PI stage and with T_2 and T_3 at harvest.

Table 19. Effect of acidity amelioration practices on available N, P and K status in the soil, kg ha^{-1}

Treatments	Available N				Available P				Available K			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	359.59	345.04	388.87	307.23	4.60	18.86	19.19	6.83	120.85	153.42	98.07	46.64
T_2	437.81	366.31	380.50	276.66	4.33	14.58	15.35	6.23	116.18	160.60	82.80	49.39
T_3	423.43	347.05	363.78	317.78	4.93	18.05	17.20	4.14	121.00	157.81	94.31	52.60
T_4	401.63	320.31	407.73	342.87	4.10	12.63	13.80	5.95	139.71	173.36	98.96	52.33
T_5	354.55	397.22	418.14	326.14	4.43	17.51	14.57	7.92	120.77	187.48	107.22	60.45
T_6	372.34	401.41	347.05	292.69	5.30	13.96	12.65	4.89	113.80	177.96	101.81	70.93
T_7	283.55	238.34	234.16	230.21	3.83	8.62	9.53	5.75	112.63	135.97	94.74	68.62
SEm (±)	20.12	26.99	27.12	39.00	0.40	1.14	1.04	0.93	8.93	12.06	5.91	5.74
CD(0.05)	62.001	83.155	83.568	-	-	3.502	3.204	-	-	-	-	-

4.1.6.9 Available Mg

Table 20 depicts the influence of acidity amelioration practices on available Mg in the soil. Initially, the soil was deficient in Mg (Table 3). The dolomite treatments raised available Mg above the deficiency level at all stages. Available Mg status in dolomite applied plots generally increased upto PI stage and decreased at harvest. In the case of all other treatments, it was above initial status at seedling and tillering stages but below the initial value at PI and harvest stages. The control showed drastic decline in available Mg content at harvest stage.

The treatments had significant influence on available Mg status at all stages of experimentation. Dolomite as basal + PI (T_4) recorded significantly higher available Mg at seedling and harvest stages which was on par with dolomite as basal + 30 DAS at seedling stage. At tillering and PI stages, dolomite as basal + 30 DAS registered significantly higher Mg status.

4.1.6.10 Available S

The effect of treatments on soil available S is presented in Table 20. The initial S content of soil was very high (Table 3) and it decreased during the cropping period (Table 20). Available S content increased at harvest compared to PI stage for all the treatments.

Significant influence of acidity amelioration practices on soil available S at all stages except harvest is evident from Table 20. At all stages, control (T_7) had the highest available S content. It was on par with all others except dolomite or lime as basal + PI (T_4 and T_2) at seedling stage, with RHA as basal + PI (T_6), and dolomite treatments (T_3 and $T_{4,}$) at tillering stage and with dolomite as basal + 30 DAS (T_3) at PI stage.

Table 20. Effect of acidity amelioration practices on available Ca, Mg and S status in the soil, mg kg^{-1}

Treatments	Available Ca				Available Mg				Available S			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	484.40	497.30	375.97	128.53	69.00	67.80	51.87	41.47	489.23	227.70	318.40	578.97
T_2	412.10	399.30	452.67	175.70	62.63	54.30	43.30	32.60	323.40	414.90	301.63	467.20
T_3	350.00	527.60	361.50	161.30	137.00	184.67	207.07	128.30	602.83	454.53	462.03	538.57
T_4	350.60	430.23	505.57	178.57	139.30	123.07	148.93	159.17	423.03	469.87	289.13	595.93
T_5	273.33	219.63	170.33	108.67	92.63	71.40	50.80	42.27	503.83	405.83	377.47	541.63
T_6	315.80	184.70	226.63	111.07	96.93	81.20	50.10	33.83	574.60	511.00	356.67	512.87
T_7	180.47	142.27	151.50	39.34	60.17	49.20	32.67	22.70	627.30	536.03	489.60	646.30
SEm (±)	26.72	26.87	22.61	14.23	7.87	6.10	8.66	8.94	54.63	38.43	20.77	49.79
CD(0.05)	82.342	82.803	69.672	43.838	24.266	18.783	26.693	27.558	168.324	118.399	63.989	-

4.1.6.11 Available Fe

Table 21 shows the effect of acidity amelioration practices on available Fe content in the soil. The soil was initially high in Fe (Table 3) which decreased in the ameliorated plots. However, available Fe content increased at harvest.

Table 21 shows the significant effect of acidity amelioration practices on soil available Fe content. The control (T_7) recorded significantly higher contents of soil available Fe at all stages. All other treatments were on par except lime as basal + PI (T_2) at seedling stage and lime as basal + 30 DAS (T_1) at tillering stage which showed significantly lower values. Lime as basal + PI (T_2) registered significantly lower values at PI and harvest stages.

4.1.6.12 Available Mn

Initially, Mn content in the soil was high (Table 3) which decreased during the cropping period (Table 21).

A perusal of the data in Table 21 shows the significant effect of treatments on available Mn content in the soil at all stages except at harvest. The highest soil available Mn was recorded by lime as basal + PI (T_2) at seedling stage and was on par with dolomite as basal + PI (T_4) and lime as basal + 30 DAS (T_1). At tillering, lime as basal + 30 DAS (T_1) registered the highest value but was on par with T_2, dolomite as basal + 30 DAS (T_3) and RHA as basal + PI (T_6). At PI stage, the highest soil available Mn was found with T_2 and was on par with T_4. At all stages, control (T_7) registered the lowest value of available Mn in the soil.

4.1.6.13 Available Zn

The data on soil available Zn status as influenced by the treatments are furnished in Table 21. Available Zn status in the soil showed values lower than the initial status during and after the cropping period (Table 3).

No significant effect of treatment on available Zn status was observed at any stage of sampling.

Table 21. Effect of acidity amelioration practices on available Fe, Mn and Zn status in the soil, mg kg^{-1}

Treatments	Available Fe				Available Mn				Available Zn			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	280.03	235.77	226.47	344.07	5.61	7.09	5.69	4.59	1.90	2.13	2.16	2.82
T_2	237.30	277.57	184.07	315.53	8.26	6.36	7.62	4.36	2.94	2.29	1.97	3.01
T_3	358.67	285.30	200.93	364.73	4.75	6.16	5.23	4.16	3.37	2.48	2.37	3.61
T_4	359.20	309.43	239.87	373.30	6.16	5.27	6.69	4.68	2.12	1.63	1.57	2.19
T_5	310.80	287.27	252.03	366.97	4.70	5.33	5.79	3.78	2.44	1.93	2.22	2.41
T_6	328.87	314.70	237.10	366.00	3.87	5.83	5.17	4.46	3.22	2.84	2.66	3.49
T_7	473.00	429.8	439.07	501.63	2.67	3.27	2.83	2.92	3.57	2.22	1.84	2.25
SEm (±)	29.90	15.39	20.53	18.98	0.93	0.49	0.38	0.36	0.50	0.30	0.22	0.40
CD(0.05)	92.141	47.406	63.246	58.490	2.853	1.493	1.159	-	-	-	-	-

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4.1.6.14 Available Cu

Table 22 depicts the effect of acidity amelioration practices on soil available Cu. During and after the crop, available Cu content decreased from the initial status (Table 3).

The treatments had significant influence on available Cu status at tillering and PI stages only. At tillering stage, control (T_7) recorded the highest value and was on par with dolomite treatments (T_4 and T_3). At PI stage, higher soil available Cu content was registered by dolomite as basal + PI (T_4) which was on par with control (T_7) and lime as basal + PI (T_2).

4.1.6.15 Available B

Available B content in the soil as influenced by acidity amelioration practices is furnished in Table 22. Initially, the soil was deficient in B (Table 3) which improved during the cropping period (Table 22).

Significant effect of treatments was observed on soil available B at all stages of sampling except at harvest (Table 22). The highest soil available B was recorded by dolomite as basal + 30 DAS (T_3) which was on par with lime as basal + 30 DAS (T_1) and RHA as basal + PI (T_6) at both seedling and tillering stages. At PI stage, dolomite as basal + PI (T_4) showed the highest content of soil available B but was on par with lime as basal + PI (T_2). At all these stages, lower values were recorded by control (T_7).

4.1.6.16 Available Na

The data on soil available Na status as influenced by acidity amelioration practices is presented in Table 23. Soil Na content increased over the initial value (Table 3) during all the stages, irrespective of treatments.

Table 22. Effect of acidity amelioration practices on available Cu and B status in the soil, mg kg^{-1}

Treatments	Available Cu				Available B			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	3.84	3.08	2.94	3.90	0.58	0.51	0.42	0.38
T_2	3.98	2.45	4.00	3.64	0.50	0.48	0.56	0.44
T_3	4.39	3.96	3.13	4.14	0.65	0.59	0.48	0.41
T_4	2.89	4.18	4.52	3.88	0.49	0.46	0.60	0.34
T_5	3.58	2.12	2.50	4.05	0.44	0.49	0.39	0.44
T_6	3.15	2.09	2.67	2.81	0.54	0.56	0.40	0.35
T_7	3.58	4.41	4.27	3.98	0.38	0.38	0.33	0.29
SEm (±)	0.36	0.24	0.43	0.51	0.04	0.03	0.03	0.04
CD(0.05)	-	0.751	1.328	-	0.121	0.093	0.089	-

Table 23. Effect of acidity amelioration practices on available Na and exchangeable Al status in the soil, mg kg^{-1}

Treatments	Available Na				Exchangeable Al			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	82.39	60.28	65.68	70.17	35.33	35.63	54.88	54.08
T_2	81.38	61.91	78.88	59.69	35.19	42.39	53.42	54.45
T_3	92.13	63.33	72.98	69.67	35.06	41.42	55.21	57.15
T_4	88.12	56.83	75.24	56.25	35.81	34.62	55.21	57.37
T_5	69.73	53.79	83.27	65.68	37.92	39.63	54.60	56.63
T_6	75.06	46.96	75.28	61.84	36.51	34.31	55.89	47.67
T_7	86.79	81.67	75.55	62.90	48.31	41.15	62.18	62.35
SEm (±)	2.64	4.73	8.25	4.71	1.60	2.45	1.92	1.54
CD(0.05)	8.122	14.583	-	-	4.925	7.554	5.905	4.757

The treatments had significant influence on Na content in the soil only at seedling and tillering stages. Significantly higher Na content in the soil were registered by dolomite treatments (T_3 and T_4) and control (T_7) which were on par at seedling stage. At tillering stage, T_7 recorded the highest Na content in the soil. Also, all other treatments except RHA as basal + PI (T_6) were on par.

4.1.6.17 Exchangeable Al

The effect of acidity amelioration practices on soil exchangeable Al is shown in Table 23. Exchangeable Al status was reduced from the initial value (Table 3) at seedling and tillering stages which further increased at PI stage and that status was maintained at harvest.

Table 23 proved the significance of treatment effects on exchangeable Al status. At seedling stage, significantly higher exchangeable Al was recorded by control (T_7) while all other treatments were on par in their effects. All treatments except dolomite as basal + PI (T_4) and RHA as basal + PI (T_6) were on par in their effects on soil exchangeable Al at tillering stage. At PI stage, all treatments were on par except T_7 which registered significantly higher exchangeable Al in the soil. Significantly higher content of exchangeable Al was registered by control (T_7) at harvest while all other treatments except T_6 were on par.

4.1.7 Pest and Disease Incidence

When the incidence of stem borer (*Scirpophaga incertulas*) was noticed at tillering stage, scoring was done as per the score chart (Appendix IV) of International Rice Research Institute (IRRI, 1981). Soil application of Fertera (chlorantraniliprole 0.4% GR) was done against the pest. The control treatment (T_7) had the highest score but was on par with dolomite treatments (T_3 and T_4) and lime as basal + 30 DAS (T_1) and lower incidence of stem borer was observed with T_5 and T_6 (RHA treatments) (Table 24.).

4.1.8 Economics of Cultivation

The data presented in Table 25 revealed significant effect of treatments on net income and BCR. The highest net income and BCR were recorded by dolomite as basal + 30 DAS (T_3) but was on par with RHA as basal + 30 DAS (T_5) and lime as basal + 30 DAS (T_1) in both the cases and also with RHA as basal + 30 DAS (T_6) in the case of BCR. The lowest net income and BCR were registered by control (T_7).

4.1.9 Correlation analysis

Correlation analysis of grain yield versus LAI, K/Na_{leaves}, panicle number, flag leaf nutrient content and nutrient uptake are given in Table 26 and soil pH versus available nutrients in the soil in Table 27.

The grain yield was significantly and positively correlated with LAI at MT and PI stages and panicle number (Table 26). The grain yield was also significantly and positively correlated with P, Mg and B contents and significantly and negatively correlated with S, Fe, Mn, Cu, Na and Al contents of the flag leaf. There was significant and positive correlation of grain yield with uptake of all nutrients except that of Fe, Zn and Al.

Table 27 depicts correlation analysis of soil pH versus available nutrients in the soil during seedling, tillering, PI and harvest stages. Soil pH had significant and positive correlation with available N at seedling and tillering stages and with available P at tillering and PI stages. Significant and positive correlation of pH with available Ca was observed at all stages. Soil pH was significantly and negatively correlated with available S at tillering and PI stages and with available Fe at all stages. Soil pH had significant and positive correlation with available Mn at seedling, tillering and PI stages and significant and negative correlation with Zn only at seedling stage. At seedling and PI stages, there was significant and positive correlation of pH with available B whereas significant and negative correlation with exchangeable Al.

Table 24. Effect of acidity amelioration practices on the incidence of stem borer (*Scirpophaga incertulas*), %

Treatments	Incidence of stem borer
T_1	7.33
T_2	5.33
T_3	8.67
T_4	6.67
T_5	3.33
T_6	4.67
T_7	9.33
SEm (±)	1.11
CD (0.05)	3.429

Table 25. Effect of acidity amelioration practices on economics of cultivation

Treatments	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	BCR
T_1	136420	99417	3.23
T_2	140220	78263	2.76
T_3	157130	105980	3.38
T_4	129960	88817	3.00
T_5	150480	100647	3.31
T_6	128060	89057	3.05
T_7	74100	39327	1.93
SEm (±)	-	5246	0.12
CD(0.05)	-	16164	0.366

Table 26. Correlation analysis of grain yield versus LAI, K/Na $_{Leaves}$, panicle number, nutrient content of flag leaf and nutrient uptake at harvest

Variables correlated with grain yield	Correlation coefficient
LAI at maximum tillering stage	0.895**
LAI at panicle initiation stage	0.869**
Number of panicles m^{-2}	0.731**
K/Na_{Leaves}	0.424
N content of flag leaf	0.408
P content	0.499*
K content	0.412
Ca content	0.311
Mg content	0.534*
S content	-0.630**
Fe content	-0.691**
Mn content	-0.860**
Zn content	-0.245
Cu content	-0.439*
B content	0.541**
Na content	-0.588**
Al content	-0.436*
N uptake at harvest	0.847**
P uptake	0.846**
K uptake	0.815**
Ca uptake	0.747**
Mg uptake	0.869**
S uptake	0.751**
Fe uptake	0.321
Mn uptake	0.511*
Zn uptake	0.396
Cu uptake	0.565**
B uptake	0.924**
Na uptake	0.855**
Al uptake	0.098

* significant at 0.05 level
** significant at 0.01 level

Table 27. Correlation analysis of soil pH versus available nutrients in soil

Variables correlated with soil pH	Seedling	Tillering	PI	Harvest
Available N	0.556**	0.112	0.532*	0.134
Available P	0.186	0.629**	0.454*	0.178
Available K	0.298	-0.068	-0.331	-0.401
Available Ca	0.898**	0.780**	0.801**	0.659**
Available Mg	0.282	0.252	0.120	0.152
Available S	-0.367	-0.790**	-0.595**	-0.172
Available Fe	-0.706**	-0.715**	-0.597**	-0.539*
Available Mn	0.478*	0.677**	0.772**	0.413
Available Zn	-0.506*	-0.125	-0.229	0.227
Available Cu	0.000	0.024	0.235	0.038
Available B	0.587**	0.387	0.603**	0.247
Available Na	0.223	-0.111	0.048	-0.043
Exchangeable Al	-0.757**	-0.156	-0.465*	-0.050

* significant at 0.05 level
**significant at 0.01 level

4.2. Experiment II- Standardization of nutrient management practices for rice in vaikom kari.

4.2.1 Growth Characters

The growth characters of rice such as plant height, number of tillers m^{-2} and LAI at MT, PI and harvest stages as influenced by nutrient management practices during 2015 and 2016 are given in Table 28, 29 and 30.

4.2.1.1 Plant Height

The data presented in Table 28 revealed significant influence of nutrient management practices on plant height at all stages during both the years.

During first year, the tallest plants at MT were found with lime + $MgSO_4$ + POP+ 13:0:45 + borax (T_8) but were on par with dolomite + borax (T_3), dolomite + 13:0:45 + borax (T_4) and lime + $MgSO_4$ + POP (T_5). At PI stage, T_3 had the tallest plants but was on par with all treatments except dolomite + POP + 13:0:45 (T_2), 75% POP + lime + $MgSO_4$ + 13:0:45 + borax (T_{13}) and RHA treatments (T_9, T_{10}, T_{11} and T_{12}). Plant height at harvest was the highest with lime + POP + 13:0:45 (T_{14}) which was on par with T_2 and T_3. RHA treatments produced significantly shorter plants compared to other treatments at all stages, except T_3, T_5 and T_8 during PI stage.

Plants at MT were significantly taller with dolomite + POP (T_1) during second year, which was on par with all treatments except RHA treatments (T_9, T_{10}, T_{11} and T_{12}), T_{15} and T_{16}. At PI stage, lime + POP + borax (T_{15}) produced significantly taller plants but was on par with lime+ POP + $MgSO_4$ + borax (T_7). Plant height at harvest was the highest with T_7 which was on par with all other treatments except dolomite + POP + 13:0:45 + borax (T_4), RHA treatments and T_{16}. Significantly shorter plants were produced by RHA treatments at all stages.

Table 28. Effect of nutrient management practices on plant height, cm

Treatments	Plant height					
	2015			2016		
	MT	PI	Harvest	MT	PI	Harvest
T_1	71.47	73.20	92.00	76.00	83.13	91.60
T_2	71.00	71.93	96.07	72.73	82.60	92.93
T_3	72.87	74.60	97.00	75.07	86.13	92.07
T_4	73.47	74.00	92.87	74.33	85.13	90.40
T_5	73.87	74.20	94.33	74.33	84.33	92.00
T_6	71.80	73.13	94.93	72.67	84.93	91.33
T_7	71.93	73.40	92.93	73.33	88.13	93.20
T_8	73.90	74.53	94.93	75.80	84.53	92.67
T_9	69.40	70.00	90.73	68.73	82.87	89.07
T_{10}	68.87	72.00	91.40	64.33	83.13	87.20
T_{11}	69.60	71.20	90.80	64.40	81.33	88.87
T_{12}	68.87	71.13	90.93	65.93	81.87	87.20
T_{13}	71.13	71.93	93.93	75.80	84.20	92.07
T_{14}	72.47	73.33	97.67	74.33	84.20	91.87
T_{15}	70.00	72.67	95.13	69.87	88.20	91.27
T_{16}	72.40	73.27	95.00	66.40	82.40	90.60
SEm (±)	0.45	0.74	0.79	1.70	0.60	0.89
CD (0.05)	1.302	2.137	2.294	4.918	1.719	2.579

4.2.1.2 Number of Tillers

A perusal of Table 29 reveals that the effect of treatments on number of tillers at MT was not significant during first year. However, at PI stage lime + $MgSO_4$ + POP+ 13:0:45 (T_6) had the highest tiller number (445) which was on par with all other treatments except RHA treatments. Number of tillers at harvest was significantly more with dolomite treatments except that with combined spray (T_1 to T_3), lime + $MgSO_4$ + POP treatments except that with combined spray (T_5 to T_7) and lime + POP + 13:0:45 (T_{14}) which were on par with each other.

During second year, the treatment lime + $MgSO_4$ + POP (T_5) recorded the highest number of tillers at MT (428.33) and dolomite + POP + borax (T_3) and lime + POP + borax (T_{15}) had the highest tiller number at PI (same value-501.67). All other treatments except those involving RHA were found on par during MT and PI stages. However, at harvest, dolomite + POP (T_1) produced significantly higher tiller number but was on par with all treatments except T_8 and RHA treatments.

4.2.1.3 Leaf Area Index

The data on the effect of treatments on LAI in Table 30 during both the years showed significant influence of the treatments at all stages except at harvest during second year.

During first year, the highest LAI was recorded by lime + $MgSO_4$ + POP (T_5) at MT (5.33) and PI (5.52) stages which was on par with all treatments except T_{15} and RHA at MT and 75% POP (T_{13}) and RHA treatments at PI stage. At harvest, LAI was the highest (2.13) with dolomite + POP + borax (T_3) which was on par with other dolomite treatments and significantly superior to other treatments.

Second year data also showed plants with the highest LAI with the treatment T_5 at both MT (5.42) and PI (6.47) stages which was on par with all treatments except those involving RHA at MT and T_{13} and RHA treatments at PI stage. The treatments had no significant effect on LAI at harvest.

Table 29. Effect of nutrient management practices on number of tillers m^{-2}

Treatments	Number of tillers m^{-2}					
	2015			2016		
	MT	PI	Harvest	MT	PI	Harvest
T_1	426.67	433.33	351.67	426.67	485.00	361.67
T_2	401.67	430.00	345.00	416.67	496.67	355.00
T_3	413.33	440.00	356.67	420.00	501.67	355.00
T_4	423.33	436.67	341.67	420.00	483.33	353.33
T_5	416.67	436.67	336.67	428.33	495.00	348.33
T_6	413.33	445.00	335.00	426.67	490.00	353.33
T_7	388.33	436.67	331.67	406.67	486.67	351.67
T_8	395.00	418.33	320.00	406.67	498.33	333.33
T_9	356.67	370.00	251.67	383.33	426.67	301.67
T_{10}	355.00	378.33	261.67	380.00	435.00	311.67
T_{11}	361.67	365.00	276.67	366.67	440.00	325.00
T_{12}	356.67	381.67	263.33	353.33	410.00	310.00
T_{13}	408.33	423.33	316.67	411.67	476.67	345.00
T_{14}	413.33	428.33	331.67	416.67	496.67	346.67
T_{15}	401.67	428.33	316.67	403.33	501.67	343.33
T_{16}	395.00	425.00	328.33	395.00	491.67	355.00
SEm (±)	23.83	15.21	8.84	11.73	13.82	6.71
CD(0.05)	-	43.944	25.542	33.892	39.904	19.385

Table 30. Effect of nutrient management practices on leaf area index

Treatments	Leaf area index					
	2015			2016		
	MT	PI	Harvest	MT	PI	Harvest
T_1	4.98	5.46	2.12	5.02	6.25	2.16
T_2	4.73	5.27	2.03	5.15	6.35	2.09
T_3	5.06	5.47	2.13	5.23	6.33	2.09
T_4	5.19	5.28	1.99	5.16	6.18	2.09
T_5	5.33	5.52	1.93	5.42	6.47	2.01
T_6	4.86	5.42	1.97	5.28	6.36	2.71
T_7	4.89	5.36	1.96	5.13	6.14	2.06
T_8	4.84	5.33	1.89	5.07	6.44	1.95
T_9	4.14	4.07	1.31	4.70	4.77	1.66
T_{10}	3.91	4.40	1.39	4.48	4.66	1.72
T_{11}	3.84	4.19	1.46	4.18	4.70	1.83
T_{12}	3.83	4.39	1.38	4.07	4.30	1.71
T_{13}	4.92	4.95	1.83	4.92	5.72	2.01
T_{14}	4.99	5.15	1.90	5.13	6.24	2.03
T_{15}	4.47	5.34	1.86	4.87	6.38	2.01
T_{16}	4.75	5.13	1.86	4.88	6.27	2.10
SEm (±)	0.27	0.16	0.05	0.21	0.18	0.18
CD(0.05)	0.777	0.462	0.148	0.613	0.517	-

4.2.2 Yield Attributes and Yield

The effect of treatments on yield attributes such as panicle number m^{-2}, 1000 grain weight and sterility percentage at harvest is furnished in Table 31. The grain yield (year wise and pooled), straw yield and HI as influenced by nutrient management practices are depicted in Table 32.

4.2.2.1 Number of Panicles m^{-2}

The data in Table 31 revealed significant influence of treatments on panicle number during both the years.

Dolomite + POP + 13:0:45 (T_2) produced the highest panicle number during first year (336.67) closely followed by dolomite + POP + borax (T_3 - 335) and dolomite + POP + 13:0:45 + borax (T_4 - 335). Other dolomite treatments and lime + $MgSO_4$ + POP treatments except T_8 were found on par with T_2.

During second year, the highest panicle number (345) was produced by T_2 followed by dolomite + POP (T_1 - 341.67), T_4 (338.33) and lime + POP + 13:0:45 + borax (T_{16} - 336.67). But all treatments were on par except T_7 and T_8 and those involving RHA as well as 75% POP.

4.2.2.2 1000 Grain Weight

Significant effect of treatments on 1000 grain weight was observed during both the years (Table 31).

During first year, all treatments except those involving RHA and T_{15} were on par in their effects on 1000 grain weight. The highest value (24.87 g) was recorded by dolomite + POP + 13:0:45 (T_2) followed by dolomite + POP (T_4 - 24.8) and lime + $MgSO_4$ + POP+ borax (T_7 - 24.8).

Table 31. Effect of nutrient management practices on yield attributes

Treatments	2015			2016		
	Panicle no. m^{-2}	1000 grain weight (g)	Sterility (%)	Panicle no. m^{-2}	1000 grain weight (g)	Sterility (%)
T_1	325.00	24.60	11.33	341.67	24.20	11.67
T_2	336.67	24.87	10.80	345.00	25.07	11.13
T_3	335.00	24.47	10.93	335.00	24.80	11.53
T_4	335.00	24.80	10.33	338.33	25.33	11.00
T_5	328.33	24.73	11.60	331.67	24.40	11.47
T_6	321.67	24.73	11.53	333.33	25.00	11.27
T_7	318.33	24.80	11.33	321.67	24.73	11.33
T_8	305.00	24.67	11.13	320.00	25.00	11.13
T_9	230.00	23.47	16.00	285.00	23.33	15.53
T_{10}	236.67	23.27	15.20	286.67	23.47	14.80
T_{11}	246.67	23.27	15.20	298.33	23.27	14.60
T_{12}	231.67	23.13	16.60	283.33	23.47	14.07
T_{13}	295.00	24.33	13.27	321.67	24.27	12.87
T_{14}	308.33	24.47	13.13	323.33	24.60	12.40
T_{15}	291.67	24.13	12.87	325.00	24.47	12.80
T_{16}	295.00	24.33	12.80	336.67	24.67	12.53
SEm (±)	7.82	0.22	0.46	7.60	0.15	0.30
CD(0.05)	22.572	0.627	1.333	21.956	0.439	0.863

The highest value of 1000 grain weight during second year (25.33) was registered by dolomite + POP + 13:0:45 + borax (T_4) but was on par with dolomite + POP + 13:0:45 (T_2), lime + $MgSO_4$ + POP+ 13:0:45 (T_6) and lime + $MgSO_4$ + POP+ 13:0:45 + borax (T_8).

4.2.2.3 Sterility Percentage

The data in Table 31 showed the significant influence of treatments on grain sterility percentage during both the years.

During first year, dolomite + POP + 13:0:45 + borax (T_4) recorded the lowest sterility percentage (10.33%) closely followed by dolomite + POP + 13:0:45 (T_2 - 10.8%) but was on par with all other treatments of dolomite and lime + $MgSO_4$ + POP+ 13:0:45 (T_6). Comparatively higher sterility percentage was recorded by RHA treatments.

During second year also, the treatment T_4 registered the lowest sterility percentage (11 %) followed by T_2 (11.13 %) and lime + $MgSO_4$ + POP+ 13:0:45 + borax (T_8 - 11.13%). Also all treatments involving dolomite and lime + $MgSO_4$ + POP registered lower sterility percentage and were on par. The RHA treatments showed higher sterility percentage of grains.

4.2.2.4 Grain Yield

The data in Table 32 unveil the significant effect of treatments on grain yield during both the years as well as in the pooled data.

Dolomite + POP + 13:0:45 (T_2) registered the highest yield of 5.42 t ha^{-1} during first year but it was on par with dolomite + POP + 13:0:45 + borax (T_4) and lime + $MgSO_4$ + POP + 13:0:45 (T_6). Significantly lower yields were produced by the treatments involving RHA (T_9 to T_{12}). Lime + $MgSO_4$ + POP+ 13:0:45 + borax (T_8) recorded significantly higher yield than treatment involving 75% POP (T_{13}).

During second year also, the treatment T_2 recorded the highest yield (5.57 t ha^{-1}) and it was on par with T_4, T_8, T_6, T_3 (dolomite + POP + borax) and lime + POP + 13:0:45 + borax (T_{16}). The treatments involving RHA as well as 75% POP produced lower yields. It can be seen that the effects of T_2, T_4 and T_6 were on par during both the years.

The pooled analysis of two years' data also proved the significance of treatments on grain yield. The highest yield of 5.49 t ha^{-1} was recorded by the treatment T_2 followed by T_4, T_6, T_8 and T_3 which were on par. The treatments involving RHA and 75% POP, which were on par, registered significantly lower grain yield in the pooled data.

4.2.2.5 Straw Yield

Straw yield was profoundly influenced by the treatments (Table 32). Dolomite + POP + 13:0:45 (T_2) registered the highest straw yield during first year which was on par with other dolomite treatments (T_1, T_3 and T_4), lime + $MgSO_4$ + POP + 13:0:45 (T_6), treatment involving 75% POP (T_{13}) and lime without $MgSO_4$ combined with 13:0:45 or 13:0:45 + borax (T_{14} and T_{16}). The treatments involving RHA recorded significantly lower straw yield.

During second year, the highest straw yield was produced by T_6 but was on par with all treatments except dolomite or lime + $MgSO_4$ along with 100% POP alone (T_1 and T_5) and RHA treatments (T_9 to T_{12}).

4.2.2.6 Harvest Index

The treatments expressed significant effect on HI only during first year (Table 32).

The HI was the highest for dolomite + POP + 13:0:45 + borax (T_4) during first year and was on par with all treatments except T_9 and T_{11} (RHA treatments), 75% POP (T_{13}) and treatments of lime without $MgSO_4$ (T_{14}, T_{15} and T_{16}). The lowest value was recorded by T_{13}.

Table 32. Effect of nutrient management practices on yield and harvest index

Treatments	2015			2016			Pooled grain yield ($t\ ha^{-1}$)
	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	HI	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	HI	
T_1	5.00	6.10	0.45	5.13	5.84	0.47	5.06
T_2	5.42	6.58	0.45	5.57	6.21	0.47	5.49
T_3	4.95	6.33	0.44	5.25	6.62	0.44	5.10
T_4	5.33	6.08	0.47	5.48	6.48	0.46	5.41
T_5	4.33	5.30	0.45	5.01	5.83	0.46	4.67
T_6	5.10	6.00	0.46	5.32	6.73	0.44	5.21
T_7	4.80	5.75	0.46	5.15	6.32	0.45	4.98
T_8	4.92	5.83	0.46	5.37	6.20	0.46	5.14
T_9	3.22	4.58	0.41	3.97	5.12	0.44	3.59
T_{10}	3.62	4.42	0.45	4.79	5.57	0.46	4.20
T_{11}	3.42	4.92	0.41	4.45	5.47	0.45	3.93
T_{12}	3.78	4.85	0.44	4.58	5.42	0.46	4.18
T_{13}	4.17	6.28	0.40	4.88	6.11	0.44	4.53
T_{14}	4.48	6.10	0.42	4.95	6.19	0.45	4.72
T_{15}	4.22	5.83	0.42	5.03	6.07	0.45	4.63
T_{16}	4.63	6.10	0.43	5.20	6.58	0.44	4.92
SEm (±)	0.12	0.22	0.01	0.14	0.32	0.01	0.13
CD(0.05)	0.333	0.627	0.030	0.410	0.663	-	0.386

4.2.3. Dry Matter Production

Data on dry matter production as affected by the treatments are given in Table 33.

4.2.3.1 Grain Dry Matter Yield

The treatments had significant influence on grain dry matter yield during both the years (Table 33).

During first year, higher grain dry matter yield was recorded by dolomite with 13:0:45 (T_2) or 13:0:45 and borax (T_4) which were on par. During second year, all the dolomite treatments except the one with borax (T_3) and lime + $MgSO_4$ with 13:0:45 alone (T_6) or 13:0:45 and borax (T_8) were on par in recording higher grain dry matter yield. During both the years, the treatments involving RHA (T_9 to T_{12}) and T_{13} (75% POP), which were on par, registered significantly lower grain dry matter yield.

4.2.3.2 Straw Dry Matter Yield

The straw dry matter yield was profoundly influenced by the treatments (Table 33).

The straw dry matter yield also was higher for dolomite with 13:0:45 (T_2) or 13:0:45 and borax (T_4) which were on par during first year. During second year, all dolomite treatments (T_1 to T_4) and lime + $MgSO_4$ + POP with 13:0:45 alone (T_6) or 13:0:45 and borax (T_8) produced significantly higher straw dry matter yield and were on par with each other. In general, RHA treatments (T_9 to T_{12}) and treatment involving 75% POP (T_{13}) were found inferior in this respect.

4.2.3.3 Total Dry Matter Production

The data presented in Table 33 revealed significant influence of treatments on TDMP during both the years.

Table 33. Effect of nutrient management practices on dry matter production at harvest, t ha^{-1}

Treatments	2015			2016		
	Grain dry matter yield	Straw dry matter yield	TDMP	Grain dry matter yield	Straw dry matter yield	TDMP
T_1	5.35	6.37	11.72	6.27	7.22	13.66
T_2	6.55	7.60	14.15	6.55	7.43	14.30
T_3	5.90	6.86	12.77	5.88	7.23	13.00
T_4	6.51	7.66	14.17	6.14	7.44	13.64
T_5	5.22	6.36	11.58	5.37	6.60	11.48
T_6	6.00	6.99	12.99	6.20	7.39	14.64
T_7	5.21	6.29	11.50	5.52	6.70	11.83
T_8	5.67	6.95	12.62	6.47	7.73	13.74
T_9	4.29	5.75	10.05	4.16	5.39	9.21
T_{10}	4.67	5.71	10.38	4.38	5.44	8.54
T_{11}	4.59	5.50	10.08	3.96	5.14	7.90
T_{12}	4.68	6.07	10.75	4.48	5.71	10.53
T_{13}	4.47	5.86	10.33	4.57	6.01	10.13
T_{14}	5.33	6.30	11.63	5.60	6.98	11.86
T_{15}	4.67	5.73	10.40	5.39	6.66	11.69
T_{16}	5.14	5.96	11.11	5.63	6.87	11.13
SEm (±)	0.15	0.19	0.29	0.26	0.20	0.41
CD (0.05)	0.426	0.534	0.830	0.760	0.570	1.183

During first year, TDMP by dolomite + POP + 13:0:45 + borax (T_4) was the highest (14.17 t ha^{-1}) and was on par with dolomite + POP + 13:0:45 (T_2). Dry matter production was lower with RHA treatments which were on par with treatment involving 75% POP (T_{13}) and lime without $MgSO_4$ (T_{15} and T_{16}).

During second year, TDMP was significantly higher (14.64 t ha^{-1}) with lime + $MgSO_4$ + POP+ 13:0:45 (T_6) and was on par with the treatments of dolomite except the one with borax and T_8 (lime + $MgSO_4$ + POP with combined spray). As in the case of first year, RHA treatments and treatment involving 75% POP registered lower TDMP values.

4.2.4 Plant Analysis

4.2.4.1 K/Na_{Leaves} One Week before PI

The data on analysis of youngest three leaves for K and Na status one week before PI and K/Na_{Leaves} ratio as affected by the nutrient management practices are given in Table 34.

There was significant effect of treatments on K and Na contents in the youngest leaves as well as in K/Na_{Leaves} during both the years. During first year, higher K contents of youngest leaves were recorded with lime + MgSO4 + POP+ borax (T_7), lime + MgSO4 + POP+ 13:0:45 (T_6) and higher Na content with the above treatments along with RHA+ 13:0:45 (T_{10}). All dolomite treatments (T_1 to T_4) and lime + POP + borax (T_{15}) registered higher K contents during second year. Regarding Na content, dolomite treatments as well as RHA + $MgSO_4$ + POP + borax (T_{11}), 75% POP (T_{13}) and lime + POP + 13:0:45 (T_{14}) registered higher values.

Application of dolomite + POP + 13:0:45 + borax (T_4) registered higher K/Na_{Leaves} which was on par with lime + POP + 13:0:45 + borax (T_{16}) and T_2 during first year. During second year, lime with borax (T_{15}) showed higher ratio which was on par with all dolomite treatments (T_1, T_2 and T_3) except the one with combined spray (T_4).

Table 34. Effect of nutrient management practices on K/Na_{Leaves} one week before PI

Treatments	2015			2016		
	K content (mg kg^{-1})	Na content (mg kg^{-1})	K/Na_{Leaves}	K content (mg kg^{-1})	Na content (mg kg^{-1})	K/Na_{Leaves}
T_1	6500.00	526.67	12.35	10160.00	946.67	10.74
T_2	9253.33	693.33	13.43	9760.00	926.67	10.54
T_3	8346.67	653.33	12.80	9826.67	913.33	10.79
T_4	7866.67	513.33	15.32	10760.00	1140.00	9.42
T_5	11053.33	840.00	13.20	8000.00	873.33	9.18
T_6	14493.33	1100.00	13.16	6766.67	760.00	8.89
T_7	14793.33	1266.67	11.76	7546.67	820.00	9.23
T_8	7666.67	933.33	8.39	8366.67	833.33	10.10
T_9	7686.67	1066.67	7.19	7440.00	886.67	8.39
T_{10}	7886.67	1113.33	7.08	6826.67	800.00	8.53
T_{11}	7506.67	1006.67	7.60	6900.00	913.33	7.58
T_{12}	7173.33	1020.00	7.25	7986.67	873.33	9.16
T_{13}	6460.00	740.00	8.87	7166.67	1006.67	7.19
T_{14}	8740.00	660.00	13.29	8373.33	920.00	9.18
T_{15}	7373.33	633.33	11.68	9866.67	826.67	12.07
T_{16}	9300.00	633.33	14.71	8480.00	880.00	9.75
SEm (±)	477.80	58.00	0.69	395.57	40.65	0.56
CD(0.05)	1379.979	167.495	1.979	1142.344	117.390	1.611

4.2.4.2 Nutrient Content of Flag Leaf

The data on the effect of nutrient management practices on the contents of macronutrients, micronutrients, Na and Al of flag leaf are presented in Table 35 and 36.

4.2.4.2.1 Macronutrient Content

The nutrient management practices had significant effect on macronutrient content of the flag leaf during both the years (Table 35).

The N content varied from 1.84 to 3.11% during first year and 2.08 to 3.17% during second year (Table 35). The flag leaf N content was optimum during both the years (Appendix III). Significantly higher N content was recorded by dolomite +POP + 13:0:45 + borax (T_4) during first year and the lowest by lime + POP + 13:0:45 (T_{14}). During second year, all treatments except lime + $MgSO_4$ + POP with borax (T_7), lime + $MgSO_4$ + POP with 13:0:45 and borax (T_8) and RHA+ $MgSO_4$ with borax (T_{11}) recorded higher N content and were on par.

The P content varied from 0.12 to 0.234% during first year and 0.23 to 0.43 % during second year (Table 35). The P content was optimum with all treatments except those involving RHA during first year and slightly higher during second year (Appendix III). The flag leaf P content during first year was significantly higher for dolomite +POP (T_1), lime + $MgSO_4$ + POP with 13:0:45 and borax) (T_8), treatment involving 75% POP (T_{13}), lime + POP with 13:0:45 or with 13:0:45 and borax (T_{15} and T_{16} respectively). During second year, P content was significantly higher with the treatments T_1 to T_8 those involving dolomite and lime $MgSO_4$ which were on par and superior to others.

The K content varied from 0.27 to 0.63% during first year and 0.27 to 0.36 % during second year (Table 35). The flag leaf recorded lower K content during second year than that during first year (Table 35).

Table 35. Effect of nutrient management practices on macronutrient status of flag leaf, %

Treatments	2015						2016					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T_1	2.74	0.218	0.55	0.44	0.090	0.15	2.80	0.43	0.34	0.89	0.14	0.17
T_2	2.24	0.197	0.53	0.57	0.077	0.12	3.17	0.37	0.31	0.84	0.10	0.17
T_3	2.71	0.213	0.54	0.48	0.123	0.13	2.74	0.37	0.32	0.92	0.11	0.18
T_4	3.11	0.197	0.27	0.42	0.093	0.12	2.83	0.40	0.35	0.87	0.12	0.19
T_5	2.36	0.193	0.48	0.51	0.097	0.18	2.83	0.39	0.32	0.78	0.12	0.19
T_6	2.67	0.200	0.46	0.45	0.083	0.12	3.02	0.39	0.32	0.88	0.12	0.19
T_7	2.74	0.210	0.46	0.46	0.083	0.12	2.08	0.37	0.32	0.85	0.13	0.16
T_8	2.55	0.234	0.53	0.42	0.100	0.13	2.49	0.37	0.33	0.80	0.10	0.15
T_9	2.43	0.190	0.34	0.38	0.070	0.14	2.71	0.35	0.29	0.81	0.11	0.21
T_{10}	2.64	0.120	0.36	0.36	0.070	0.13	2.86	0.31	0.29	0.67	0.11	0.24
T_{11}	2.18	0.190	0.54	0.38	0.070	0.17	2.12	0.23	0.27	0.71	0.11	0.23
T_{12}	2.27	0.140	0.36	0.40	0.073	0.15	2.74	0.31	0.32	0.64	0.09	0.23
T_{13}	2.58	0.229	0.34	0.42	0.057	0.22	2.92	0.33	0.36	0.82	0.11	0.21
T_{14}	1.84	0.210	0.39	0.43	0.043	0.13	2.99	0.35	0.33	0.79	0.09	0.22
T_{15}	2.61	0.220	0.49	0.47	0.040	0.17	2.83	0.31	0.33	0.82	0.09	0.18
T_{16}	2.71	0.230	0.63	0.40	0.033	0.11	3.11	0.36	0.35	0.88	0.12	0.20
SEm (±)	0.12	0.006	0.03	0.02	0.008	0.01	0.18	0.02	0.01	0.03	0.01	0.01
CD(0.05)	0.333	0.0168	0.083	0.049	0.0241	0.025	0.516	0.052	0.027	0.086	0.022	0.017

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However, the K content was lower than CNC during both the years (Appendix III). During first year, the highest K content of flag leaf was registered with lime + POP + 13:0:45 + borax (T_{16}) and was followed by dolomite + POP alone (T_1) which were on par and superior to other treatments. During second year, treatment with 75% POP (T_{13}) recorded the highest K content in flag leaf followed by dolomite + POP (T_1), dolomite + POP or lime + $MgSO_4$ + POP with combined spray (T_4 and T_8) and lime treatments without $MgSO_4$ (T_{14} to T_{16}). These treatments were on par and superior to other treatments.

The Ca content in the flag leaf was higher than CNC during both the years (Table 35 and Appendix III) and it was comparatively higher during second year. During first year, the highest Ca content in the flag leaf was shown by dolomite + POP + 13:0:45 (T_2) which was superior to others. The treatments T_1 to T_4 (all dolomite treatments) and lime + $MgSO_4$ + POP with 13:0:45 or borax (T_6 and T_7) and lime + POP with borax or combined spray (T_{16}) were on par and recorded significantly higher Ca in the flag leaf during second year.

The Mg content of the flag leaf was lower than CNC during both the years (Table 35 and Appendix III). Significantly higher Mg content was registered with dolomite + POP + borax (T_3) and lime + $MgSO_4$ + POP with 13:0:45 and borax (T_8) during first year and were on par. During second year, dolomite + POP alone or with combined spray (T_1 and T_4), T_5, T_6 and T_7 (lime + $MgSO_4$ + POP treatments except the one with combined spray) and lime + POP with combined spray (T_{16}) registered higher Mg content in the flag leaf.

The flag leaf S content was near optimum during first year and slightly higher during second year (Table 35 and Appendix III). The highest S content was registered with treatment involving 75% POP during first year (T_{13}) whereas RHA treatments (T_9 to T_{12}) and T_{14} lime + POP with 13:0:45 recorded significantly higher S content during second year.

4.2.4.2.2 Micronutrient Content

Table 36 depicts the significant effect of treatments on the content of micronutrients except on B content during second year. The flag leaf content of Fe was above the critical level of toxicity during both the years (Table 36 and Appendix III). The treatments T_9 to T_{12} (RHA treatments), T_{13} (75% POP) and T_{14} and T_{15} (lime + POP with 13:0:45 or borax) registered significantly higher Fe content during fist year while significantly higher Fe contents were with T_9 and T_{11} (RHA + $MgSO_4$ + POP alone or with borax) and T_{13} (75% POP) during second year.

Flag leaf Mn content was towards lower range of optimum level during both the years and was lower during second year than during first year (Table 36 and Appendix III). Significantly higher Mn content was registered with T_9 and T_{11} (RHA + $MgSO_4$ + POP alone or with borax) and T_6 and T_7 (lime + $MgSO_4$ + POP with 13:0:45 or borax) during first year and the highest with T_9 during second year.

The Zn content of flag leaf was optimum during first year but was towards lower range of CNC during second year (Table 36 and Appendix III). During first year, the higher Zn content was recorded by RHA + $MgSO_4$ + POP combined spray (T_{12}) which was on par with T_1 to T_4 (dolomite treatments), lime +$MgSO_4$ + POP with 13:0:45 or borax (T_6 and T_7) and lime + POP with 13:0:45 (T_{14}). During second year, T_3 and T_4 (dolomite treatments with borax or combined spray) along with T_5, T_6, T_8 (lime + $MgSO_4$ alone or with 13:0:45 or 13:0:45 and borax) and treatment with 75% POP (T_{13}) recorded higher Zn content.

During first year, Cu content was higher than CNC and agreed with CNC during second year (Table 36 and Appendix III). The flag leaf Cu content was significantly higher for T_9, T_{10} and T_{12} (RHA + $MgSO_4$ + POP alone or with 13:0:45 or with combined spray), lime + $MgSO_4$ + POP alone (T_5) and treatments of lime without $MgSO_4$ (T_{14} and T_{16}) during first year. During second year, RHA

+ $MgSO_4$ + POP (T_9) and lime + $MgSO_4$ + POP with combined spray (T_8) showed significantly superior values.

During first year, the B content was towards the lower range of CNC but showed a slight increase within CNC during second year (Table 36 and Appendix III). Dolomite + POP + borax (T_3) and lime + $MgSO_4$ + POP with borax or combined spray (T_7 and T_8) recorded higher B during first year. The treatment effects were not significant during second year.

4.2.4.2.3 Na and Al Content

The flag leaf showed marked increase in Na and Al contents during second year than that during first year (Table 37). The Al content went above CNC but was below the critical level of toxicity (Appendix III). The treatments had significant effect on Na and Al contents during both the years.

During first year, significantly higher Na content was registered with dolomite treatments (T_2 and T_3), lime + $MgSO_4$ + POP treatments (T_5, T_6, T_7 and T_8), RHA treatments (T_9, T_{10} and T_{11}) and T_{15} (lime + POP + borax) which were on par. During second year, T_5, T_6 and T_8 (lime + $MgSO_4$ + POP with 13:0:45 or 13:0:45 and borax) and T_{11} and T_{12} (RHA treatment with borax or combined spray) recorded significantly higher Na content in the flag leaf. All RHA treatments except the one with 13:0:45 and T_{16} (lime + POP with combined spray) recorded significantly higher Al content during first year while T_3 (dolomite + POP + borax) and T_9 (RHA + $MgSO_4$ + POP) and T_8 (lime + $MgSO_4$ + POP with combined spray) recorded higher Al content during second year.

Table 36. Effect of nutrient management practices on the status of micronutrients, Na and Al of flag leaf, mg kg^{-1}

Treatments	2015							2016						
	Fe	Mn	Zn	Cu	B	Na	Al	Fe	Mn	Zn	Cu	B	Na	Al
T_1	539.13	94.05	64.45	36.99	6.52	280.00	69.13	567.30	85.59	21.12	13.01	7.78	1122.22	155.37
T_2	525.20	104.03	64.80	41.21	6.51	353.33	73.80	655.03	103.97	24.73	14.17	6.67	1144.44	144.64
T_3	423.98	115.12	57.94	44.98	7.45	320.00	52.60	691.90	102.77	29.73	13.58	12.22	1100.00	177.83
T_4	429.49	132.06	55.85	54.37	6.90	300.00	86.73	598.97	98.27	29.58	15.45	10.56	1122.22	170.63
T_5	640.13	160.39	43.76	97.26	6.58	366.67	102.45	564.40	122.08	31.40	13.98	8.33	1188.89	163.70
T_6	491.93	172.51	68.08	66.04	6.17	333.33	63.94	550.30	108.29	27.57	13.20	7.06	1222.22	155.79
T_7	570.73	172.35	52.99	40.04	7.22	326.67	82.97	552.10	93.97	19.17	13.95	11.11	1111.11	156.99
T_8	573.27	168.87	41.98	29.23	7.12	366.67	62.87	564.53	109.22	26.95	17.10	11.67	1200.00	189.08
T_9	752.80	242.11	42.71	92.56	6.08	353.33	149.73	1005.70	141.31	20.75	19.78	9.44	1077.78	184.94
T_{10}	889.40	160.93	42.90	119.47	6.11	333.33	110.13	949.50	107.06	24.29	11.06	5.00	1166.67	158.33
T_{11}	724.33	185.26	46.30	60.14	6.11	333.33	152.20	1069.40	105.13	21.37	12.37	8.89	1311.11	158.56
T_{12}	803.27	167.69	69.42	88.74	6.82	293.33	213.60	857.07	85.48	25.17	14.27	11.11	1255.56	163.20
T_{13}	795.73	132.39	42.04	50.41	6.88	293.33	132.47	1070.17	91.01	29.72	10.77	12.22	1055.56	156.13
T_{14}	808.20	164.31	53.96	84.59	6.40	260.00	114.87	553.80	84.02	25.39	9.95	6.67	1133.33	144.10
T_{15}	705.53	119.12	51.71	37.47	6.96	353.33	136.93	587.13	83.84	22.74	10.75	10.56	1100.00	142.18
T_{16}	589.93	104.13	41.07	82.06	6.94	280.00	151.80	853.63	84.86	24.61	10.93	8.89	1155.56	147.06
SEm (±)	70.93	24.20	6.10	14.64	0.15	17.02	22.77	27.42	5.79	1.34	1.07	1.56	44.07	6.29
CD(0.05)	204.863	69.896	17.619	42.293	0.445	49.153	65.752	79.169	16.722	3.857	3.077	-	127.274	18.157

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4.2.4.3 Nutrient Content in the Grain and Straw at Harvest

At harvest, grain and straw were analysed separately for the contents of macronutrients, micronutrients, Na and Al and the data are presented in Table 37 to 40.

4.2.4.3.1 Primary Nutrient Content in the Grain and Straw

Primary nutrient content in the grain and straw are presented in Table 37.

The N content in the grain was higher than CNC during both the years and straw content was near optimum during first year and higher than optimum during second year (Appendix III). During both the years, the grain and the straw recorded higher P content than CNC. The grain K was found to be below CNC during first year and slightly above optimum during second year. The straw K content was below CNC during first year and slightly above CNC for some of the treatments during second year. Higher K content in the grain and straw was observed during second year compared to first year.

The N, P and K contents were profoundly influenced by the treatments (Table 37). Significantly higher N content in the grain during first year was found with lime + $MgSO_4$ + POP with combined spray (T_8) which was on par with RHA + $MgSO_4$ + POP + borax (T_{11}) and lime + POP with combined spray (T_{16}) whereas T_{11} recorded the highest grain N content which was superior to other treatments during second year. During both the years, lime + $MgSO_4$ + POP (T_5) recorded superior value of N content in the straw.

Table 37. Effect of nutrient management practices on primary nutrient content in grain and straw at harvest, %

Treatments	2015						2016					
	N		P		K		N		P		K	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.25	0.46	0.34	0.22	0.18	0.95	1.99	0.73	0.43	0.27	0.34	1.48
T_2	1.49	0.39	0.28	0.23	0.20	0.99	1.74	0.73	0.37	0.20	0.31	1.70
T_3	1.53	0.57	0.32	0.21	0.22	1.08	2.05	0.53	0.37	0.28	0.32	1.12
T_4	1.51	0.55	0.27	0.20	0.23	1.06	1.99	0.78	0.40	0.20	0.35	1.67
T_5	1.68	0.87	0.30	0.23	0.20	0.87	1.56	0.92	0.39	0.17	0.32	1.07
T_6	1.57	0.49	0.35	0.19	0.20	0.76	2.02	0.73	0.35	0.14	0.32	1.67
T_7	1.79	0.37	0.31	0.21	0.22	0.96	1.90	0.67	0.37	0.24	0.32	1.27
T_8	1.99	0.57	0.31	0.21	0.15	1.00	1.84	0.75	0.37	0.21	0.33	1.75
T_9	1.61	0.66	0.31	0.21	0.20	0.98	2.18	0.65	0.39	0.21	0.29	1.13
T_{10}	1.72	0.69	0.27	0.23	0.18	1.01	2.27	0.62	0.31	0.24	0.29	1.43
T_{11}	1.90	0.62	0.29	0.21	0.20	0.93	2.52	0.76	0.23	0.17	0.27	1.10
T_{12}	1.77	0.53	0.28	0.24	0.21	0.88	1.52	0.76	0.31	0.25	0.32	1.51
T_{13}	1.72	0.41	0.28	0.23	0.22	0.97	1.62	0.54	0.33	0.14	0.36	1.35
T_{14}	1.68	0.50	0.28	0.25	0.19	1.23	1.43	0.53	0.35	0.16	0.33	1.49
T_{15}	1.70	0.59	0.29	0.22	0.22	0.77	1.68	0.54	0.31	0.21	0.33	1.13
T_{16}	1.87	0.47	0.29	0.26	0.19	0.93	1.52	0.62	0.36	0.23	0.35	1.74
SEm (±)	0.06	0.06	0.01	0.01	0.01	0.05	0.08	0.04	0.02	0.02	0.01	0.07
CD(0.05)	0.159	0.168	0.029	0.017	0.031	0.143	0.229	0.122	0.052	0.046	0.027	0.200

During first year, lime + $MgSO_4$ + POP with 13:0:45 (T_6) recorded significantly higher P content in the grain along with dolomite + POP alone or with borax (T_1 and T_3). During second year, the grain P content was higher for dolomite + POP alone or with combined spray (T_1 and T_4) and lime or RHA + $MgSO_4$ + POP (T_5 and T_9). The straw P content during first year was significantly higher with lime + POP with 13:0:45 or combined spray (T_{16} and T_{14}) and RHA + $MgSO_4$ + POP with combined spray (T_{12}). During second year, the highest P content in the straw was recorded by dolomite + POP + borax (T_3) which was on par with dolomite + POP alone (T_1), lime + $MgSO_4$ + POP with borax (T_7), RHA + $MgSO_4$ + POP with 13:0:45 (T_{10}), RHA + $MgSO_4$ + POP with combined spray (T_{12}) and lime + POP + combined spray (T_{16}).

In the case of grain K content, all treatments were on par except dolomite + POP alone (T_1), lime + $MgSO_4$ + POP with combined spray (T_8), RHA + $MgSO_4$ + POP with borax (T_{10}), T_{14} and lime + POP with 13:0:45 or combined spray (T_{16}) during first year. During second year, significantly higher K content in the grain was recorded by T_1 and T_4 (dolomite + POP alone or with combined spray), lime + $MgSO_4$ + POP with combined spray (T_8) and treatments involving 75% POP

(T_{13}) and lime without $MgSO_4$ (T_{14} to T_{16}). The treatments lime + POP + 13:0:45 (T_{14}) recorded superior value of K content in the straw during first year. Lime + $MgSO_4$ + POP with 13:0:45 or combined spray (T_6 and T_8), dolomite with 13:0:45 or combined spray (T_2 and T_4) and lime + POP with combined spray (T_{16}) registered superior values which were on par during second year.

4.2.4.3.2 Secondary Nutrient Content in the Grain and Straw

Table 38 reveals the effect of nutrient management practices on secondary nutrient content in rice.

During both the years, the grain Ca content was markedly higher (nearly 10 times) than CNC (Table 38 and Appendix III). The straw Ca content was also nearly two times higher than CNC during first year and three times higher during second year. Grain Mg content was near optimum during both the years but the content was slightly lower during second year compared to first year. Straw Mg content was markedly lower than CNC during first year whereas the Mg content improved during second year but below CNC. Grain and straw S content was within CNC during both the years.

The treatments had significant influence on Ca, Mg and S contents of the grain and straw during both the years (Table 38). Higher content of Ca in the grain during first year was registered with dolomite + POP + 13:0:45 + borax (T_4). Meanwhile, during second year, treatment involving 75% POP (T_{13}), T_{14} and T_{15} (lime + POP with 13:0:45 or borax) and lime + $MgSO_4$ + POP with combined spray (T_8) recorded significantly higher Ca grain content. The straw content of Ca during first year was the highest with lime + POP + 13:0:45 (T_{14}). During second year, lime + $MgSO_4$ + POP with 13:0:45 or borax (T_6 and T_7), dolomite + POP alone or with 13:0:45 (T_1 and T_2) and lime + POP with 13:0:45 + borax (T_{16}) registered significantly higher straw Ca content and were on par.

During first year, the highest grain Mg content was recorded by lime + $MgSO_4$ + POP with borax (T_7) which was on par with dolomite + POP + 13:0:45 + borax

(T_4), lime + $MgSO_4$ + POP with combined spray (T_8) and lime + $MgSO_4$ + POP alone (T_5) and superior to others. Dolomite + POP with borax (T_3) along with lime + $MgSO_4$ + POP treatments (T_5 to T_8) registered significantly higher Mg content of grain during second year. Straw Mg content was the highest for dolomite + POP + 13:0:45 + borax (T_4) during first year. During second year, significantly higher straw Mg values were recorded by dolomite + POP alone or with 13:0:45 (T_1 and T_2), lime + $MgSO_4$ + POP alone or with 13:0:45 or borax (T_5, T_6 and T_7) and were on par.

Table 38. Effect of nutrient management practices on secondary nutrient content in grain and straw at harvest, %

Treatments	2015						2016					
	Ca		Mg		S		Ca		Mg		S	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	0.40	0.73	0.15	0.067	0.09	0.15	0.47	1.50	0.10	0.17	0.07	0.25
T_2	0.51	0.73	0.14	0.060	0.16	0.27	0.47	1.50	0.09	0.17	0.14	0.24
T_3	0.54	0.84	0.15	0.057	0.15	0.18	0.49	1.38	0.12	0.14	0.10	0.23
T_4	0.62	0.79	0.19	0.070	0.19	0.17	0.49	1.41	0.10	0.14	0.12	0.21
T_5	0.54	0.78	0.18	0.060	0.15	0.21	0.48	1.40	0.13	0.17	0.09	0.20
T_6	0.57	0.90	0.15	0.063	0.09	0.20	0.48	1.45	0.11	0.16	0.13	0.18
T_7	0.61	0.94	0.20	0.060	0.16	0.17	0.49	1.54	0.13	0.16	0.11	0.18
T_8	0.46	0.91	0.19	0.057	0.18	0.25	0.50	1.40	0.13	0.13	0.10	0.24
T_9	0.40	0.93	0.06	0.063	0.15	0.21	0.48	1.28	0.07	0.12	0.10	0.20
T_{10}	0.40	1.01	0.07	0.057	0.14	0.26	0.47	1.24	0.07	0.10	0.12	0.23
T_{11}	0.41	0.96	0.14	0.060	0.14	0.27	0.46	1.24	0.09	0.09	0.10	0.22
T_{12}	0.40	0.93	0.06	0.060	0.13	0.25	0.46	1.25	0.09	0.09	0.14	0.20
T_{13}	0.42	0.82	0.15	0.063	0.20	0.20	0.55	1.43	0.10	0.10	0.16	0.21
T_{14}	0.44	1.12	0.07	0.060	0.15	0.24	0.51	1.39	0.09	0.13	0.11	0.26
T_{15}	0.42	0.92	0.06	0.067	0.10	0.23	0.51	1.41	0.07	0.10	0.10	0.24
T_{16}	0.47	0.91	0.07	0.063	0.18	0.26	0.48	1.45	0.10	0.11	0.11	0.26
SEm (±)	0.02	0.03	0.007	0.002	0.01	0.05	0.02	0.04	0.01	0.01	0.01	0.02
CD(0.05)	0.043	0.096	0.020	0.0069	0.031	0.017	0.051	0.105	0.019	0.022	0.016	0.048

During first year, 75% POP (T_{13}), dolomite + POP + 13:0:45 + borax (T_4) and lime + 13:0:45 + borax (T_{16}) registered higher S content in the grain. Treatment involving 75% POP (T_{13}), RHA with combined spray (T_{12}) and dolomite with 13:0:45 (T_2) showed significantly higher grain S content during second year. Higher straw S content was registered by T_2 and RHA with borax (T_{11}) during first year but was on par with lime + $MgSO_4$ + POP or RHA + $MgSO_4$ + POP or lime + POP with combined spray (T_8, T_{12} and T_{16}) and RHA + $MgSO_4$ + POP with 13:0:45 (T_{10}) which were superior to other treatments. During second year, all treatments except lime + $MgSO_4$ + POP alone or with 13:0:45 or borax (T_5, T_6 and T_7), RHA alone or with combined spray (T_9 and T_{12}) were on par in registering significantly higher S content in the straw.

4.2.4.3.3 Micronutrient Content in the Grain and Straw

The data on the effect of nutrient management practices on micronutrient content in the grain and straw are shown in Table 39.

The grain Fe content was two times higher than CNC during first year except for dolomite treatments whereas it was lower than CNC during second year (Appendix III). The straw Fe content was three to six times higher than CNC during first year whereas slightly higher than during second year. During first year, the grain and straw Mn content was markedly above the CNC and it was drastically reduced below CNC during second year. The Zn content in the grain agreed with CNC during both the years while the straw Zn content was markedly below the toxic level. The grain Cu content was above the CNC during first year which markedly was below CNC during second year. The straw Cu content was above the CNC during first year which also was reduced drastically below the CNC during second year. Grain B content was only $1/10^{th}$ of the CNC during first year and even below that during second year (Appendix III). The straw B content was lower than the CNC during first year but increased sharply by two to five times the CNC during second year.

The data revealed significant effect of the treatments on grain and straw Fe contents. The grain Fe was the highest for RHA + $MgSO_4$ + POP + borax (T_{11}) which was on par with RHA treatments (T_9 and T_{10}) and lime + $MgSO_4$ + POP alone (T_5) during first year. All treatments involving RHA except the one without foliar spray (T_{10}, T_{11} and T_{12}) and lime + $MgSO_4$ + POP+ 13:0:45 (T_6) registered significantly higher grain Fe content but were on par during second year. In the case of straw Fe content, all treatments except T_1 to T_4 (those involving dolomite) and lime + $MgSO_4$ + POP with combined spray (T_8) were on par and recorded significantly higher Fe content during first year. During second year, treatment involving 75% POP (T_{13}) registered the highest straw Fe content which was superior to other treatments.

The treatments significantly influenced Mn content of grain and straw during both the years. The Mn content of grain during first year was the highest with RHA+ $MgSO_4$ + POP (T_9) but was on par with lime + $MgSO_4$ + POP with combined spray (T_8). During second year, lime + $MgSO_4$ + POP (T_5) showed the highest Mn in the grain but it was on par with dolomite + POP (T_1) and RHA + $MgSO_4$ + POP (T_9). The straw Mn content was significantly higher with lime + POP + borax or combined spray (T_{15} and T_{16} respectively), dolomite + POP alone or with 13:0:45 (T_1 and T_2) and lime + $MgSO_4$ + POP with 13:0:45 (T_6) but were on par during first year. The treatments RHA + $MgSO_4$ + POP + combined spray (T_{12}) and dolomite + POP + 13:0:45 (T_2) recorded significantly higher straw Mn content and were on par during second year.

The treatments had significant effect on the grain Zn content during both the years while on the straw Zn content only during second year. The grain Zn content during first year was significantly higher with RHA + $MgSO_4$ + POP alone or with 13:0:45 (T_9 and T_{10}) dolomite + POP + 13:0:45 (T_2), T_5, T_7 and T_8 (all treatments of lime + $MgSO_4$ + POP except the one with 13:0:45) and all treatments of lime without $MgSO_4$ (T_{14}, T_{15} and T_{16}). During second year, dolomite treatments with foliar spray (T_2, T_3 and T_4), lime + $MgSO_4$ + POP treatments with foliar spray (T_6, T_7 and T_8), treatments of RHA + $MgSO_4$ + POP alone or with 13:0:45 (T_9 and T_{10}) and lime without $MgSO_4$ with 13:0:45 or borax (T_{14} and T_{15}) recorded significantly higher grain Zn content and were on par. The straw Zn content was not influenced significantly by nutrient management treatments during first year. During second year, the treatments RHA + $MgSO_4$ + POP except the one with borax (T_9, T_{10} and T_{12}), dolomite + POP (T_1) and lime + $MgSO_4$ + POP with 13:0:45 or borax (T_6 and T_7) registered significantly higher values of straw Zn content.

The treatments had significant effect on Cu content both in the grain and straw during both the years. The treatment involving 75% POP (T_{13}) recorded higher Cu content in the grain during first year which was on par with all treatments except those involving RHA (T_9 to T_{12}), dolomite with 13:0:45 (T_2) and lime + $MgSO_4$ + POP with combined spray (T_8). The grain Cu content during second year was significantly higher with lime + $MgSO_4$ + POP with borax (T_7), dolomite + POP (T_1), lime + $MgSO_4$ + POP (T_5) and RHA + $MgSO_4$ + POP with borax (T_{11}) which were on par.

The straw content of Cu during first year was higher with dolomite treatments except the one without foliar spray (T_2, T_3 and T_4), lime + $MgSO_4$ + POP alone or with 13:0:45 (T_5 and T_6), RHA + $MgSO_4$ + POP with 13:0:45 or with combined spray (T_{10} and T_{12}) and lime + POP with 13:0:45 (T_{14}). During second year, dolomite treatments without foliar spray or with combined spray (T_1 and T_4), lime + $MgSO_4$ + POP (T_5), RHA + $MgSO_4$ + POP with 13:0:45 (T_{10}) and lime + 13:0:45 (T_{14}) recorded significantly higher straw Cu content which were on par.

Table 39. Effect of nutrient management practices on micronutrient content in grain and straw at harvest, mg kg^{-1}

Treatments	2015										2016									
	Fe		Mn		Zn		Cu		B		Fe		Mn		Zn		Cu		B	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	284.97	423.15	247.03	261.94	26.00	54.06	99.19	79.56	10.27	10.25	163.33	139.38	15.22	15.00	19.62	25.70	21.36	18.69	6.67	67.17
T_2	294.26	366.31	144.75	306.49	33.15	52.87	73.90	99.21	11.29	10.16	163.40	201.18	10.39	30.92	26.85	18.24	16.94	10.71	8.89	85.33
T_3	272.56	436.22	164.98	199.48	25.80	34.58	87.63	87.85	11.39	12.74	147.49	171.02	11.54	25.10	30.90	20.67	19.15	13.68	11.11	92.56
T_4	161.03	480.11	135.51	118.96	23.69	24.79	99.09	121.04	11.11	11.03	135.16	175.48	13.36	13.66	30.46	20.44	12.85	19.49	11.67	99.83
T_5	582.31	503.89	125.01	150.18	36.65	45.44	91.49	98.49	11.29	10.24	140.94	182.71	16.71	9.90	25.25	23.42	20.04	15.97	7.22	55.56
T_6	511.51	537.67	159.69	301.91	29.36	33.14	101.25	83.56	10.18	10.18	164.36	169.47	9.69	17.55	30.84	25.76	13.50	11.66	10.00	56.06
T_7	471.90	576.09	97.56	133.28	32.32	26.92	95.30	73.93	11.57	11.52	162.80	198.61	13.35	13.42	26.62	26.42	23.93	8.12	10.00	93.94
T_8	513.77	261.42	380.50	154.42	34.84	20.87	42.28	44.53	10.85	12.57	138.43	179.29	13.14	9.28	25.96	23.34	19.28	11.67	12.78	71.67
T_9	732.33	661.79	387.78	140.25	34.23	26.84	48.00	38.67	10.10	10.98	146.28	221.96	14.25	8.13	26.23	24.08	14.15	7.23	7.78	46.39
T_{10}	706.22	577.11	257.83	136.17	43.63	27.26	34.28	98.37	10.83	10.94	175.97	159.82	9.89	16.13	27.14	25.78	11.53	16.10	10.56	52.89
T_{11}	758.66	651.89	165.26	186.32	25.73	21.40	40.52	51.29	10.91	11.34	183.74	139.26	10.50	19.33	24.28	22.66	20.10	8.91	8.89	57.83
T_{12}	453.60	675.67	159.39	141.10	26.51	23.04	33.49	85.82	10.12	11.33	184.63	180.19	12.59	34.11	21.01	29.29	13.38	12.61	11.67	66.44
T_{13}	550.66	572.66	186.15	142.38	30.92	30.41	123.02	74.42	10.99	10.77	157.79	263.99	12.80	13.79	24.19	18.41	15.00	10.94	9.44	55.61
T_{14}	422.77	614.78	159.58	237.75	40.13	23.42	121.57	96.65	10.75	10.63	125.64	196.27	10.60	30.60	27.67	13.17	12.27	14.68	7.78	35.11
T_{15}	527.74	563.33	175.01	314.13	33.31	34.02	103.20	79.17	11.03	11.29	126.40	118.82	11.24	27.35	29.63	14.07	14.46	13.07	10.56	37.61
T_{16}	525.67	548.78	144.99	286.29	37.71	56.10	105.32	74.56	11.01	11.45	153.22	174.02	12.87	28.45	22.83	14.82	14.66	8.35	13.33	42.11
SEm (±)	60.87	67.32	21.79	23.30	4.08	8.56	12.98	13.65	0.22	0.12	7.011	12.01	1.01	1.15	1.92	1.82	1.48	1.75	1.52	6.52
CD(0.05)	181.505	194.437	62.932	67.307	11.778	-	37.491	39.432	0.634	0.343	20.246	34.687	2.901	3.306	5.548	5.261	4.263	5.042	-	18.813

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Significant effect of treatments was observed on the grain and the straw B content during first year and only on the straw content during second year. The grain B content during first year was significantly higher with all dolomite treatments except the one without foliar spray (T_2, T_3 and T_4), lime + $MgSO_4$ + POP alone or with borax (T_5, T_7) and lime without $MgSO_4$ with borax or with combined spray (T_{15}, T_{16}) and 75% POP (T_{13}). During second year, the effect of treatments was not significant on grain B content. The straw B content was significantly higher for dolomite treatment with borax (T_3) and lime + MgSO4 + POP with combined spray (T_8) during first year and dolomite treatments except the one without foliar spray (T_2, T_3 and T_4) and lime + $MgSO_4$ + POP with borax (T_7) during second year.

4.2.4.3.4 Na and Al Content in the Grain and Straw

The Na and Al contents of the grain and straw are presented in Table 40.

The grain Na content ranged from 166.67 to 244.44 mg kg^{-1} during first year and from 422.22 to 522.22 mg kg^{-1} during second year. Grain Na content during second year was more than twice the content during first year. Straw Na content was six times the grain Na status during first year and three times during second year. It is also observed that Na status in the straw increased by 10 times during second year compared to first year. The Na content was also significantly influenced by the treatments.

The treatments had significant influence on Na and Al contents of the grain and straw during both the years. During first year, the highest content of Na in the grain was recorded by RHA + $MgSO_4$ + POP alone or with combined spray (T_9 and T_{12}) which was on par with all treatments except dolomite alone or with 13:0:45 (T_1 and T_2), lime + $MgSO_4$ + POP with 13:0:45 or borax (T_6 and T_8), RHA + $MgSO_4$ + POP + borax (T_{11}) and lime + POP without $MgSO_4$ with borax or 13:0:45 + borax (T_{15} and T_{16}). The highest grain Na content during second year was registered with RHA + $MgSO_4$ + POP (T_9) and was on par with lime + $MgSO_4$ + POP with borax (T_7) and lime without $MgSO_4$ with 13:0:45 or borax

Table 40. Effect of nutrient management practices on Na and Al contents in grain and straw at harvest, mg kg^{-1}

Treatments	2015				2016			
	Na		Al		Na		Al	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	177.78	1200.00	113.22	68.33	444.44	14822.22	127.40	74.23
T_2	166.67	1055.56	126.89	122.33	422.22	11533.33	84.78	69.17
T_3	211.11	1366.67	145.78	240.44	455.56	11977.78	104.92	72.53
T_4	222.22	1033.33	103.89	151.00	466.67	12088.89	100.06	73.92
T_5	211.11	1077.78	125.89	151.00	444.44	13433.33	171.19	73.52
T_6	200.00	1088.89	92.11	294.44	444.44	13100.00	175.43	87.29
T_7	211.11	1544.44	231.00	170.33	500.00	13900.00	143.40	87.78
T_8	188.89	1111.11	159.00	178.55	477.78	13088.89	107.50	88.54
T_9	244.44	1344.44	209.89	185.33	522.22	15233.33	180.88	97.72
T_{10}	222.22	1844.44	212.89	287.33	466.67	14655.56	158.08	108.21
T_{11}	188.89	1522.22	163.11	208.78	444.44	15444.44	155.40	86.44
T_{12}	244.44	1322.22	178.89	283.55	455.56	15188.89	160.36	94.08
T_{13}	233.33	1055.56	100.22	297.44	433.33	12144.44	136.23	92.40
T_{14}	211.11	1511.11	221.66	276.33	500.00	13555.56	111.42	77.29
T_{15}	177.78	1288.89	292.55	124.55	488.89	14866.67	138.62	88.46
T_{16}	188.89	1466.67	160.11	92.33	477.78	15044.44	87.37	83.43
SEm (±)	13.28	111.25	16.64	33.44	15.18	797.99	4.25	3.51
CD(0.05)	38.363	321.313	48.057	96.585	43.839	2304.450	12.278	10.137

(T_{14} and T_{15}) but superior to other treatments. Significantly higher straw Na content was registered with RHA + $MgSO_4$ + POP with 13:0:45 (T_{10}) and lime + MgSO4 + POP with borax (T_7) which were on par during first year. Dolomite + POP alone (T_1), lime + $MgSO_4$ + POP alone or with borax (T_5 and T_7), treatments involving RHA except the one with 13:0:45 (T_9, T_{11} and T_{12}) and treatments of lime without $MgSO_4$ (T_{14}, T_{15} and T_{16}) were on par with significantly higher straw Na content during second year.

The Al content in both grain and straw (Table 40) was above the CNC but below critical level of toxicity during both the years (Appendix III). The grain Al content was comparatively lower and straw Al content was markedly lower during second year than those during first year.

Nutrient management practices had significant influence on the Al content. The grain Al content was the highest with lime + POP with borax (T_{15}) during first year. Significantly higher Al status in the grain was registered with RHA + $MgSO_4$ + POP alone (T_9) and lime + $MgSO_4$ + POP alone or with 13:0:45 (T_5 and T_6) during second year. Significantly higher straw Al content was registered with the treatment involving 75% POP (T_{13}), dolomite + POP with borax (T_3), lime + $MgSO_4$ + POP with 13:0:45 (T_6), RHA + $MgSO_4$ + POP with 13:0:45 or borax or both (T_{10}, T_{11} and T_{12}) and lime + POP with 13:0:45 (T_{14}) which were on par during first year. During second year, the highest straw Al content was shown by RHA + $MgSO_4$ + POP with 13:0:45 (T_{10}).

4.2.5 Uptake of Nutrients

Uptake of macronutrients, micronutrients, Na and Al as influenced by nutrient management practices was computed separately for grain and straw as well as total uptake at harvest during 2015 and 2016 and the data are presented in Table 41 to 45.

4.2.5.1 Uptake of Primary Nutrients

Uptake of primary nutrients *viz.* N, P and K as affected by the treatments are shown in Table 41 and was found to be significant for all the three nutrients during both the years.

During first year, the grain uptake of N was the highest and superior for RHA + $MgSO_4$ + POP + borax (T_{11}). During second year, it was significantly higher with all dolomite treatments (T_1, T_2, T_3 and T_4) and lime + $MgSO_4$ + POP with 13:0:45 or 13:0:45 + borax (T_6 and T_8) which were on par. Straw uptake of N was superior with lime + $MgSO_4$ + POP (T_5) during first year and was significantly higher with T_1, T_2, T_4, T_5 and T_8 during second year which were on par.

During first year, lime + $MgSO_4$ + POP (T_5) recorded the highest N uptake by the crop (142.64 kg ha^{-1}) which was on par with T_3 and T_4 (dolomite with 13:0:45 or borax or with combined spray) and lime + $MgSO_4$ + POP with combined spray (T_8 and T_2). During second year, the highest N uptake (179.36 kg ha^{-1}) was with T_4 but was on par with dolomite alone or with 13:0:45 (T_1 and T_2), lime + $MgSO_4$ + POP with 13:0:45 or 13:0:45 + borax (T_6 and T_8).

The treatments dolomite alone or with borax (T_1 and T_3), lime + $MgSO_4$ + POP with 13:0:45 (T_6) registered significantly higher grain P uptake during first year which were also on par (Table 41). During second year, all dolomite treatments except the one with borax (T_1, T_2 and T_4) and lime + $MgSO_4$ + POP with 13:0:45 + borax (T_8) recorded significantly higher grain P content which were on par. Straw P uptake during first year was the highest with T_2 and during second year T_3 and T_1 registered superior values. The plant uptake of P was the highest with dolomite + POP (T_1 - 35.65 and 47.07 kg ha^{-1} during first and second year respectively) which was on par with other dolomite treatments (T_2, T_3 and T_4) during first year and dolomite + POP with borax (T_3) during second year. The treatments involving RHA registered lower P uptake.

Table 41. Effect of nutrient management practices on uptake of N, P and K, kg ha^{-1}

Treatments	N uptake						P uptake						K uptake					
	2015			2016			2015			2016			2015			2016		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	66.85	29.18	96.04	124.55	52.82	177.37	20.38	15.27	35.65	27.29	19.77	47.07	9.64	60.54	70.18	21.21	107.24	128.45
T_2	97.93	29.76	127.68	113.87	54.34	168.20	18.07	17.55	35.62	24.37	14.69	39.06	13.23	75.48	88.71	20.29	126.63	146.92
T_3	71.44	39.52	129.84	121.20	38.30	159.50	18.71	14.08	32.79	21.97	19.89	41.86	12.84	74.65	87.49	18.51	81.14	99.66
T_4	69.31	42.10	140.57	121.62	57.74	179.36	17.53	15.33	32.86	24.57	14.81	39.37	14.34	81.17	95.51	21.38	124.24	145.62
T_5	78.62	54.88	142.64	83.53	60.51	144.04	15.54	14.86	30.40	21.09	11.32	32.40	10.47	55.38	65.85	17.51	70.96	88.47
T_6	94.18	34.28	128.46	124.93	54.13	179.07	18.66	11.87	30.53	21.67	9.95	31.62	11.81	53.09	64.90	19.42	123.72	143.14
T_7	93.48	23.34	116.82	105.16	44.78	149.95	16.24	13.43	29.66	20.32	15.92	36.24	11.70	60.15	71.85	17.87	84.97	102.84
T_8	91.28	40.00	131.28	118.87	57.74	176.61	17.32	14.54	31.86	23.83	16.24	40.07	11.16	69.54	80.70	21.54	135.40	156.94
T_9	85.38	37.69	123.07	90.79	35.30	126.09	13.23	12.02	25.25	16.21	11.47	27.67	6.57	56.57	63.15	12.03	60.86	72.89
T_{10}	101.21	39.48	119.63	99.21	33.99	133.20	12.57	12.86	25.43	13.37	13.19	26.55	8.52	57.53	66.05	12.69	77.26	89.96
T_{11}	123.89	33.99	121.19	98.91	39.03	137.94	13.30	11.39	24.70	9.10	8.89	17.99	9.09	50.88	59.97	10.94	56.67	67.62
T_{12}	92.68	32.22	115.20	67.99	43.74	111.73	13.00	14.75	27.75	13.95	14.48	28.43	10.04	53.57	63.61	14.31	86.15	100.46
T_{13}	76.63	24.29	100.92	74.17	32.65	106.82	12.65	13.23	25.88	18.65	9.63	28.27	9.76	56.92	66.67	16.28	81.34	97.61
T_{14}	89.78	31.21	120.99	80.36	37.04	117.40	14.99	15.48	30.47	19.68	11.01	30.70	10.32	77.13	87.45	18.47	103.87	122.34
T_{15}	79.41	35.79	112.88	90.23	36.24	126.47	13.75	12.53	26.28	16.69	13.84	30.52	10.29	44.11	54.40	17.62	75.34	92.96
T_{16}	95.68	27.80	123.48	86.36	42.51	128.88	15.08	15.60	30.68	16.42	13.65	30.07	9.75	55.46	65.22	19.45	119.34	138.79
SEm (±)	4.39	3.60	5.47	5.44	3.16	6.51	0.66	0.59	1.41	1.44	1.17	2.12	0.59	4.07	4.23	0.94	5.35	5.63
CD(0.05)	12.687	10.396	15.783	15.702	9.134	18.791	1.895	1.701	2.880	4.162	3.381	6.11	1.713	11.753	12.209	2.711	15.445	16.257

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The highest uptake of grain K was registered with dolomite + POP +13:0:45 + borax (T_4) during first year but was on par with dolomite + POP with 13:0:45 or borax (T_2 and T_3) (Table 41). During second year, the grain K uptake was significantly higher with dolomite treatments (T_1, T_2 and T_4,), lime + $MgSO_4$ + POP with 13:0:45 or 13:0:45 + borax (T_6 and T_8) and lime + POP + 13:0:45 + borax (T_{16}) which were on par. The straw K uptake during first year was also the highest with T_4 which was on par with T_2, T_3, T_8 and lime + POP + 13:0:45 (T_{14}). During second year, T_8 registered the highest value which was on par with T_2, T_4 and T_6. Significantly higher total K uptake was recorded by dolomite treatments with foliar spray (T_4, T_2 and T_3) and lime with 13:0:45 (T_{14}) during first year (87.45 to 95.51 kg ha^{-1}) which were found to be on par. During second year, lime + $MgSO_4$ + POP with combined spray (T_8) had the highest uptake of K which was on par with dolomite with 13:0:45 or combined spray (T_2 and T_4) and lime + $MgSO_4$ + POP with 13:0:45 (T_6) during second year (143.14 to 156.94 kg ha^{-1}).

4.2.5.2 Uptake of Secondary Nutrients

The influence of treatments on the uptake of secondary nutrients Ca, Mg and S is given in Table 42. During both the years, the treatment effects were significant.

Dolomite + POP + 13:0:45 + borax (T_4) registered the highest uptake of grain Ca during first year (Table 42). During second year, the grain Ca uptake was significantly higher with all dolomite treatments (T_1, T_2, T_3 and T_4), lime + POP + 13:0:45 or 13:0:45 + borax (T_6 and T_8) and lime + POP + borax (T_{15}) which were on par. The straw Ca uptake with T_6, T_8 and lime + POP + 13:0:45 (T_{14}) was significantly higher and were on par during first year. Dolomite + POP alone or with 13:0:45 or 13:0:45 + borax (T_1, T_2, T_4) lime + $MgSO_4$ + POP with 13:0:45 or borax or both (T_6, T_7 and T_8) recorded significantly higher Ca in the straw during second year which were also on par. During first year, the total uptake of Ca was the highest with dolomite + POP + 13:0:45 + borax (T_4) and was on par with lime + $MgSO_4$ + POP + 13:0:45 or borax (T_6 and T_7) and lime + POP + 13:0:45 (T_{14})

Uptake of Ca during second year recorded the highest value with dolomite + POP + 13:0:45 (T_2) which was on par with dolomite + POP alone or with 13:0:45 + borax (T_1 and T_4) and lime + $MgSO_4$ + POP with either 13:0:45 or borax or both (T_6, T_7 and T_8). All treatments involving RHA (T_9 to T_{12}) and 75% POP (T_{13}) recorded lower uptake of Ca.

The grain and straw Mg uptake was superior with dolomite + POP + 13:0:45 + borax (T_4) during first year (Table 42). During second year, lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) recorded the highest grain Mg uptake which was on par with dolomite + POP + borax (T_3) and lime + $MgSO_4$ + POP (T_5). The uptake of Mg by straw was significantly higher with dolomite + POP or lime + $MgSO_4$ + POP with or without 13:0:45 (T_1, T_2, T_5 and T_6) during second year. With respect to total Mg uptake, dolomite + POP + 13:0:45 + borax (T_4) recorded superior value during first year. During second year, lime + $MgSO_4$ + POP + 13:0:45 (T_6) registered the highest uptake which was on par with other lime + $MgSO_4$ + POP treatments and all dolomite treatments except T_1 and T_2. The treatments involving RHA registered lower Mg uptake.

The grain S uptake was superior with dolomite + POP + 13:0:45 + borax (T_4) and straw uptake with dolomite + POP + 13:0:45 (T_2) during first year (Table 42). During second year, the uptake of S in the grain was the highest with T_2 which was on par with T_4, lime + $MgSO_4$ + POP + 13:0:45 (T_6) and the treatment involving 75% POP (T_{13}). During second year, all dolomite treatments (T_1 to T_4), lime + $MgSO_4$ + 13:0:45 + borax (T_8) and all lime + POP treatments (T_{14} to T_{16}) registered significantly higher values of straw S uptake which were on par. The total uptake of S during both the years was found to be the highest with dolomite + POP + 13:0:45 (T_2) which was on par with dolomite alone or with combined spray (T_4 and T_1), lime with 13:0:45 or combined spray (T_{16} and T_{14}) or lime + $MgSO_4$ + POP with combined spray (T_8) during second year.

Table 42. Effect of nutrient management practices on uptake of Ca, Mg and S, kg ha^{-1}

Treatments	Ca uptake						Mg uptake						S uptake					
	2015			2016			2015			2016			2015			2016		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	21.59	46.45	68.04	29.52	108.07	137.59	7.83	4.26	12.09	6.10	12.20	18.31	4.79	9.37	14.16	4.63	18.17	22.80
T_2	33.43	55.44	88.86	30.83	111.55	142.38	9.17	4.56	13.73	5.98	12.39	18.37	10.26	20.43	30.69	8.95	17.68	26.63
T_3	31.58	58.38	89.97	28.42	99.62	128.04	8.64	3.89	12.53	7.06	9.89	16.94	8.66	11.88	20.54	5.75	16.40	22.14
T_4	40.45	60.38	100.83	30.17	104.91	135.08	12.60	5.36	17.97	6.01	10.40	16.41	12.56	13.29	25.86	7.53	15.55	23.08
T_5	27.99	49.67	77.66	25.68	92.59	118.27	9.58	3.82	13.39	7.12	11.15	18.28	7.64	13.58	21.22	5.10	12.91	18.01
T_6	34.08	63.46	97.55	29.97	106.89	136.86	9.20	4.41	13.61	7.01	12.06	19.07	5.39	13.78	19.17	8.05	12.92	20.97
T_7	32.07	59.44	91.51	26.97	103.16	130.13	10.25	3.77	14.02	6.99	10.66	17.65	8.18	10.88	19.06	6.08	12.15	18.22
T_8	26.26	63.06	89.32	32.08	108.43	140.52	10.79	3.94	14.73	8.23	10.15	18.38	10.23	17.64	27.88	6.34	18.36	24.70
T_9	17.25	53.32	70.57	19.82	68.98	88.79	2.58	3.65	6.22	3.09	6.44	9.52	6.30	12.27	18.58	4.28	10.92	15.20
T_{10}	18.49	57.47	75.97	20.56	67.57	88.13	3.27	3.23	6.50	3.04	5.76	8.80	6.69	14.60	21.28	5.16	12.43	17.60
T_{11}	18.63	52.59	71.22	18.17	64.11	82.28	6.42	3.30	9.72	3.58	4.61	8.19	6.59	14.85	21.44	4.05	11.38	15.43
T_{12}	18.70	56.63	75.33	20.69	71.22	91.92	2.82	3.64	6.46	3.89	5.23	9.12	6.09	14.97	21.06	6.31	11.26	17.57
T_{13}	18.85	47.90	66.75	25.11	86.06	111.17	6.84	3.72	10.55	4.65	6.16	10.81	9.10	11.89	20.99	7.45	12.38	19.83
T_{14}	23.22	70.53	93.75	28.46	96.88	125.33	3.57	3.78	7.34	4.79	9.24	14.04	7.97	14.89	22.85	6.35	18.45	24.80
T_{15}	19.56	52.50	72.05	27.44	93.76	121.20	2.96	3.82	6.78	4.01	6.65	10.66	4.68	12.97	17.65	5.40	16.28	21.68
T_{16}	24.14	54.50	78.64	26.98	99.43	126.41	3.44	3.78	7.22	5.50	7.29	12.80	9.05	15.53	24.58	6.16	17.77	23.93
SEm (±)	1.01	2.99	3.46	1.67	3.31	4.00	0.44	0.19	0.50	0.42	0.57	0.72	0.61	1.04	0.92	0.52	1.24	1.47
CD(0.05)	2.903	8.635	10.005	4.822	9.562	11.552	1.283	0.548	1.440	1.206	1.652	2.086	1.770	3.010	2.669	1.504	3.576	4.248

4.2.5.3 Uptake of Micronutrients

Table 43 and 44 show the influence of treatments on uptake of micronutrients *viz.* Fe, Mn, Zn, Cu and B during 2015 and 2016. A drastic reduction in the uptake of Fe, Mn and Cu during second year could be observed from the tables while uptake of B was higher during first year. However, significant influence of the treatments was observed in the data.

Dolomite + POP + 13:0:45 + borax (T_8) along with lime + $MgSO_4$ + POP treatments alone or with 13:0:45 or borax (T_5, T_6 and T_7) registered significantly higher grain Fe uptake during first year (Table 43). During second year, dolomite + POP alone or with 13:0:45 (T_1 and T_2) and lime + $MgSO_4$ + POP + 13:0:45 (T_6) showed significantly higher Fe uptake in the grain which were on par. Straw Fe uptake was not significantly affected by the treatments during first year. The highest straw Fe uptake during second year was registered by the treatment involving 75% POP (T_{13}) which was on par with T_2, dolomite + POP with 13:0:45 + borax (T_4), T_7, T_8 and lime + POP + 13:0:45 (T_{14}) Significantly higher total uptake of Fe during first year was observed with RHA + $MgSO_4$ + POP (T_9) which was on par with all treatments except those involving dolomite. During second year, dolomite + POP with 13:0:45 (T_2) recorded the highest Fe uptake but was on par with lime + $MgSO_4$ + POP with 13:0:45 or borax or combined spray (T_6, T_7 and T_8) and the treatment having 75% POP (T_{13}).

Significantly superior grain Mn uptake during first year was shown by lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8). During second year, the highest uptake of grain Mn was recorded by dolomite + POP alone (T_1) which was on par with dolomite + POP + 13:0:45 + borax (T_4) and lime + $MgSO_4$ + POP + 13:0:45 and 13:0:45 + borax (T_5 and T_8). Straw Mn uptake during first year was significantly higher with dolomite + POP + 13:0:45 (T_2) and lime + $MgSO_4$ + POP + 13:0:45 (T_6) which were on par during first year. The treatments T_2, RHA

+ $MgSO_4$ + POP with 13:0:45 + borax (T_{12}) and lime + POP with 13:0:45 or 13:0:45 + borax (T_{14} and T_{16}) registered significantly higher straw Mn uptake which were on par. The highest total uptake of Mn during both the years (Table 43) was recorded by dolomite + POP + 13:0:45 (T_2) but was on par with T_8, T_6 and T_1 during first year and T_{14} and T_{16} during second year.

Significantly higher grain Zn uptake was registered with dolomite + POP + 13:0:45 (T_2), all lime + $MgSO_4$ + POP treatments (T_5 to T_8), RHA + $MgSO_4$ + POP with 13:0:45 (T_{10}) and lime + POP with 13:0:45 or 13:0:45 + borax (T_{14} and T_{16}) during first year and were on par (Table 43). During second year dolomite + POP with 13:0:45 or borax or both (T_2, T_3, T_4), lime + $MgSO_4$ + POP + 13:0:45 or borax or both (T_6, T_7, T_8), lime + POP + 13:0:45 or borax or 13:0:45 + borax (T_{14} and T_{15}) recorded significantly higher grain Zn uptake which were on par. The straw Zn uptake during first year was the highest with T_2 which was on par with dolomite + POP + 13:0:45 (T_1), lime + $MgSO_4$ + POP alone or with 13:0:45 (T_5, T_6) and T_{16}. During second year, the dolomite + POP alone or with 13:0:45 or both 13:0:45 + borax (T_1, T_3, T_4) lime + $MgSO_4$ + POP + 13:0:45 or borax (T_5 to T_8) and lime + POP + 13:0:45 or borax (T_{12}) registered significantly higher straw Zn which were on par. In general, the treatments involving RHA registered lower grain and straw Zn uptake. Dolomite + POP + 13:0:45 (T_2) showed the highest total Zn uptake during first year which was on par with dolomite + POP (T_1), lime + $MgSO_4$ + POP (T_5) and lime + POP + 13:0:45 + borax (T_{16}). Lime + $MgSO_4$ + POP with 13:0:45 (T_6) registered the highest uptake during second year but was on par with dolomite + POP + borax with or without 13:0:45 (T_4 and T_3) and lime + $MgSO_4$ + POP with or without 13:0:45 (T_8 and T_7).

Table 43. Effect of nutrient management practices on uptake of Fe, Mn and Zn, kg ha^{-1}

Treatments	Fe uptake						Mn uptake						Zn uptake					
	2015			2016			2015			2016			2015			2016		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	1.52	2.66	4.18	1.02	1.01	2.03	1.33	1.67	3.00	0.10	0.11	0.20	0.14	0.34	0.48	0.12	0.19	0.31
T_2	1.94	2.78	4.72	1.07	1.49	2.56	0.95	2.30	3.25	0.07	0.23	0.30	0.22	0.39	0.61	0.18	0.14	0.31
T_3	1.62	3.05	4.67	0.86	1.24	2.10	0.97	1.36	2.33	0.07	0.18	0.25	0.15	0.23	0.38	0.18	0.15	0.33
T_4	1.05	3.67	4.72	0.83	1.31	2.14	0.88	0.91	1.79	0.08	0.10	0.18	0.15	0.19	0.34	0.19	0.15	0.34
T_5	3.06	3.19	6.24	0.76	1.21	1.97	0.65	0.96	1.61	0.09	0.07	0.15	0.19	0.29	0.48	0.14	0.15	0.29
T_6	3.06	3.73	6.79	1.01	1.25	2.26	0.96	2.10	3.06	0.06	0.13	0.19	0.18	0.24	0.41	0.19	0.19	0.38
T_7	2.46	3.61	6.07	0.90	1.33	2.23	0.51	0.84	1.35	0.07	0.09	0.16	0.17	0.16	0.33	0.15	0.18	0.32
T_8	4.31	1.82	6.13	0.90	1.39	2.28	2.16	1.07	3.24	0.09	0.07	0.16	0.20	0.14	0.34	0.17	0.18	0.35
T_9	3.13	3.80	6.92	0.61	1.20	1.81	1.66	0.81	2.47	0.06	0.04	0.10	0.15	0.15	0.30	0.11	0.13	0.24
T_{10}	3.30	3.30	6.59	0.77	0.88	1.65	1.20	0.78	1.98	0.04	0.09	0.13	0.20	0.16	0.36	0.12	0.14	0.26
T_{11}	2.35	3.57	5.93	0.73	0.72	1.45	0.76	1.02	1.78	0.04	0.10	0.14	0.12	0.12	0.24	0.10	0.12	0.22
T_{12}	2.12	4.12	6.23	0.83	1.03	1.85	0.75	0.86	1.61	0.06	0.20	0.25	0.12	0.14	0.26	0.09	0.17	0.26
T_{13}	2.46	3.36	5.82	0.72	1.58	2.31	0.83	0.84	1.67	0.06	0.08	0.14	0.14	0.18	0.32	0.11	0.11	0.22
T_{14}	2.26	3.88	6.14	0.70	1.38	2.08	0.85	1.50	2.35	0.06	0.21	0.27	0.21	0.15	0.36	0.16	0.09	0.25
T_{15}	2.46	3.27	5.72	0.68	0.79	1.47	0.82	1.81	2.63	0.06	0.18	0.24	0.15	0.19	0.35	0.16	0.09	0.25
T_{16}	2.70	3.28	5.98	0.86	1.22	2.08	0.75	1.70	2.46	0.07	0.20	0.27	0.19	0.33	0.53	0.13	0.10	0.23
SEm (±)	0.32	0.404	0.48	0.05	0.09	0.13	0.13	0.15	0.16	0.01	0.01	0.012	0.021	0.06	0.07	0.01	0.01	0.02
CD(0.05)	0.94	-	1.384	0.143	0.271	0.365	0.362	0.446	0.461	0.018	0.027	0.034	0.0619	.163	0.193	0.038	.037	0.056

All the treatments except those from lime + $MgSO_4$ + POP + 13:0:45 or borax (T_7, T_8) all RHA treatments (T_9 to T_{12}) registered significantly higher grain Cu uptake during first year which were on par (Table 44). During second year, dolomite + POP alone or with 13:0:45 or borax (T_1, T_2 and T_3), lime + $MgSO_4$ + POP + 13:0:45 or 13:0:45 + borax (T_5 and T_8) showed significantly higher grain Cu uptake and were on par. During first year, dolomite with combined spray (T_4) and T_2 and during second year, T_4 and T_1 recorded significantly higher straw Cu uptake. The total Cu uptake was the highest with T_4 which was on par with lime + POP + 13:0:45 (T_{14}) and dolomite + POP + 13:0:45 (T_2) during first year. Meanwhile, dolomite + POP alone (T_1) registered superior value during second year.

Significantly higher grain B uptake was recorded by the treatments dolomite + POP + 13:0:45 (T_2) and dolomite with combined spray (T_4) during first year which were on par (Table 44). During second year, the highest grain B recorded by lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) was on par with dolomite + POP with borax or with 13:0:45 + borax (T_3, T_4), lime + $MgSO_4$ + POP + 13:0:45 (T_6) and lime + POP with 13:0:45 + borax (T_{16}). The treatments T_3, T_4 and T_8 during first year and the treatments T_2, T_3, T_4 and lime + POP with borax (T_7) during second year registered significantly higher straw B uptake which were on par. During both the years, the highest total B uptake was registered with dolomite with combined spray (T_4) which was on par with dolomite + POP + 13:0:45 (T_2), dolomite + POP + borax (T_3) and lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) during first year and T_2, T_3 and lime + $MgSO_4$ + POP + borax (T_7) during second year.

4.2.5.4 Uptake of Na and Al

A perusal of the data in Table 45 revealed the influence of treatments on the uptake of Na and Al which were found to be significant during both the years.

The grain Na uptake was highest with dolomite + POP + 13:0:45 + borax (T_4) during first year which was on par with dolomite + POP + borax (T_3). During second year, all treatments except T_5, all RHA treatments (T_9 to T_{12}), treatment with 75% POP (T_{13}) and lime + POP + borax (T_{15}) registered significantly higher grain Na uptake and were on par. The highest straw Na was recorded by RHA + $MgSO_4$ + POP (T_9) during first year which was superior to others. During second year, all treatments except T_2, T_3 and T_9 to T_{13} registered significantly higher grain Na uptake which were on par. During first year, total uptake of Na ranged from 7.24 to 11.57 kg ha^{-1} and was the highest with RHA + $MgSO_4$ + POP with 13:0:45 (T_{10}) which was on par with dolomite + POP + borax (T_3), lime + $MgSO_4$ + borax (T_7) and lime + POP + 13:0:45 with or without borax (T_{16} and T_{14}). During second year, total uptake of Na ranged from 75.09 to 109.65 kg ha^{-1}. Dolomite + POP (T_1) recorded the highest Na uptake but was on par with dolomite + combined spray (T_4) and the treatments involving lime + POP with and without $MgSO_4$ (T_5 to T_8 and T_{14} to T_{16}).

Application of lime + $MgSO_4$ + POP + borax (T_7) and lime + POP with 13:0:45 or borax (T_{14} and T_{15}) recorded significantly higher grain Al uptake during first year which were on par. During second year, lime + $MgSO_4$ + POP + 13:0:45 (T_6) registered the highest grain Al uptake which was superior to other treatments. During first year, T_6 registered the highest straw Al uptake which was on par with dolomite + POP + borax (T_3), RHA + $MgSO_4$ + POP + 13:0:45 or 13:0:45 + borax (T_{10}, T_{12}) and 75% POP (T_{13}). Lime + $MgSO_4$ + POP + 13:0:45 or 13:0:45 + borax (T_6 and T_8) recorded significantly higher straw Al uptake which were on par during second year. The total uptake of Al ranged from 1.04 to 2.92 kg ha^{-1} during first year and from 1.06 to 1.41 kg ha^{-1} during second year. The highest total Al uptake during first year was recorded by lime + POP + 13:0:45 (T_{14}) which was on par with all treatments except T_1, T_{15} and T_{16}. During second year, the highest Al uptake was observed with lime + $MgSO_4$ + POP + 13:0:45 (T_6).

Table 44. Effect of nutrient management practices on uptake of Cu and B, kg ha-1

Treatments	Cu uptake						B uptake					
	2015			2016			2015			2016		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T1	0.53	0.51	1.04	0.13	0.14	0.27	0.055	0.065	0.12	0.042	0.49	0.53
T2	0.48	0.76	1.24	0.11	0.08	0.19	0.074	0.077	0.15	0.058	0.63	0.69
T3	0.51	0.60	1.11	0.11	0.10	0.21	0.067	0.087	0.15	0.065	0.67	0.74
T4	0.64	0.93	1.57	0.08	0.15	0.22	0.072	0.085	0.16	0.071	0.74	0.81
T5	0.48	0.63	1.11	0.11	0.11	0.21	0.059	0.065	0.12	0.039	0.37	0.41
T6	0.61	0.59	1.20	0.08	0.09	0.17	0.061	0.071	0.13	0.061	0.41	0.47
T7	0.50	0.46	0.96	0.13	0.05	0.19	0.060	0.072	0.13	0.055	0.63	0.69
T8	0.24	0.31	0.55	0.11	0.08	0.19	0.061	0.087	0.15	0.083	0.56	0.64
T9	0.21	0.22	0.43	0.06	0.04	0.10	0.043	0.063	0.11	0.033	0.25	0.28
T10	0.16	0.56	0.72	0.05	0.09	0.14	0.051	0.062	0.11	0.045	0.29	0.33
T11	0.19	0.28	0.47	0.08	0.05	0.13	0.050	0.062	0.11	0.034	0.30	0.33
T12	0.16	0.52	0.68	0.06	0.07	0.13	0.047	0.069	0.12	0.052	0.38	0.43
T13	0.55	0.44	0.99	0.07	0.07	0.13	0.049	0.063	0.11	0.043	0.34	0.38
T14	0.65	0.61	1.25	0.07	0.10	0.17	0.057	0.067	0.12	0.044	0.24	0.29
T15	0.48	0.45	0.93	0.08	0.09	0.17	0.052	0.065	0.12	0.057	0.25	0.31
T16	0.54	0.44	0.98	0.10	0.06	0.16	0.057	0.068	0.13	0.075	0.29	0.37
SEm (±)	0.07	0.09	0.12	0.01	0.01	0.01	0.002	0.002	0.003	0.008	0.05	0.05
CD(0.05)	0.200	0.271	0.340	0.025	0.034	0.041	0.0057	0.0066	0.010	0.0229	0.137	0.133

Table 45. Effect of nutrient management practices on uptake of Na and Al, kg ha^{-1}

Treatments	Na uptake						Al uptake					
	2015			2016			2015			2016		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	0.95	7.63	8.58	2.79	106.86	109.65	0.61	0.43	1.04	0.80	0.54	1.34
T_2	1.09	7.73	9.14	2.76	85.79	88.55	0.82	0.93	1.75	0.55	0.51	1.06
T_3	1.24	9.28	10.52	2.69	86.66	89.35	0.85	1.65	2.49	0.62	0.52	1.14
T_4	1.45	7.93	9.38	2.87	90.26	93.13	0.68	1.15	1.83	0.62	0.55	1.17
T_5	1.11	6.86	7.96	2.38	88.78	91.17	0.66	0.96	1.61	0.92	0.49	1.41
T_6	1.20	7.54	8.74	2.76	97.04	99.80	0.55	2.01	2.56	1.09	0.65	1.73
T_7	1.10	9.66	10.77	2.75	93.35	96.10	1.21	1.07	2.27	0.79	0.59	1.38
T_8	1.07	7.73	8.80	3.09	101.36	104.45	0.90	1.24	2.14	0.70	0.69	1.38
T_9	1.04	14.00	8.77	2.17	82.10	84.27	0.90	1.06	1.97	0.75	0.53	1.28
T_{10}	1.04	6.04	11.57	2.03	79.42	81.45	0.99	1.64	2.63	0.69	0.59	1.28
T_{11}	0.86	8.36	9.23	1.75	79.65	81.40	0.75	1.15	1.90	0.61	0.45	1.06
T_{12}	1.14	8.04	9.19	2.05	86.63	88.68	0.83	1.73	2.56	0.72	0.54	1.26
T_{13}	1.04	6.20	7.24	1.98	73.11	75.09	0.45	1.75	2.20	0.62	0.55	1.18
T_{14}	1.12	9.55	10.67	2.79	95.28	98.07	1.18	1.74	2.92	0.63	0.54	1.17
T_{15}	0.83	7.40	8.23	2.64	98.91	101.55	1.37	0.71	2.07	0.75	0.59	1.34
T_{16}	0.97	8.78	9.75	2.68	103.32	105.99	0.82	0.55	1.37	0.49	0.58	1.07
SEm (±)	0.07	0.63	0.65	0.15	6.74	6.78	0.08	0.20	0.23	0.05	0.03	0.07
CD(0.05)	0.206	1.829	1.889	0.425	19.465	19.567	0.242	0.572	0.657	0.132	0.093	0.190

4.2.6 Soil Analysis

4.2.6.1 Soil pH

There was a hike in the soil pH from the initial status upto PI stage for all the treatments except those involving RHA (Table 3 and 46). At harvest, the pH went below the initial status for all the treatments. In general, pH increased from basal to tillering stage and showed a reduction at PI stage and declined at harvest during both the years.

The significant effect of nutrient management practices on soil pH is evident from the data furnished in Table 46. First year data showed the highest soil pH at seedling stage with dolomite + POP with borax (T_3) which was on par with dolomite + POP with 13:0:45 (T_2), lime + $MgSO_4$ + POP (T_5), 75% POP (T_{13}), lime + POP with 13:0:45 or borax (T_{14} and T_{15}). At tillering stage and PI stages, lime + $MgSO_4$ + POP (T_5) registered the highest pH but it was on par with all treatments except T_2, T_6 (lime + $MgSO_4$ + POP+ 13:0:45), RHA treatments and T_{13} at tillering stage. At PI stage, the treatment T_5 was on par with all treatments except those involving RHA. However, at harvest, lime + $MgSO_4$ + POP+ 13:0:45 (T_6) recorded the highest value which was on par with dolomite + POP with 13:0:45 or 13:0:45 and borax (T_2 and T_8), and T_{13}. At all stages of sampling, the treatments involving RHA showed lower pH values compared to other treatments.

During second year, the pH value was the highest with dolomite + POP + 13:0:45 (T_2) at seedling stage and was on par with dolomite + POP + borax (T_3), lime + $MgSO_4$ + POP alone or with 13:0:45 or 13:0:45 + borax (T_5, T_6, T_8) and 75% POP (T_{13}) and all lime + POP treatments (T_{14} to T_{16}). At tillering, all treatments except RHA treatments and T_{15} recorded pH values on par with lime + $MgSO_4$ + POP+ borax (T_7) which showed the highest value. Treatment T_6 registered the highest pH at PI stage which was on par with all treatments except those involving RHA. At harvest, the highest pH was with dolomite + POP (T_1)

and was on par with T_7 and T_4. During second year also, RHA treatments registered lower pH values than other treatments.

4.2.6.2 EC

The data on soil EC as influenced by the treatments are furnished in Table 46. Electrical conductivity showed an increase over the initial status upto PI stage but showed a sharp increase after the crop (Table 3 and 46).

The treatments showed significant effect on soil EC at all stages of sampling except at tillering during second year. During first year, at seedling stage, EC was the highest for RHA + $MgSO_4$ + POP + borax (T_{11}). At tillering, significantly higher EC values were recorded by RHA treatments (T_9, T_{10} and T_{12}) which were on par. At PI stage, both dolomite with borax (T_3) and lime + 13:0:45 (T_{14}) registered the highest value and was on par with RHA treatments except the one with borax (T_9, T_{10}, T_{12}), lime + POP with 13:0:45 + borax (T_{16}) and T_2. Data at harvest stage indicated the highest EC value with both RHA + $MgSO_4$ + POP alone or with 13:0:45 (T_9 and T_{10}) on par with T_3 and T_{12}.

During second year, at seedling stage, the treatments lime + $MgSO_4$ + POP alone or with 13:0:45 or borax or both (T_5, T_6, T_8) and RHA + $MgSO_4$ + borax (T_{11}) had significantly higher values with the highest value with lime + $MgSO_4$ + POP with borax (T_7). At tillering, the effect of treatments was not significant. The highest EC value at PI stage was with T_{11} which was on par with RHA + $MgSO_4$ + 13:0:45 + borax (T_{12}) and lime + POP + borax (T_{15}). At harvest, lime with combined spray (T_{16}) registered the highest value and was on par with dolomite treatments except the one with combined spray (T_1, T_2, T_3), lime + $MgSO_4$ + POP + 13:0:45 (T_6) and RHA + $MgSO_4$ + POP alone or with 13:0:45 (T_9 and T_{10}).

Table 46. Effect of nutrient management practices on soil pH and EC

Treatments	pH								EC (dS m^{-1})							
	2015				2016				2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	5.51	5.75	5.32	3.83	4.90	5.60	5.14	3.66	0.51	0.43	0.43	1.16	0.35	0.66	0.47	2.02
T_2	5.60	5.68	5.32	4.25	5.18	5.59	5.07	3.05	0.64	0.43	0.60	1.31	0.28	0.52	0.32	1.88
T_3	5.73	5.80	5.27	3.80	5.11	5.29	5.12	3.06	0.61	0.42	0.69	1.36	0.51	0.57	0.48	1.81
T_4	5.53	5.83	5.33	3.91	4.84	5.34	5.07	3.36	0.73	0.43	0.55	1.17	0.50	0.56	0.31	1.50
T_5	5.70	6.01	5.42	3.91	5.07	5.42	5.19	3.19	0.52	0.78	0.37	1.19	0.58	0.58	0.45	1.54
T_6	5.44	5.66	5.28	4.32	5.05	5.49	5.34	3.04	0.60	0.77	0.44	1.22	0.63	0.45	0.35	1.78
T_7	5.40	5.97	5.26	3.80	4.94	5.69	5.11	3.42	0.83	0.73	0.41	1.29	0.67	0.52	0.39	1.70
T_8	5.45	5.90	5.31	4.09	5.02	5.28	5.22	3.15	0.65	0.57	0.48	1.18	0.56	0.55	0.40	1.63
T_9	4.48	4.52	4.23	3.52	4.38	4.27	4.22	2.95	0.79	1.47	0.65	1.40	0.42	0.55	0.47	1.82
T_{10}	4.57	4.58	4.39	3.64	4.20	4.69	4.19	2.89	0.77	1.44	0.59	1.40	0.40	0.52	0.61	1.75
T_{11}	4.42	4.43	4.24	3.50	4.09	4.29	4.32	2.79	1.07	1.19	0.53	1.30	0.56	0.54	0.77	1.65
T_{12}	4.48	4.56	4.29	3.42	4.15	3.95	4.39	2.69	0.75	1.63	0.58	1.37	0.43	0.58	0.71	1.68
T_{13}	5.57	5.72	5.32	4.14	5.03	5.34	5.26	3.00	0.79	0.47	0.56	1.25	0.34	0.51	0.52	1.25
T_{14}	5.66	5.99	5.31	3.75	5.16	5.41	5.17	3.22	0.78	0.47	0.69	1.19	0.53	0.59	0.50	1.67
T_{15}	5.55	5.90	5.37	3.75	5.01	5.23	5.26	3.19	0.72	0.50	0.44	1.17	0.30	0.57	0.68	1.64
T_{16}	5.54	5.90	5.26	3.89	5.04	5.31	5.24	3.17	0.64	0.67	0.58	1.18	0.37	0.53	0.54	2.13
SEm (±)	0.06	0.10	0.06	0.11	0.08	0.15	0.13	0.14	0.05	0.08	0.04	0.02	0.04	0.03	0.05	0.14
CD(0.05)	0.184	0.278	0.173	0.330	0.224	0.422	0.388	0.414	0.139	0.216	0.122	0.060	0.116	-	0.136	0.400

4.2.6.3. Dehydrogenase Enzyme Activity

The data on dehydrogenase enzyme activity is furnished in Table 47. At all the stages of sampling except at harvest, the dehydrogenase enzyme activity improved over the initial status (Table 3) for all treatments except those involving RHA. The RHA treatments recorded lower enzyme activity during the crop growth stages even below the initial value. The dehydrogenase activity declined, after the crop irrespective of treatments, during both the years of experimentation.

Significant effect of nutrient management practices on the dehydrogenase activity was noticed at all stages except at harvest. The highest enzyme activity during first year at seedling stage was recorded with dolomite + POP + 13:0:45 (T_2), but the treatments dolomite + POP + borax (T_3), lime + POP with 13:0:45 or 13:0:45 + borax (T_{14}, T_{16}) and 75% POP (T_{13}) were on par with it. Significantly higher activity was registered by lime with 13:0:45 (T_{14}) at tillering. At PI stage, lime + $MgSO_4$ + POP + 13:0:45 (T_6) recorded the highest activity of enzyme but was on par with all treatments except those involving RHA and T_{14}.

The highest enzyme activity during second year was registered with dolomite + POP (T_1) at seedling and T_4 at PI stages but were on par with all treatments except those involving RHA and 75% POP (T_{13}) at both the stages. Meanwhile, lime + POP + 13:0:45 (T_{14}) registered the highest enzyme activity at tillering.

4.2.6.4. Organic Carbon

Table 47 unveils the effect of treatments on soil OC which was significant at all stages during both the years. The soil was high in OC and a slight reduction in OC was observed at harvest stage during both the years.

Table 47. Effect of nutrient management practices on dehydrogenase activity and organic carbon status in the soil

Treatments	Dehydrogenase (μg TPF g^{-1} soil 24 h^{-1})								Organic carbon (%)							
	2015				2016				2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	114.05	105.74	106.00	68.33	154.95	113.32	117.55	64.72	5.82	4.78	5.14	4.20	5.32	6.03	5.48	4.89
T_2	134.47	117.58	104.01	58.43	151.71	132.24	115.04	72.32	5.12	5.16	4.39	4.46	5.05	5.32	5.55	4.96
T_3	126.53	105.33	114.32	50.87	140.78	118.64	122.58	65.59	5.32	4.99	4.68	5.01	4.79	5.23	5.63	4.84
T_4	110.45	101.85	107.59	41.21	129.53	124.66	123.17	54.34	5.98	4.91	5.27	4.44	5.19	6.16	5.02	4.87
T_5	113.78	108.79	114.22	36.72	150.95	123.72	119.71	58.08	5.00	5.02	4.89	4.48	4.82	5.60	4.81	4.93
T_6	106.17	116.99	116.24	44.09	136.28	133.92	110.83	50.15	6.13	5.00	4.38	4.33	4.39	5.60	4.02	4.94
T_7	113.80	108.00	96.35	67.08	137.04	124.11	111.33	74.62	5.59	4.33	4.29	4.94	4.38	5.39	5.22	4.34
T_8	104.69	110.49	109.98	59.64	130.47	127.41	116.41	46.49	5.95	4.87	4.80	4.26	4.15	5.03	5.16	4.94
T_9	94.53	85.82	79.05	46.93	82.72	73.13	62.96	59.72	5.58	5.21	5.17	4.38	4.67	5.36	4.52	4.57
T_{10}	84.69	79.93	84.07	40.35	72.33	72.05	81.87	36.52	5.21	5.19	4.57	4.43	4.46	5.09	4.70	5.43
T_{11}	94.39	88.67	61.75	37.01	67.97	80.95	66.27	57.42	5.27	5.25	5.27	4.53	5.39	5.67	5.22	4.81
T_{12}	81.33	80.34	70.23	33.08	84.93	76.52	59.56	37.99	5.46	5.32	5.08	4.74	5.11	5.89	5.48	4.98
T_{13}	118.10	112.89	103.33	40.06	132.83	125.07	119.83	45.02	5.97	5.19	4.83	4.11	5.51	4.87	4.52	4.56
T_{14}	119.77	175.78	85.88	35.09	146.21	165.85	122.99	56.37	4.99	5.26	4.47	4.85	5.39	5.89	4.91	4.23
T_{15}	112.37	128.03	110.77	42.61	146.97	134.67	115.43	52.10	6.04	5.24	4.98	4.35	5.52	5.78	4.66	4.41
T_{16}	125.75	115.25	97.53	36.34	143.48	130.23	112.36	47.26	5.76	4.65	4.96	4.24	4.78	5.02	4.35	4.23
SEm (±)	6.99	7.79	7.79	11.16	10.11	6.16	5.77	9.97	0.22	0.19	0.23	0.22	0.150	0.20	0.22	0.22
CD(0.05)	20.184	22.509	22.493	-	29.207	17.792	16.676	-	0.643	0.541	0.654	0.638	0.433	0.568	0.620	0.628

During first year, soil samples at seedling stage showed significantly higher OC with dolomite treatments T_1 and T_4, lime + $MgSO_4$ + POP treatments (T_6, T_7 and T_8), RHA + $MgSO_4$ + POP alone or with 13:0:45 + borax (T_9, T_{12}) and 75% POP (T_{13}) and lime + POP with 13:0:45 or 13:0:45 + borax (T_{15} and T_{16}) which were on par. At tillering stage, RHA + $MgSO_4$ + POP + 13:0:45 + borax (T_{12}) recorded the highest soil OC but was on par with all except T_7 and T_{16}. At PI stage, both T_4 (dolomite + POP + 13:0:45 + borax) and RHA + $MgSO_4$ + POP + borax (T_{11}) had recorded the highest OC that was on par with all treatments except dolomite + POP + 13:0:45 (T_2), lime + $MgSO_4$ + POP treatments (T_6 and T_7), RHA treatment (T_{10}) and lime + POP treatment (T_{14}). At harvest, the highest OC was recorded by dolomite treatment (T_3) and was on par with all except dolomite treatment, T_1, lime + $MgSO_4$ + POP treatment, T_8, treatment involving 75% POP (T_{13}), lime + POP with 13:0:45 or 13:0:45 + borax (T_{15} and T_{16}).

At seedling stage of second year, dolomite + POP alone or with 13:0:45 or 13:0:45 + borax (T_1, T_2, T_4) recorded significantly higher OC values which were on par. The highest OC recorded by dolomite + POP + 13:0:45 + borax (T_3) at tillering stage was on par with T_1, lime + $MgSO_4$ + POP alone or with 13:0:45 (T_5 and T_6), RHA treatments except the one without foliar spray (T_{10}, T_{11} and T_{12}) and lime + POP + 13:0:45 or with 13:0:45 + borax (T_{15} and T_{16}). At PI stage, significantly higher soil OC contents were recorded by dolomite treatments and lime + $MgSO_4$ + POP with borax or with 13:0:45 + borax (T_7 and T_8) RHA + $MgSO_4$ + POP with borax or 13:0:45 + borax (T_{11} and T_{12}) which were on par. Meanwhile, at harvest, RHA + $MgSO_4$ + POP + 13:0:45 (T_{10}) recorded the highest which was on par with dolomite treatments except T_1 and also with T_5, T_8, T_{11} and T_{12}.

4.2.6.5 Available N

The data on soil available N status is depicted in Table 48. The data showed an increase in the availability of N in the soil at seedling stage over the initial status upto tillering stage during 2015 and upto PI stage during 2016, but available N status in the soil decreased at harvest during both the years. However, available N status was maintained near the initial status during first year but showed a slight reduction during second year.

The data also showed that treatment effects were significant only during first year. The highest available N in the soil was registered with dolomite + POP + 13:0:45 (T_2) at seedling stage which was on par with dolomite + POP + borax (T_3 and T_1) and lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8). At tillering, PI and harvest stages, comparatively higher available N was registered with lime + POP + 13:0:45 + borax (T_{16}). However, it was on par with the treatments lime + POP with 13:0:45 (T_{14}) at tillering stage dolomite + POP alone or with 13:0:45 (T_1, T_2) T_{14} and lime + POP with borax (T_{15}) at PI stage and RHA + $MgSO_4$ + POP + 13:0:45 (T_{10}) and lime + POP + borax (T_{15}) at harvest.

4.2.6.6 Available P

The data on the influence of treatments on soil available P is shown in Table 49. Soil available P status increased sharply from the initial low status (Table 3) upto tillering but decreased afterwards. Available P status in the soil at harvest decreased below the initial status during second year.

Significant effect of treatments on available P status at all stages during both the years was also observed from Table 49. First year data showed the highest soil available P with lime + $MgSO_4$ + POP+ 13:0:45 (T_6) at seedling stage which was on par with all dolomite + POP treatments except the one with combined spray (T_1, T_2, T_3) and lime + $MgSO_4$ + POP + borax (T_7). At tillering, dolomite + POP + 13:0:45 (T_2) recorded significantly higher value which was on par with T_1 and lime + $MgSO_4$ + POP (T_5). All treatments of dolomite, T_5 and lime + POP with 13:0:45 (T_{14}) were on par but superior to other treatments at PI stage. At harvest, the highest value was registered with T_{14} which was on par with all dolomite POP treatments except T_3, other lime without $MgSO_4$ treatments and T_6.

Table 48. Effect of nutrient management practices on available N status in the soil, kg ha^{-1}

Treatments	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	214.15	233.01	220.21	188.85	203.84	229.97	256.11	146.35
T_2	233.91	214.99	220.21	188.85	188.16	229.97	250.88	151.57
T_3	233.00	209.76	178.40	183.63	188.16	224.75	277.01	146.35
T_4	204.53	214.99	199.31	194.08	177.71	224.75	266.56	146.35
T_5	204.53	232.57	188.85	188.85	177.71	219.52	256.11	141.12
T_6	209.76	209.76	173.17	173.17	188.16	224.75	266.56	146.35
T_7	209.76	209.76	173.17	178.40	188.16	229.97	266.56	151.57
T_8	220.21	199.31	178.40	183.63	182.93	219.52	261.33	141.12
T_9	199.31	214.99	194.08	204.53	193.39	240.43	261.33	156.80
T_{10}	204.53	204.53	209.76	230.67	193.39	219.52	261.33	141.12
T_{11}	183.63	199.31	194.08	204.53	182.93	229.97	261.33	151.57
T_{12}	204.53	188.85	178.40	183.63	188.16	224.75	282.24	146.35
T_{13}	199.31	199.31	209.76	183.63	198.61	224.75	250.88	146.35
T_{14}	199.31	233.91	220.21	178.40	182.93	229.97	250.88	135.89
T_{15}	204.53	225.44	241.12	235.89	203.84	219.52	266.56	151.57
T_{16}	214.99	277.71	251.57	241.12	198.61	229.97	271.79	141.12
SEm (±)	6.50	11.35	11.08	12.57	10.03	6.99	8.62	6.75
CD(0.05)	18.769	32.790	32.008	36.303	-	-	-	-

During second year, at seedling stage, dolomite + POP + borax (T_3) registered higher available P which was on par with dolomite + POP alone or with 13:0:45 +borax (T_1 and T_4) and (T_5). At tillering, significantly higher available soil P was recorded by dolomite + POP alone or with 13:0:45 (T_1 and T_2) which were on par. At PI, lime + POP + borax (T_{15}) recorded the highest available P content. At harvest, the highest value was observed with lime + $MgSO_4$ + POP + 13:0:45 (T_6) which was on par with all other treatments of lime + $MgSO_4$ + POP and dolomite treatments except T_1, T_{14} and T_{16}.

4.2.6.7 Available K

Soil available K status as influenced by the nutrient management practices is presented in Table 50. In general, an increase in the available K status over the initial status (Table 3) was observed during first year upto tillering which afterwards decreased, with a sharp decline at harvest. During second year, the data showed not much increase in the available K status upto PI stage over the initial status. In general, available K content increased from tillering to PI stage during second year but decreased below the initial status at harvest. However, available K status was in the medium range throughout the cropping period during both the years except at harvest during first year.

Significant effect of treatments was observed during both the years. During first year, RHA + $MgSO_4$ + POP + borax (T_{11}) registered the highest available K which was on par with all other RHA treatments, lime + $MgSO_4$ + POP + 13:0:45 (T_6) and lime + POP with borax or 13:0:45 + borax (T_{15} and T_{16}) at seedling stage. The highest value of available K observed with RHA + MgSO4 + POP + 13:0:45 + borax (T_{12}) at tillering stage was on par with lime + POP + 13:0:45 (T_{14}). Lime + POP + borax or 13:0:45 + borax (T_{15} and T_{16}) and lime + $MgSO_4$ + POP + 13:0:45 (T_6) showed significantly higher available K at PI stage. At harvest, dolomite + POP alone (T_1) recorded higher value but was on par with dolomite + POP + 13:0:45 (T_2).

Table 49. Effect of nutrient management practices on available P status in the soil, kg ha^{-1}

Treatments	Available P							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	19.45	41.59	29.57	11.44	24.27	35.30	16.58	4.07
T_2	20.43	41.96	30.17	11.52	17.25	34.17	14.28	5.38
T_3	18.75	36.22	28.97	10.11	26.75	31.13	17.05	4.63
T_4	17.17	33.53	26.48	11.66	25.09	15.63	16.19	4.89
T_5	16.43	40.24	29.34	10.37	23.97	15.16	16.65	5.82
T_6	20.49	38.30	23.74	11.62	10.38	15.97	15.43	6.50
T_7	19.11	36.51	18.82	9.90	15.12	16.85	18.24	6.31
T_8	17.30	36.96	19.94	10.11	12.43	15.02	20.71	5.38
T_9	18.22	25.84	10.97	7.30	9.71	21.58	17.59	1.68
T_{10}	13.11	26.28	17.32	3.01	11.05	16.71	14.68	1.68
T_{11}	14.90	24.34	17.50	6.20	7.43	15.90	15.97	1.62
T_{12}	13.55	29.94	23.29	8.14	9.56	13.60	13.87	3.32
T_{13}	15.79	35.24	19.86	9.34	18.37	17.73	19.29	4.33
T_{14}	17.34	32.63	25.61	14.05	13.89	20.64	17.86	5.25
T_{15}	19.83	35.17	23.22	12.85	11.83	24.53	26.39	5.37
T_{16}	15.83	34.20	23.89	11.73	12.28	25.85	15.63	5.25
SEm (±)	0.70	1.16	1.92	0.97	1.60	1.28	1.52	0.58
CD(0.05)	2.028	3.338	5.545	2.805	4.616	3.706	4.388	1.672

Table 50. Effect of nutrient management practices on available K status in the soil, kg ha^{-1}

Treatments	Available K							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	146.32	118.72	123.92	49.07	189.85	195.63	200.11	180.50
T_2	127.65	138.13	133.63	45.50	177.82	209.43	184.80	158.50
T_3	120.19	127.31	129.89	41.60	171.73	181.81	212.43	193.50
T_4	119.81	113.12	113.47	38.60	147.47	201.60	214.83	185.67
T_5	128.40	149.33	106.75	41.33	125.07	177.33	205.71	185.83
T_6	148.19	108.27	149.31	27.67	195.25	170.72	202.67	182.83
T_7	144.83	151.95	130.91	39.00	181.07	223.25	204.59	188.83
T_8	141.84	135.15	129.61	28.50	235.20	224.00	215.79	184.17
T_9	150.24	152.32	110.08	26.93	211.68	238.56	235.20	171.00
T_{10}	155.45	176.59	110.48	27.33	169.12	192.27	247.52	175.00
T_{11}	158.64	198.61	106.37	25.83	219.52	227.36	230.72	174.83
T_{12}	151.55	229.60	113.87	22.00	228.11	232.96	253.49	178.17
T_{13}	144.83	203.47	102.92	17.43	183.51	203.84	219.36	207.33
T_{14}	140.35	227.7	128.69	33.83	235.20	257.59	254.61	170.33
T_{15}	154.91	203.47	153.04	39.50	234.83	215.04	247.53	158.17
T_{16}	157.52	215.79	144.69	21.83	215.39	223.25	249.76	171.50
SEm (±)	3.57	5.77	3.74	2.40	17.15	14.75	10.51	9.13
CD(0.05)	10.303	16.660	10.804	6.925	49.520	42.594	30.357	26.378

Second year data showed higher available K with dolomite + POP alone (T_1), lime + $MgSO_4$ + POP + 13:0:45 or 13:0:45 + borax (T_6 and T_8), RHA treatments except the one with 13:0:45 (T_9, T_{11} and T_{12}) and all lime without $MgSO_4$ treatments (T_{14}, T_{15} andT_{16}) which were on par at seedling stage. At tillering, T_{14}, RHA treatments except T_{10} and lime + $MgSO_4$ + POP with borax or with 13:0:45 + borax (T_7, T_8) and lime without $MgSO_4$ treatments were on par. At PI stage, the treatments involving RHA and lime without $MgSO_4$ were on par and significantly superior to others.

4.2.6.8 Available Ca

Table 51 shows the data on available Ca status as affected by the treatments. It is evident that generally an increase in available Ca was observed upto PI stage over the initial status (Table 3) during first year. At harvest, available Ca content decreased even below the initial status during both the years. The initial available Ca status was maintained throughout the season during second year.

Significant effect of treatments on soil available Ca at all stages of sampling during both the years was also evident from the Table 51. During first year, at seedling stage, higher status of available Ca was recorded by the lime + $MgSO_4$ + POP alone or with borax or 13:0:45 + borax (T_5, T_7 and T_8), RHA + $MgSO_4$ + POP with 13:0:45 or 13:0:45 + borax (T_{11} and T_{12}), 75% POP (T_{13}) and all lime + POP treatments (T_{14}, T_{15} and T_{16}). At tillering, the highest value recorded by dolomite + POP + borax (T_3) was on par with all treatments except dolomite + POP + 13:0:45 (T_2), T_{13} and all RHA treatments. The dolomite + POP + borax (T_3) recorded the highest available Ca at PI stage which was on par with T_1, T_2, T_5, T_6, and T_{15}. At harvest, the treatments T_2 and T_3 registered higher available Ca and were on par.

Table 51. Effect of nutrient management practices on available Ca status in the soil, mg kg^{-1}

Treatments	Available Ca							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	355.67	644.50	517.33	283.00	549.83	519.00	610.67	530.67
T_2	363.00	590.33	536.17	413.33	516.33	571.67	508.33	439.50
T_3	313.17	684.00	600.00	395.33	470.17	530.17	576.83	655.83
T_4	371.67	683.00	463.17	308.67	461.67	646.50	637.83	696.00
T_5	491.67	673.33	512.67	246.33	451.17	548.17	549.67	579.33
T_6	374.83	676.50	561.33	334.67	586.00	540.33	595.83	719.50
T_7	479.17	643.50	456.33	334.67	497.50	528.83	511.83	594.17
T_8	462.33	634.50	341.17	327.33	656.67	604.83	509.00	480.50
T_9	342.33	575.33	483.00	230.67	565.67	501.17	578.50	523.50
T_{10}	365.00	582.17	323.50	218.67	454.67	490.67	483.33	516.50
T_{11}	404.00	427.00	304.00	223.33	571.00	434.83	512.33	575.17
T_{12}	410.17	532.17	319.00	241.67	630.17	558.17	571.50	576.17
T_{13}	437.50	566.50	326.83	297.67	534.17	532.00	675.00	569.00
T_{14}	400.33	655.33	403.83	246.33	668.33	535.17	631.50	592.50
T_{15}	407.67	637.33	529.17	238.33	700.33	567.83	687.67	565.67
T_{16}	415.50	690.83	414.67	297.00	671.67	593.33	538.83	561.83
SEm (±)	31.59	23.30	39.08	23.34	24.43	30.72	32.70	43.75
CD(0.05)	91.249	67.287	112.862	67.405	70.564	88.727	94.430	126.343

During second year, RHA treatment (RHA + $MgSO_4$ + POP + 13:0:45 + borax) T_{12}, lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) and all lime without $MgSO_4$ treatments (T_{14}, T_{15} and T_{16}) were superior to other treatments at seedling stage. At tillering, the dolomite + POP + 13:0:45 + borax (T_4) registered higher value which was on par with dolomite + POP + 13:0:45 (T_2), T_8, T_{12}, T_{15} and T_{16}. At PI stage, T_{15} recorded the highest value which was on par with dolomite + POP alone or with 13:0:45 + borax (T_1, T_4), lime + $MgSO_4$ + POP + 13:0:45 (T_6), 75% POP (T_{13}) and T_{14}. Lime + $MgSO_4$ + POP + 13:0:45 (T_6) registered the highest content of available Ca at harvest and was on par with T_4, dolomite + POP + borax (T_3) and lime + $MgSO_4$ + POP + borax (T_7).

4.2.6.9 Available Mg

The data on the status of available Mg in the soil as influenced by nutrient management practices is given in Table 52. Available Mg content in the soil increased over the initial status at all stages of sampling during both the years. During the cropping period, the highest status was noticed at tillering stage during first year and at harvest during second year especially with treatments involving dolomite or $MgSO_4$.

The treatments had significant influence on soil available Mg during both the years (Table 52). During first year, soil available Mg content at seedling stage was higher with lime + $MgSO_4$ + POP + borax (T_7) but was on par with dolomite + POP alone or with borax (T_1, T_3) and lime + $MgSO_4$ + POP alone or with 13:0:45 + borax (T_5, T_8) and 75% POP (T_{13}). At tillering, T_{13} recorded higher value which was on par with T_3, dolomite + POP + 13:0:45 + borax (T_4), lime + $MgSO_4$ + POP (T_5) and RHA + $MgSO_4$ + POP + 13:0:45 + borax (T_{12}). At PI stage, the highest available Mg with T_3 was on par with T_2, T_5 and T_1. The highest available Mg value was also with T_3 at harvest and was on par with T_2 and T_1.

During second year at seedling stage, lime + $MgSO_4$ + POP + 13:0:45 (T_6) registered higher available content of Mg and was on par with T_1, T_2, T_5 and T_8. At tillering, the highest value registered with dolomite + POP + 13:0:45 + borax (T_4) was on par with T_2, T_3 T_5 and T_8. Dolomite + POP + 13:0:45 (T_2)

recorded the highest value at PI and harvest stages and was on par with T_1 and T_4 at PI stage and T_1, T_3 and T_4 at harvest.

4.2.6.10 Available S

The influence of treatments on soil available S during both the years is depicted in Table 53. A reduction from the initial status of available S in the soil due to the treatments was observed at all stages of sampling. Comparing the status at different stages, it can be seen that the available S status decreased after tillering stage but showed an increase at harvest.

The data also revealed significant influence of treatments on soil available S content during both the years. First year sampling at seedling stage showed significantly higher soil available S content with 75% POP (T_{13}), dolomite +POP + 13:0:45 + borax (T_4) lime + $MgSO_4$ + POP +13:0:45 or 13:0:45 + borax (T_6 and T_8), RHA + $MgSO_4$ + POP (T_9) and lime +POP + 13:0:45 or borax (T_{14} and T_{15}) which were on par. At tillering, significantly higher values were recorded by lime + POP + borax or 13:0:45 + borax (T_{15} and T_{16}), RHA + $MgSO_4$ + POP with 13:0:45 or 13:0:45 + borax (T_{10}, T_{11} and T_{12}) and dolomite + POP + 13:0:45 + borax (T_4). The treatment RHA + $MgSO_4$ + POP (T_9) recorded the highest value at PI stage and lime + $MgSO_4$ + POP (T_5) at harvest. But T_5 was on par with T_{12} at harvest.

During second year, at seedling stage, soil available S content with dolomite + POP (T_1) was the highest and was on par with dolomite + POP with borax or with 13:0:45 + borax (T_3 and T_4) and lime + $MgSO_4$ + POP (T_5). At tillering, the highest value recorded by lime + POP + borax (T_{15}) was on par with dolomite + POP with 13:0:45 or borax or 13:0:45 + borax (T_2, T_3, T_4), lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) and RHA + $MgSO_4$ + POP with 13:0:45 or 13:0:45 + borax (T_{11} and T_{12}) At PI stage, significantly higher values were recorded by T_4, T_5 and T_6 which were on par. At harvest also, significantly higher available S was recorded by T_2, T_3, T_4, RHA + $MgSO_4$ + POP + 13:0:45 (T_{10}) and all lime + POP treatments (T_{14}, T_{15} and T_{16}).

Table 52. Effect of nutrient management practices on available Mg status in the soil, mg kg^{-1}

Treatments	Available Mg							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	157.93	143.53	131.63	134.90	147.57	147.57	147.57	229.47
T_2	134.70	145.83	138.50	139.97	143.40	152.43	152.43	234.20
T_3	140.87	147.23	140.20	142.30	124.97	132.57	132.57	233.10
T_4	134.43	148.83	126.40	123.77	126.33	138.67	138.67	221.60
T_5	144.70	152.30	134.00	114.87	143.97	134.37	134.37	190.23
T_6	124.63	130.83	123.53	110.97	152.93	135.57	135.57	200.60
T_7	160.63	142.07	124.20	112.33	131.33	130.93	130.93	151.60
T_8	148.47	133.83	127.67	102.59	149.17	127.57	127.57	153.97
T_9	128.20	122.77	115.90	96.27	126.97	130.80	130.80	163.37
T_{10}	126.30	125.57	115.13	96.47	116.17	112.67	112.67	186.63
T_{11}	120.60	123.47	112.87	95.15	127.03	126.47	126.47	171.87
T_{12}	115.03	148.63	111.30	91.06	132.57	128.80	128.80	154.10
T_{13}	143.13	156.97	122.43	109.27	129.60	123.43	123.43	148.17
T_{14}	107.67	117.10	109.70	102.33	112.30	109.50	109.50	100.40
T_{15}	107.67	116.23	109.73	102.83	106.60	114.57	114.57	90.20
T_{16}	103.72	116.67	102.93	102.87	109.77	110.20	110.20	85.97
SEm (±)	7.66	3.74	3.74	3.23	6.77	6.14	5.45	6.02
CD(0.05)	22.118	10.789	12.043	9.340	19.563	17.726	15.735	17.376

Table 53. Effect of nutrient management practices on available S status in the soil, mg kg^{-1}

Treatments	Available S							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	335.39	388.22	209.78	316.35	337.54	250.96	155.83	302.25
T_2	314.74	322.02	392.59	147.10	237.25	294.29	218.83	425.29
T_3	366.64	371.40	352.59	121.98	363.00	296.29	161.46	400.29
T_4	541.98	473.07	407.98	289.58	403.79	272.67	327.75	397.38
T_5	416.47	428.33	294.76	462.28	301.63	237.17	339.38	288.17
T_6	485.04	341.00	222.45	324.30	270.50	226.42	340.88	323.13
T_7	412.30	322.17	175.75	251.90	399.54	217.50	227.88	271.63
T_8	500.47	341.93	232.04	269.75	358.25	282.50	226.54	299.63
T_9	509.34	431.88	485.99	304.45	471.67	240.96	173.50	254.58
T_{10}	320.29	457.04	373.38	320.32	574.08	219.21	208.54	358.50
T_{11}	452.40	482.48	211.59	336.18	538.92	324.75	164.67	289.21
T_{12}	389.73	463.81	286.70	438.12	509.79	339.08	202.83	256.21
T_{13}	564.55	422.48	319.65	270.73	489.63	251.88	162.38	276.04
T_{14}	490.25	423.87	234.14	298.50	167.79	226.54	168.63	364.92
T_{15}	508.30	486.97	378.47	231.07	155.83	348.17	170.46	412.00
T_{16}	430.70	540.04	397.84	183.48	287.67	396.33	223.83	385.25
SEm (±)	31.90	29.35	25.71	15.77	32.98	27.09	26.31	31.35
CD(0.05)	92.129	84.763	74.252	45.542	5.240	78.237	76.001	90.556

4.2.6.11 Soil available Fe

Soil available Fe status as influenced by nutrient management practices are furnished in Table 54. Compared to the initial soil status, the treatments registered lower available Fe content during both the years at all stages of sampling except at harvest during second year especially for RHA treatments. There was a decreasing trend of available Fe content from seedling to tillering stage and an increasing trend upto PI stage during first year and upto harvest stage during second year.

The lowest content of available Fe during first year at seedling and tillering and PI stages was recorded by dolomite + POP + borax (T_3) but it was on par with lime + $MgSO_4$ + POP treatments (T_5 to T_8) and lime + POP with 13:0:45 or borax (T_{14} and T_{15}). At tillering stage, treatments involving dolomite + POP and lime + $MgSO_4$ + POP except T_8 were significantly higher and on par. The treatment T_3 was the highest and on par with dolomite + POP + 13:0:45 + borax T_4 at PI stage. At harvest, dolomite + POP + 13:0:45 (T_2) recorded the lowest value but all dolomite treatments and T_{14} were on par. The RHA treatments registered higher values.

During second year, at seedling stage, the treatments dolomite + POP with borax or 13:0:45 + borax (T_3, T_4) showed significantly lower content of available Fe. At tillering stage, the treatments involving dolomite + POP, lime + MgSO4 + POP and 75% POP (T_{13}) were on par but significantly superior to others. The treatment lime + MgSO4 + POP+ borax (T_7) recorded the lowest Fe content at PI stage and T_2 (dolomite + POP + 13:0:45) at harvest. Treatments involving RHA showed higher availability of Fe in the soil.

Table 54. Effect of nutrient management practices on available Fe status in the soil, mg kg^{-1}

Treatments	Available Fe							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	818.67	625.33	888.67	613.27	1073.67	723.33	920.67	1089.67
T_2	965.83	761.23	788.13	594.57	1192.33	783.37	1075.00	917.20
T_3	504.77	464.77	608.77	618.50	948.40	808.60	1126.00	1428.33
T_4	862.07	717.87	644.07	606.90	1056.87	846.27	1162.00	1288.33
T_5	698.77	635.40	928.23	845.10	1083.67	809.77	1122.33	1428.33
T_6	720.00	540.70	1034.60	893.60	1203.67	742.80	1186.00	1723.67
T_7	747.50	714.13	930.83	870.93	1227.33	920.40	655.73	1227.67
T_8	631.40	766.33	730.57	749.40	1120.00	842.43	1015.07	1274.33
T_9	1020.00	1012.67	1197.00	1066.03	1466.33	1177.43	1235.67	1665.00
T_{10}	1064.67	992.33	1231.00	881.53	1208.00	983.60	1235.67	1654.67
T_{11}	1061.33	1114.00	1200.80	937.10	1284.33	1044.97	1464.00	1769.33
T_{12}	1134.77	1176.33	1103.33	881.67	1257.33	999.33	1442.00	1682.33
T_{13}	831.03	960.03	800.37	762.57	1199.33	858.37	1312.33	1611.67
T_{14}	663.13	908.80	781.10	669.73	1103.67	982.23	1218.67	1650.33
T_{15}	629.47	943.10	857.37	796.27	1199.33	1077.00	1114.67	1568.33
T_{16}	759.40	845.00	802.77	749.53	1240.67	942.00	1153.67	1641.33
SEm (±)	106.17	87.58	44.90	40.12	39.70	58.20	51.69	70.15
CD(0.05)	306.639	252.951	129.692	115.865	114.672	168.082	149.286	202.617

4.2.6.12 Available Mn

The data on the influence of nutrient management practices on soil available Mn are presented in Table 55. The data showed an increase in the available Mn content over the initial value at all stages of sampling during first year. During the cropping period, there was a reduction in available Mn content at harvest. During second year, the available Mn increased upto tillering stage. However, it dropped to deficiency level for some of treatments at PI stage while it underwent a sharp increase at harvest.

There was significant effect of treatments on available Mn content during both the years. During first year, at seedling stage, lime +POP with 13:0:45 or 13:0:45 + borax (T_{14}, T_{16}), RHA treatments except the one without foliar spray (T_{10}, T_{11}, T_{12}) and lime + $MgSO_4$ + POP with borax or 13:0:45 + borax (T_7 and T_8) recorded significantly higher available Mn in the soil and were on par. The dolomite treatments except T_1, lime + $MgSO_4$ + POP treatments- T_7 and T_8, RHA + $MgSO_4$ + POP + borax (T_{11}) and lime + POP + borax (T_{15}) registered superior values of available Mn at tillering stage. The treatments RHA + $MgSO_4$ + POP alone or with 13:0:45 (T_9, T_{10}), lime + POP with borax or 13:0:45 (T_{15}, T_{16}) were on par and superior to other treatments at PI stage. At harvest, all treatments except dolomite + POP (T_1), lime + $MgSO_4$ + POP alone or with 13:0:45 + borax (T_5, T_8), 75% POP (T_{13}) and lime + POP + 13:0:45 (T_{14}) were on par and superior to others.

During second year, at seedling stage, dolomite + POP + 13:0:45 + borax (T_4) recorded the highest value which was closely followed by lime + $MgSO_4$ + POP (T_5). At tillering, dolomite + POP + 13:0:45 (T_2) registered the highest content of Mn which was on par with dolomite + POP alone or with borax (T_1, T_3). At PI stage, available Mn values of some of the treatments were below the detectable limit. The treatment T_4 recorded the highest value at PI and harvest stages but at harvest, it was on par with all other dolomite treatments and lime + $MgSO_4$ + POP with borax (T_7).

Table 55. Effect of nutrient management practices on available Mn status in the soil, mg kg^{-1}

Treatments	Available Mn							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	3.23	3.63	3.26	1.90	3.12	3.25	0.41	9.76
T_2	3.83	4.93	3.91	2.96	4.40	3.48	0.62	10.06
T_3	3.94	4.38	3.18	2.37	2.55	3.20	0.79	9.73
T_4	3.97	4.45	3.53	2.76	5.67	1.60	2.16	10.55
T_5	4.02	2.16	3.94	1.46	5.66	2.21	1.08	8.43
T_6	3.80	3.04	4.02	2.55	3.18	2.01	-	8.13
T_7	5.69	4.77	2.24	2.68	3.51	1.50	-	9.63
T_8	5.65	3.87	2.61	1.14	4.95	3.34	1.37	6.87
T_9	5.04	3.73	5.64	2.42	2.62	2.60	0.42	7.96
T_{10}	6.12	3.43	4.86	2.56	3.76	1.95	1.52	7.09
T_{11}	6.11	3.90	3.28	2.67	2.85	1.86	-	8.15
T_{12}	5.49	3.37	4.03	2.84	2.19	1.31	-	7.93
T_{13}	4.43	3.10	3.35	1.79	3.08	1.73	0.72	8.44
T_{14}	5.75	3.04	3.08	1.55	4.14	2.49	1.01	7.32
T_{15}	5.17	4.27	4.18	1.35	4.22	2.87	1.48	7.94
T_{16}	6.49	3.31	4.11	1.32	2.44	2.08	0.50	8.67
SEm (±)	0.40	0.37	0.39	0.27	0.22	0.18	0.34	0.45
CD(0.05)	1.164	1.075	1.140	0.768	0.634	0.517	0.986	1.302

4.2.6.13 Available Zn

The data on the effect of treatments on soil available Zn during both the years are presented in Table 56. An increase in available Zn status compared to the initial status (Table 3) at all stages during first year and a reduction during second year was observed (Table 55). An increasing trend from seedling to tillering stage and a decrease at PI stage was observed which further increased at harvest for most of the treatments during first year. However, an increasing trend upto PI stage and a decline at harvest were noticed during second year.

The data also showed significant effect of treatments at all stages during both the years. During first year, at seedling stage, 75% POP (T_{13}) recorded the highest available Zn content and was on par with lime + $MgSO_4$ + POP with borax or 13:0:45 + borax (T_7, T_8), RHA + $MgSO_4$ + POP alone or with borax (T_9, T_{11}) and lime + POP with borax (T_{15}). At tillering, the highest value of soil available Zn was registered by lime + POP + 13:0:45 + borax (T_{16}) but was on par with dolomite + POP + 13:0:45 + borax (T_4) and RHA + $MgSO_4$ + POP alone or with 13:0:45 (T_9, T_{10}). Meanwhile, significantly higher values were recorded by lime + $MgSO_4$ + POP (T_5) at PI stage and dolomite + POP + 13:0:45 (T_2) at harvest.

During second year, RHA + $MgSO_4$ + POP + 13:0:45 + borax (T_{12}) registered the highest available Zn but was on par with dolomite + POP (T_1), lime + $MgSO_4$ + POP with borax or 13:0:45 + borax (T_7 and T_8) and RHA + $MgSO_4$ + POP with 13:0:45 or borax (T_{10} and T_{11}) at seedling stage. At tillering, lime + $MgSO_4$ + POP + 13:0:45 (T_6) registered the highest value and at PI stage, dolomite + POP with 13:0:45 or 13:0:45 + borax (T_2, T_4), lime + $MgSO_4$ + POP (T_5) and RHA treatments-T_9 and T_{10} were on par and superior in available Zn content. At harvest, lime + POP + borax (T_{15}) recorded the highest value.

Table 56. Effect of acidity amelioration practices on available Zn status in the soil, mg kg^{-1}

Treatments	Available Zn							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	1.74	3.33	2.10	5.58	1.79	2.69	3.49	1.92
T_2	2.42	2.54	2.84	6.75	1.51	2.63	4.04	2.05
T_3	2.16	3.64	3.90	5.28	1.37	2.80	3.20	1.97
T_4	2.26	4.26	3.58	5.77	1.52	2.54	4.18	1.36
T_5	1.91	3.85	5.95	3.89	1.29	2.99	4.04	1.57
T_6	2.43	3.13	2.64	2.87	1.28	3.82	3.47	1.60
T_7	2.49	3.06	1.91	3.15	1.92	2.85	3.11	1.15
T_8	2.78	3.62	1.77	4.04	1.70	3.14	3.38	2.06
T_9	2.77	2.87	2.47	1.87	1.37	2.30	4.11	1.93
T_{10}	1.81	2.90	2.00	1.48	1.67	2.98	4.05	2.08
T_{11}	2.57	3.36	3.33	3.24	1.86	2.99	3.38	2.17
T_{12}	2.31	4.54	1.82	2.80	2.00	2.73	2.73	2.01
T_{13}	3.08	3.46	2.47	2.12	1.58	2.52	3.46	1.60
T_{14}	2.08	2.96	1.64	1.85	1.12	2.78	4.01	2.33
T_{15}	2.50	3.40	2.75	1.79	1.29	3.10	3.86	2.62
T_{16}	1.98	4.70	2.19	1.51	1.64	3.23	3.97	1.69
SEm (±)	0.21	0.30	0.28	0.28	0.12	0.20	0.18	0.10
CD(0.05)	0.617	0.868	0.820	0.806	0.341	0.570	0.532	0.280

4.2.6.14 Available Cu

Table 57 depicts the effect of nutrient management practices on available Cu in the soil. Initially, the soil was deficient in available Cu during both the years (Table 3). Available Cu status was found to be deficient at seedling and tillering stages and thereafter increased to sufficient level upto harvest during first year. However, it was deficient at all stages during second year.

Treatments had significant influence on available Cu at all stages during both the years. During first year, dolomite + POP alone or with 13:0:45 + borax (T_1, T_4) and lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) recorded significantly higher available Cu which were on par at seedling stage. At tillering, T_1 and dolomite + POP + borax (T_3), lime + $MgSO_4$ + POP alone or with 13:0:45 + borax (T_5, T_8) and RHA + $MgSO_4$ + POP with borax or 13:0:45 + borax (T_{11} and T_{12}) which were on par registered significantly higher values. The treatment T_{11} recorded the highest value at PI stage and T_3 at harvest.

During second year, at seedling stage, RHA + $MgSO_4$ + POP with borax (T_{11}) recorded higher content which was on par with lime + $MgSO_4$ + POP + borax (T_7), RHA + $MgSO_4$ + POP alone or with 13:0:45 + borax (T_9, T_{12}) and 75% POP (T_{13}). The RHA treatments except T_{10} and 75% POP (T_{13}) registered significantly higher values at tillering. At PI stage, both dolomite + POP (T_1) and RHA + $MgSO_4$ + POP + 13:0:45 (T_{10}) were significantly superior. At harvest, lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) recorded the highest content.

4.2.6.15. Available B

The effect of treatments on soil available B is presented in Table 58.

The soil had deficiency of B initially (Table 3). During first year, available B contents were higher than the initial status at all stages but remained deficient throughout (Table 58). However, during second year, the available B increased at seedling stage over the level of sufficiency irrespective of treatment and increased from initial status upto tillering stage during second year. The available B status showed an increase at seedling stage during second year and thereafter decreased and for some treatments the values decreased below detectable limit during harvest. In general, higher available B status was recorded by dolomite treatments. During first year, available B contents increased from the initial status at seedling stages and increased level was maintained during other stages.

Table 58 shows the significant effect of treatments on soil available B. During first year, at seedling stage, higher soil B content was recorded by lime + POP with 13:0:45 or borax (T_{14} and T_{15}) which was on par with RHA + $MgSO_4$ + POP (T_9). At tillering stage, dolomite + POP 13:0:45 + borax (T_4) and T_9 recorded superior value. At PI also, T_4 registered the highest soil B content which was on par with other treatments of dolomite except dolomite + POP + borax (T_3) and RHA + $MgSO_4$ + POP + 13:0:45 (T_{10}). At harvest stage, all dolomite treatments except T_2, RHA + $MgSO_4$ + POP with borax or 13:0:45 + borax (T_{11}, T_{12}) and lime + POP with 13:0:45 + borax (T_{16}) recorded significantly higher available B in soil and were on par.

During second year, all dolomite treatments except T_4, lime + POP + $MgSO_4$ with borax or 13:0:45 + borax (T_7, T_8) and 75% POP (T_{13}) registered higher soil available B content at seedling stage. At tillering stage also, T_{13} recorded the highest B content in the soil which was on par with dolomite + POP (T_1), RHA + $MgSO_4$ + POP + 13:0:45 + borax (T_{12}), lime + POP with borax or 13:0:45 + borax (T_{15}, T_{16}). At PI stage, dolomite + POP + 13:0:45 (T_2) recorded the highest soil B which was on par with all other dolomite treatments and lime + $MgSO_4$ + POP + borax (T_7). At harvest, RHA + $MgSO_4$ + POP + 13:0:45 + borax (T_{12}) showed higher available B which was on par with all other RHA treatments.

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Table 57. Effect of nutrient management practices on available Cu status in the soil, mg kg^{-1}

Treatments	Available Cu							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	0.97	0.81	1.82	5.18	0.72	0.17	0.58	0.20
T_2	0.72	0.53	1.73	6.77	0.56	-	-	0.10
T_3	0.71	0.96	1.28	8.82	0.60	-	-	0.23
T_4	0.95	0.53	1.57	5.88	0.69	-	-	0.20
T_5	0.80	0.93	1.12	3.07	0.68	0.20	-	-
T_6	0.55	0.59	2.45	4.07	0.68	-	-	0.08
T_7	0.48	0.62	2.42	3.26	0.77	0.27	-	-
T_8	0.80	1.02	3.07	1.90	0.59	-	-	0.52
T_9	0.50	0.13	2.64	1.47	0.80	0.42	0.08	0.13
T_{10}	0.62	0.46	3.46	5.03	0.66	0.31	0.10	0.14
T_{11}	0.59	0.79	5.31	3.32	0.93	0.44	0.58	-
T_{12}	0.36	1.02	2.27	2.41	0.80	0.52	0.14	0.26
T_{13}	0.60	0.24	3.94	2.92	0.81	0.39	0.12	-
T_{14}	0.64	0.26	2.51	3.33	0.72	0.30	0.14	-
T_{15}	0.67	0.59	4.08	3.13	0.63	0.42	-	-
T_{16}	0.69	0.75	2.05	2.45	0.76	0.49	-	-
SEm (±)	0.081	0.08	0.08	0.21	0.07	0.04	0.02	0.03
CD(0.05)	0.235	0.243	0.228	0.597	0.190	0.131	0.076	0.085

Table 58. Effect of nutrient management practices on available B status in the soil, mg kg^{-1}

Treatments	Available B							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	0.36	0.42	0.42	0.41	1.14	1.16	0.26	-
T_2	0.40	0.42	0.41	0.34	1.36	0.69	0.30	-
T_3	0.40	0.40	0.35	0.39	1.17	0.95	0.29	0.03
T_4	0.45	0.48	0.43	0.41	0.89	0.84	0.28	-
T_5	0.43	0.40	0.36	0.32	0.54	0.85	0.21	-
T_6	0.38	0.41	0.37	0.33	0.84	0.53	0.10	-
T_7	0.44	0.43	0.39	0.32	1.08	0.51	0.23	0.07
T_8	0.42	0.43	0.33	0.40	1.24	0.25	0.16	-
T_9	0.46	0.48	0.35	0.36	0.82	0.95	0.11	0.48
T_{10}	0.44	0.44	0.41	0.36	0.76	0.94	0.15	0.68
T_{11}	0.44	0.42	0.36	0.41	0.64	1.03	0.15	0.57
T_{12}	0.44	0.39	0.36	0.38	0.58	1.27	0.15	0.71
T_{13}	0.44	0.42	0.39	0.31	1.23	1.35	0.10	-
T_{14}	0.47	0.44	0.36	0.32	0.54	0.45	0.22	-
T_{15}	0.47	0.36	0.37	0.33	0.78	1.05	0.22	-
T_{16}	0.42	0.44	0.40	0.38	0.37	1.09	0.16	-
SEm (±)	0.01	0.01	0.01	0.01	0.15	0.11	0.02	0.09
CD(0.05)	0.014	0.018	0.020	0.033	0.444	0.315	0.067	0.261

4.2.6.16 Available Na

Table 59 shows significant effect of treatments on soil available Na at all stages of sampling except at PI and harvest stages of second year. Initially, the available Na status was below toxic limit during first year and above toxic limit during second year (Table 3). A reduction in the availability of Na from the initial level was observed during the cropping period during both the years. However, there was a decline in the Na status at tillering and PI stages during second year followed by an increase in the level at harvest stage.

During first year at seedling stage, RHA + $MgSO_4$ with 13:0:45 (T_{10}) recorded higher Na which was on par with RHA with combined spray (T_{12}). At tillering, lime + POP with combined spray registered the highest available Na and and was on par with RHA treatments (T_{11}, T_{12} and T_{13}). At PI stage, dolomite + POP + borax (T_3) along with dolomite + POP with combined spray (T_2), lime + MgSO4 + POP with 13:0:45 or 13:0:45 + borax (T_6, T_8) and all RHA treatments showed higher values of Na. The highest soil available Na was registered at harvest with lime + $MgSO_4$ + POP+ borax (T_7) and was on par with dolomite + POP (T_1).

During second year, higher soil Na contents were found with lime + MgSO4 + POP+ 13:0:45 + borax (T_8), RHA treatments and lime + POP with borax or 13:0:45 + borax (T_{15}, T_{16}) at seedling stage. The treatment RHA + $MgSO_4$ + POP + 13:0:45 + borax (T_{12}) registered higher Na which was on par with dolomite + POP + 13:0:45 + borax (T_4), lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8), RHA + $MgSO_4$ + POP + 13:0:45 (T_{10}) and lime + POP + borax (T_{15}) at tillering stage. The treatments had no significant effect at PI and harvest stages.

Table 59. Effect of nutrient management practices on available Na status in the soil, mg kg^{-1}

Treatments	Available Na							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	138.83	128.17	129.50	125.00	125.00	86.50	88.00	180.50
T_2	142.33	127.00	131.67	124.00	109.00	100.83	84.50	198.17
T_3	138.17	126.33	134.33	123.37	100.83	92.17	87.00	186.17
T_4	153.17	126.67	129.17	124.50	104.83	107.17	90.33	189.83
T_5	148.17	132.17	125.33	121.33	99.17	98.17	86.17	197.67
T_6	146.33	125.50	131.33	121.67	113.33	96.17	86.67	195.00
T_7	149.33	130.33	128.67	127.67	122.17	98.33	86.00	206.17
T_8	148.17	126.50	130.20	119.33	155.17	102.83	84.83	176.17
T_9	144.73	130.17	130.67	119.33	147.50	100.17	86.17	204.67
T_{10}	164.17	135.67	132.00	122.00	133.00	105.83	86.67	205.00
T_{11}	154.77	138.00	131.67	120.67	139.50	99.67	87.33	207.00
T_{12}	158.67	136.17	132.20	120.67	138.83	110.50	87.50	198.00
T_{13}	148.07	137.83	128.40	119.50	111.17	96.33	86.83	197.17
T_{14}	137.50	131.67	126.50	119.17	130.50	97.50	85.17	177.83
T_{15}	141.67	135.33	124.83	119.17	124.17	108.17	91.17	168.00
T_{16}	146.50	138.00	125.67	119.83	138.67	96.83	83.33	169.33
SEm (±)	2.22	0.66	1.61	1.01	10.97	2.77	1.44	11.41
CD(0.05)	6.405	1.903	4.653	2.907	31.690	8.007	-	-

4.2.6.17 Exchangeable Al

The data on effect of nutrient management practices on soil exchangeable Al are shown in Table 60. Though the soil was high in exchangeable Al status initially (Table 3), it was below the critical limit of toxicity during both the years (Appendix II). The Al content decreased from the initial value during the cropping period at all stages during both the years. During first year, the Al was reduced at harvest whereas during second year, it was increased.

Exchangeable Al status was significantly influenced by the treatments. During seedling stage of first year, lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) registered the highest and was on par with lime + MgSO4 + POP+ borax (T_7) and all treatments involving RHA. At tillering and harvest stages also, the RHA treatments recorded significantly higher exchangeable Al and were on par. During PI stage, RHA treatments-T_{10} to T_{12} recorded significantly higher Al status and were on par.

During second year, RHA + $MgSO_4$ + POP with borax or 13:0:45 + borax (T_{11} and T_{12}) were superior to others at seedling stage. At tillering stage, significantly higher Al status was observed with RHA + $MgSO_4$ + POP alone or with borax (T_9 and T_{11}) and 75% POP (T_{13}). The RHA treatments (T_{10} to T_{12}) which were on par registered significantly higher Al status at PI stage. However, at harvest, significantly higher exchangeable Al was observed with lime + $MgSO_4$ + POP + borax (T_7), T_{13} and lime + POP treatments (T_{14} to T_{16}).

4.2.7 Pest and Disease Incidence

Incidence of stem borer (*Scirpophaga incertulas*) was observed at tillering stage during both the years. Scoring for the pest incidence was done and data is presented in Table 61.

Table 60. Effect of nutrient management practices on exchangeable Al in the soil, mg kg^{-1}

Treatments	Exchangeable Al							
	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
T_1	16.58	12.97	20.67	6.19	31.18	19.48	48.92	84.40
T_2	18.78	14.86	18.16	8.11	26.15	18.58	51.11	73.20
T_3	21.06	20.33	21.47	6.37	25.52	13.09	47.82	79.38
T_4	19.24	19.22	25.44	10.15	28.51	18.30	48.38	86.67
T_5	20.29	15.79	9.97	11.73	21.88	22.05	59.44	84.27
T_6	15.77	12.32	20.18	8.61	31.80	20.08	46.89	81.29
T_7	51.36	13.19	17.26	8.35	35.14	15.04	52.34	96.33
T_8	51.39	14.73	19.78	6.83	37.49	25.95	49.41	68.67
T_9	47.95	42.89	23.68	33.67	43.95	42.76	56.33	79.55
T_{10}	50.22	53.81	41.29	33.30	37.58	32.46	72.82	70.92
T_{11}	48.80	53.26	45.84	29.76	56.73	34.76	72.89	81.50
T_{12}	47.92	49.46	38.36	34.77	56.56	32.02	80.41	79.27
T_{13}	19.24	22.48	19.81	13.79	42.15	34.37	54.36	97.57
T_{14}	19.77	19.38	15.45	7.46	41.44	24.88	61.21	100.60
T_{15}	13.34	18.49	15.83	10.58	30.76	17.34	61.04	97.30
T_{16}	22.19	28.45	17.72	6.93	24.37	20.81	61.34	105.47
SEm (±)	3.97	3.03	2.95	2.89	2.09	2.99	3.23	4.51
CD(0.05)	11.470	8.757	8.522	8.355	6.036	8.634	9.334	13.022

Table 61. Effect of nutrient management practices on incidence of stem borer (*Scirpophagus incertulas*), %

Treatments	2015	2016
T_1	14.00	8.67
T_2	15.33	12.00
T_3	15.33	10.67
T_4	13.33	12.00
T_5	16.00	10.00
T_6	12.00	8.67
T_7	14.67	9.33
T_8	14.00	10.00
T_9	11.64	6.00
T_{10}	8.00	5.33
T_{11}	10.67	3.33
T_{12}	9.33	4.00
T_{13}	13.33	8.67
T_{14}	17.33	6.00
T_{15}	16.67	6.00
T_{16}	15.33	5.33
SEm (±)	1.26	1.25
CD(0.05)	3.64	3.600

The data in Table 61 revealed significant effect of nutrient management practices on stem borer incidence. The score ranged from 9.33 to 17.33% during first year and 3.33 to 12% during second year. The treatments involving RHA registered significantly lower incidence of stem borer during first year and the same treatments and the lime treatments without $MgSO_4$ recorded significantly lower incidence during second year.

4.2.8. Economics of Cultivation

Table 62 furnishes the data on the effect of nutrient management practices on economics of cultivation. Both net income and BCR varied significantly due to nutrient management during both the years.

During first year, all dolomite treatments (T_1 to T_4) recorded significantly higher net income and BCR compared to other treatments but the highest net income and BCR were recorded with dolomite + POP + 13:0:45 (T_2) followed by dolomite + POP + 13:0:45 + borax (T_4). The treatments involving RHA (T_9 to T_{12}) and 75% POP (T_{13}) registered lower net income and BCR. Lime + POP treatments without $MgSO_4$ (T_{14}, T_{15} and T_{16}) recorded higher net income and BCR compared to lime + $MgSO_4$ + POP treatments (T_5 to T_8).

During second year also, the highest net income was recorded by T_2 but was on par with all other dolomite treatments (T_1, T_3 and T_4) and lime + POP + 13:0:45 + borax (T_{16}). The highest BCR was also recorded by T_2 which was on par with T_4, T_3, T_1 and T_{16}. Lower values of net income and BCR were recorded by the treatments involving RHA and 75% POP. The lime treatments without $MgSO_4$ registered higher net income and BCR compared to lime + $MgSO_4$ treatments during second year also.

Table 62. Effect of nutrient management practices on cost of cultivation

Treatments	2015			2016		
	Gross income (` ha^{-1})	Net income (` ha^{-1})	BCR	Gross income (` ha^{-1})	Net income (` ha^{-1})	BCR
T_1	107500	57050	2.13	115350	61450	2.14
T_2	116458	65108	2.27	125325	70475	2.28
T_3	106425	55175	2.08	118200	63450	2.16
T_4	114667	63067	2.22	123225	68125	2.24
T_5	93167	33077	1.55	112725	49185	1.77
T_6	109650	48660	1.80	119775	55285	1.86
T_7	103200	42310	1.69	115950	51560	1.80
T_8	105708	44468	1.73	120825	56085	1.87
T_9	69158	10108	1.17	89325	26825	1.43
T_{10}	77758	17808	1.30	107700	44250	1.70
T_{11}	73458	13608	1.23	100050	36700	1.58
T_{12}	81342	21142	1.35	102975	39275	1.62
T_{13}	89583	29518	1.49	109875	46235	1.73
T_{14}	96392	45002	1.88	111375	56485	2.03
T_{15}	90658	39368	1.77	113250	58460	2.07
T_{16}	99617	47977	1.93	117000	61860	2.12
SEm (±)	-	2479	0.04	-	3187	0.05
CD(0.05)	-	7162.5	0.127	-	9207.2	0.156

4.2.9 Correlation analysis

The correlation analysis of grain yield versus flag leaf nutrient content, LAI, panicle number and nutrient uptake are given in Table 63 and 64.

There was significant and positive correlation of grain yield with LAI at MT and PI stages and panicle number during both the years. During first year, the content of P, Ca, Zn and B in the flag leaf had significant and positive correlation whereas S, Fe, Mn, Cu and Al had significant and negative correlation with grain yield. During second year, there was significant and positive correlation of P, K and Ca and significant and negative correlation of S, Fe and Mn in the flag leaf with grain yield. The grain yield was significantly and positively correlated with uptake of P, K, Ca, Mg, S, Mn, Zn, Cu and B and significantly and negatively correlated with Fe during first year. During second year, the yield was significantly and positively correlated with uptake of all nutrients except Na and Al.

Table 64 depicts correlation analysis of soil pH versus available nutrients in soil at seedling, tillering, PI and harvest stages during both the years. During first year, soil pH had significant and positive correlation with N at seedling and tillering stages and significant and negative correlation at harvest. Available P in soil was significantly and positively correlated with pH at all stages during first year and seedling and tillering stages during second year. The correlation of pH with available K was significant and negative at seedling and positive at PI stage during first year. Significant and negative correlation observed for the same at tillering and PI stages during second year. Significant and positive correlation of pH with available Ca was observed at all stages except seedling during first year. In the case of Mg, there was significant and positive correlation with available Mg during first year. Soil pH was significantly and negatively correlated with available S at harvest during first year and at seedling stage during second year. Soil pH was significantly and negatively correlated with available Fe at all the four stages except at harvest during second year. At seedling and PI stages, soil pH had significant and negative correlation with available Mn during first year and significant and positive correlation at tillering stage during second year. During first year, the pH had significant and positive correlation with available Zn at harvest and negative and significant correlation at seedling stage during second year. Significant and positive correlation of pH with available Cu at seedling stage but significant and negative correlation at PI stage was noticed during first year. The correlation was significant and negative at seedling and tillering stages during second year. There was significant and negative correlation of pH with available B during second year. In the case of Na, there was significant and negative correlation of soil pH at seedling, tillering and PI stages during first year and seedling and tillering stages during second year. Significant and negative correlation of pH with exchangeable Al was observed at all stages except at harvest stage during second year.

Table 63. Correlation analysis of grain yield versus LAI, panicle number, nutrient content of flag leaf and nutrient uptake at harvest

Variables correlated with grain yield	Correlation coefficient	
	2015	2016
LAI at maximum tillering stage	0.297*	0.380**
LAI at panicle initiation stage	0.415**	0.617**
number of panicles m^{-2}	0.852**	0.668**
N content of flag leaf	0.125	0.162
P content	0.449**	0.514**
K content	0.282	0.428**
Ca content	0.544**	0.416**
Mg content	0.283	0.091
S content	-0.410**	-0.611**
Fe content	-0.663**	-0.530**
Mn content	-0.408**	-0.317*
Zn content	0.376**	0.235
Cu content	-0.453**	-0.152
B content	0.377**	0.003
Na content	-0.099	-0.056
Al content	-0.581**	-0.205
N uptake at harvest	0.179	0.532**
P uptake	0.781**	0.517**
K uptake	0.584**	0.713**
Ca uptake	0.714**	0.752**
Mg uptake	0.711**	0.667**
S uptake	0.334*	0.596**
Fe uptake	-0.412**	0.385**
Mn uptake	0.371*	0.382**
Zn uptake	0.370*	0.470**
Cu uptake	0.644**	0.520**
B uptake	0.768**	0.587**
Na uptake	0.104	0.275
Al uptake	-0.120	0.032

* significant at 0.05 level
** significant at 0.01 level

Table 64. Correlation analysis of soil pH versus available nutrients in soil

Variable correlated soil pH	2015				2016			
	Seedling	Tillering	PI	Harvest	Seedling	Tillering	PI	Harvest
Available N	0.437**	0.376**	0.177	-0.309*	-0.214	-0.230	0.011	0.175
Available P	0.506**	0.755**	0.600**	0.336*	0.384**	0.343*	0.265	-0.073
Available K	-0.515**	-0.232	0.456**	0.125	-0.062	-0.319*	-0.318*	-0.043
Available Ca	0.119	0.699**	0.471**	0.301*	-0.032	0.244	0.287	0.063
Available Mg	0.203	0.174	0.398**	0.412**	-0.045	0.229	0.144	-0.171
Available S	0.086	-0.265	-0.140	-0.297*	-0.705**	-0.227	0.155	-0.072
Available B	-0.284	-0.122	0.177	-0.274	0.227	-0.349*	0.150	-0.273
Available Fe	-0.659**	-0.597**	-0.771**	-0.307*	-0.449**	-0.583**	-0.428**	-0.140
Available Mn	-0.415**	0.039	-0.403**	-0.074	0.230	0.300*	0.055	-0.018
Available Zn	-0.056	0.083	0.199	0.300*	-0.457**	0.165	-0.048	-0.157
Available Cu	0.387**	0.093	-0.420**	0.205	-0.413**	-0.537**	-0.250	-0.023
Available Na	-0.611**	-0.368*	-0.369*	0.060	-0.328*	-0.402*	-0.062	-0.170
Exchangeable Al	-0.688**	-0.859**	-0.720**	-0.552**	-0.694**	-0.647**	-0.630**	0.039

* significant at 0.05 level
** significant at 0.01 level

Discussion

5. DISCUSSION

The results of the field experiments conducted with the objective of standardizing acidity amelioration and nutrient management practices for rice to overcome yield constraints in Vaikom Kari are discussed in this chapter.

5.1. Experiment I- Evaluation of acidity amelioration practices for rice in Vaikom Kari

5.1.1 Growth Characters

Observations on growth characters of rice *viz.* plant height, tiller number m^{-2} and LAI were recorded at MT, PI and harvest stages. Plant height showed an increasing trend upto harvest stage irrespective of treatments. Tiller production showed a slight increase from MT to PI stage but reduced drastically at harvest. In this study, plants attained the highest LAI at PI stage but showed a drastic reduction at harvest stage, probably due to decline in tiller production after PI stage.

Acidity amelioration practices had significant effect on growth characters of rice at all stages. Soil acidity amelioration with different liming materials *viz.* lime, dolomite and RHA improved the growth characters of rice as evident from significantly higher values of plant height, tiller number and LAI registered by the ameliorated plots (Table 6). At all stages, the control plots were significantly inferior to the ameliorated plots in all growth characters. The ameliorants reduced soil acidity which is clearly manifested in the data on soil pH in Table 17. This is in agreement with the findings of Aslam *et al.* (2002), who reported improved growth characteristics like tillering capacity and shoot and root lengths by external supply of Ca resulting in higher rice yield. Although the different liming materials irrespective of their time of application could improve plant height over control at all stages, the tallest plants at each stage were produced by RHA treatments. Lime or dolomite or RHA applied as basal and at 30 DAS produced higher number of tillers at MT stage while these treatments and RHA as basal + PI recorded higher tiller number at PI stage. No pronounced variation in tiller number at harvest was observed due to treatments except control. Lime or dolomite or RHA as basal + 30 DAS produced higher LAI at MT and PI stage. At harvest, significantly higher LAI was produced by RHA or dolomite as basal + 30 DAS.

5.1.2. Yield Attributes and Yield

As in the case of growth characters, improvement in yield attributes *viz.* number of panicles m^{-2}, 1000 grain weight and sterility percentage were noticed due to acidity amelioration (Table 7). Soil acidity amelioration with lime, dolomite or RHA, irrespective of the time of application, registered higher panicle number and 1000 grain weight and lower sterility percentage. The panicle number m^{-2}, being the most important yield attribute was increased due to better tiller production by the application of ameliorants. The ameliorants increased soil pH and nutrient absorption which is evident from the data on plant nutrient content (Table 10 and 11). Marykutty (1986) also reported increased growth and yield characters of rice due to lime application.

Acidity amelioration resulted in improvement of rice yield. The lowest grain yield and straw yield were registered by the control and higher grain yield was obtained by the application of lime or dolomite or RHA as basal + 30 DAS (Fig. 4). Improvement in growth characters and yield attributes due to acidity amelioration was reflected in the grain yield and straw yield (Table 7). Correlation analysis revealed significant and positive correlation of grain yield with LAI at MT and PI stages and panicle number m^{-2} at harvest (Table 36). Lime, dolomite or RHA were found equally effective in ameliorating acidity in strongly acidic soils where the present experiment was conducted. Moschler *et al.* (1973) and Arshad and Gill (1996) also observed that lime increased soil pH and improved crop growth in direct seeded rice systems. Santhosh (2013) also observed substantial improvement in rice yield due to amelioration of soil acidity with the application of lime @ 600 kg ha^{-1}. Increase in rice yield due to application of dolomite has been reported by Rahman *et al.* (2002) and Suriyagoda *et al.* (2016). Utilization of RHA as liming material for rice also improved yield as reported by Amarasiri (1978) and Prakash *et al.* (2007). The effect of soil amelioration practices on grain yield conclusively proved the superiority of split application of soil ameliorants as basal and at 30 DAS. KAU (2016) also recommends application of lime for rice in two splits as basal and at 30 DAS. Higher straw yield was also produced by applying lime or dolomite as basal + 30 DAS or by applying RHA as basal + 30 DAS or one week before PI stage. However, the treatments failed to register any significant effect on harvest index. But higher values of HI were recorded by dolomite as basal + 30 DAS or one week before PI stage and lime as basal + 30 DAS.

The positive impact of acidity amelioration on growth and yield attributes was also reflected in the TDMP (Table 8) as evidenced from the lowest dry matter yield obtained in the control plot (without ameliorants). As in the case of grain yield and straw yield, lime, dolomite or RHA applied as basal + 30 DAS could produce higher dry matter yield of grain and straw as well as total dry matter with the highest value in each case being obtained with dolomite.

5.1.3 Plant Nutrient Content

High acidity and high salinity especially during low rainfall conditions affecting nutrient availability in the soil are major yield limiting factors in Vaikom Kari soil. Nutrient availability in the soil in optimum quantities and in the readily available form to plants affects nutrient uptake by the crop for higher yield. The nutrient content in the plant is an index of nutrient availability to plants and its uptake. Hence, in the present experiment, plant parts were analyzed to assess the nutrient content during the cropping period and also at harvest to compute nutrient uptake by the crop.

5.1.3.1 Nutrient content of Flag Leaf

The results revealed that acidity amelioration practices improved the nutrient content in the flag leaf. When the nutrient content of flag leaf in the present experiment was compared with the critical nutrient concentration (CNC) in rice as

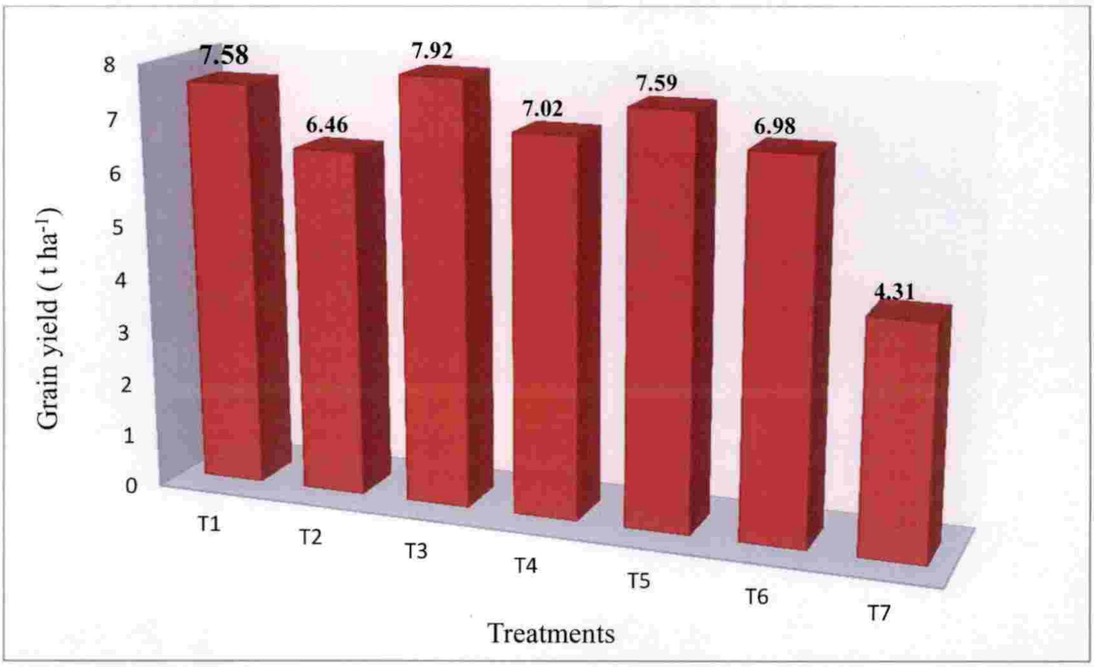

Fig. 4 Effect of acidity amelioration practices on grain yield, t ha^{-1}

suggested by Dobermann and Fairhurst (2000) (Appendix III), it was observed that the contents of N, P, Mn, Zn, Cu and B agreed with CNC (Table 10). However, the contents of K, Ca and Mg in the flag leaf were below CNC and that of S, Fe and Al were above CNC. In general, control plots registered lower contents of P, K, Ca and Mg and higher contents of S, Fe, Mn, Zn, Na and Al. This might be due to lower soil pH and higher available Fe and Al contents in the soil of the control plots. Lower K content in the plant due to higher available Fe in the soil was also observed by Ishizuka and Tanaka (1969). The grain yield was significantly and positively correlated with P, Mg and B contents of flag leaf and significantly and negatively correlated with S, Fe, Mn, Cu, Na and Al contents (Table 26).

5.1.3.2 Nutrient Content in Grain and Straw at Harvest

Primary nutrient content in the grain and straw was near or within CNC (Appendix III). No variation in the primary nutrient content in the grain and straw due to treatments was noticed except grain P content. The control plots registered the lowest grain P content and dolomite as basal + 30 DAS recorded the highest value. However, Ca content in the grain was slightly higher whereas that in the straw was slightly lower than CNC. The content of Mg in both the grain and straw were lower than CNC. The S content agreed with CNC in the grain but was higher in the straw. Among the treatments, the control registered the lowest Ca and Mg and the highest S contents (Table 11). The lowest Ca and Mg contents in the control might be due to the deficiency of Ca and Mg in the soil (Table 3) and no supplementation of the nutrients through ameliorants. Higher S content in the control could be due to low pH and high available S in soil. Karan *et al.* (2014) also observed significant reduction in S concentration in rice plant after 60 days of growth period as well as in straw and grain at harvest due to liming. Amelioration practices could markedly reduce Fe content in both the grain and straw below the level of toxicity as revealed from higher Fe content in the grain and straw in the control (Table 12). Lower Fe content due to dolomite application was also observed. Addition of nutrient amendments such as Ca, Mg or K was found to reduce the plant uptake of Fe compared to untreated plants by Benckiser *et al.* (1984). Concentration of Mn in the grain and straw was below CNC which might be due to higher Fe content in the soil affecting Mn uptake. Ottow *et al.* (1983), Yamauchi (1989) and Sahrawat *et al.* (1996) endorsed the occurrence of nutrient disorders and deficiencies of P, K, Ca, Mg, Mn and Zn due to Fe toxicity in plants. Among the treatments, dolomite as basal + PI and lime treatments recorded higher Mn contents. Zn and Cu contents in the grain and straw were near CNC. Higher content of Zn in the grain was also observed in the control as well as with dolomite as basal + PI. Lime or dolomite as basal + 30 DAS and RHA as basal + PI registered higher straw Zn content. No pronounced variation in the Cu content in the grain and straw was observed between ameliorated and control plots. Content of B in the grain was below CNC whereas that in the straw was near CNC. Higher content of B in the grain and straw were observed with lime or dolomite or RHA as basal + 30 DAS but below CNC.

No marked variation in Na content in the plant was observed due to treatments (Table 12). This might be due to initial lower Na status in the soil which was below the critical level (Table 3) since the field was situated away from Vembanad lake. Higher Al content was observed with control and the lowest with dolomite as basal + 30 DAS. The straw had Al content higher than CNC and near to the toxic limit. Higher content of Al could be due to low soil pH resulting in higher exchangeable Al status in the soil (Table 23).

5.1.4 Uptake of Nutrients

Significantly higher uptake of N and K were observed for lime or dolomite or RHA applied as basal + 30 DAS while dolomite as basal + 30 DAS recorded the highest P uptake (Fig. 5). Lime as basal + 30 DAS recorded the highest uptake of Ca and dolomite as basal + 30 DAS recorded the highest Mg and S uptake (Fig. 6). No conspicuous variation in Fe uptake was observed due to treatments. The highest uptake of Mn, Zn and Cu were observed with lime as basal + 30 DAS. Lime or dolomite or RHA applied as basal + 30 DAS registered the highest B uptake. Application of soil ameliorants in split doses as basal and at 30 DAS proved to be better than application as basal and one week before PI with regard to nutrient uptake

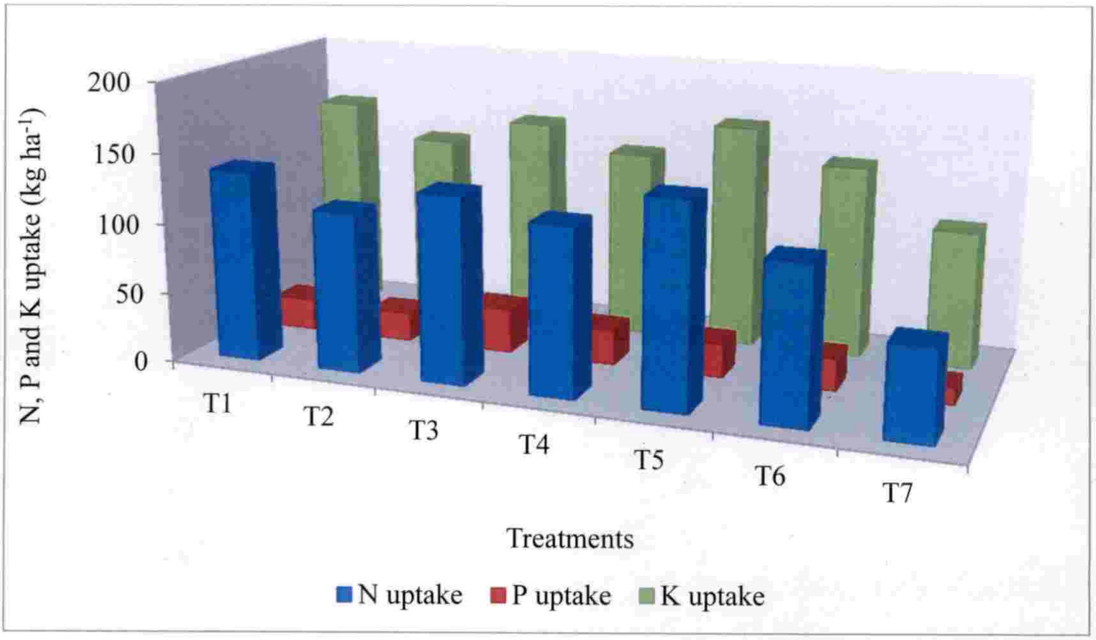

Fig. 5 Effect of acidity amelioration practices on N, P and K uptake, kg ha^{-1}

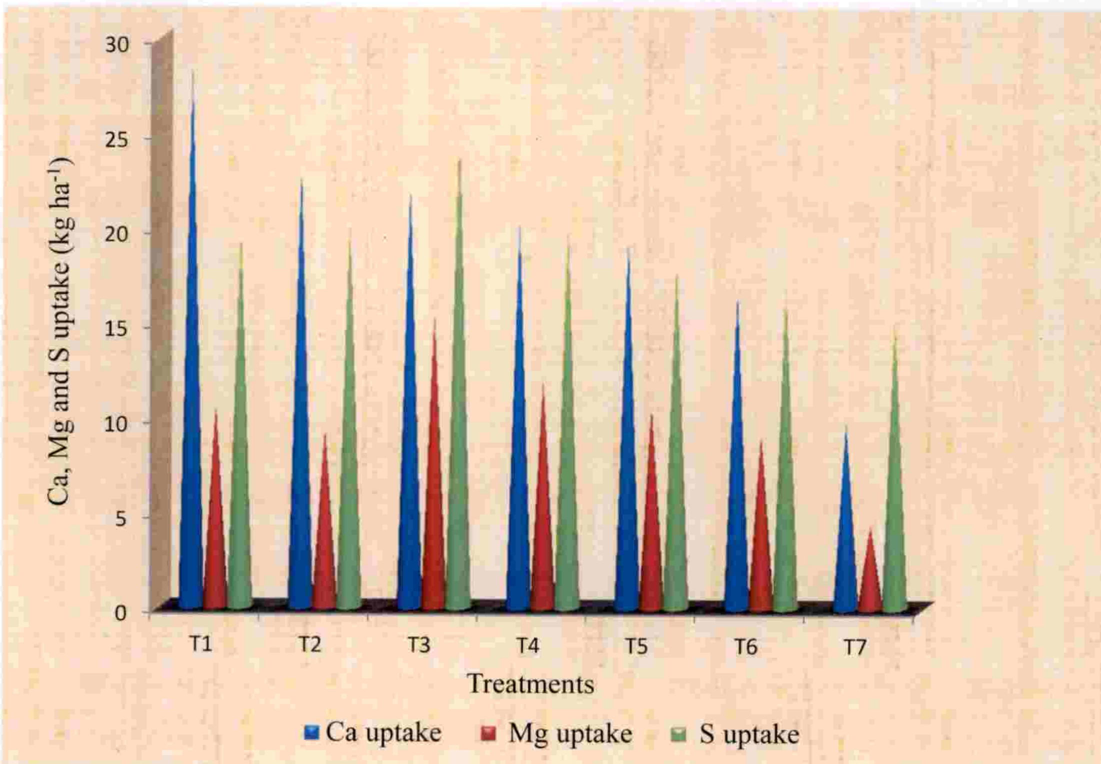

Fig. 6 Effect of acidity amelioration practices on uptake of Ca, Mg and S uptake, kg ha^{-1}

which was reflected in the grain yield. The control plots registered significantly lower uptake of macronutrients as well as micronutrients which might have resulted in lower grain yield in the control plots. Correlation analysis also revealed significant and positive correlation of grain yield with the uptake of macronutrients and micronutrients except Fe and Zn.

The control treatment and RHA as basal + PI registered significantly lower Na uptake. Higher Al uptake registered with RHA treatments might be the consequence of higher exchangeable Al in the soil due to comparatively lower soil pH resulting in increased crop removal of Al from the soil (Table 23).

5.1.5 Soil Chemical Properties and Nutrient Availability

5.1.5.1 Soil pH and EC

Initially, the soil was strongly acidic (Table 3) and the treated plots showed an increase in soil pH over the initial value which decreased at harvest (Fig. 7). Among the liming materials, lime and dolomite treatments were more effective in reducing soil acidity and ensuring sufficient availability of nutrients in the soil. This was reflected in higher uptake of nutrients with these treatments. Rastija *et al.* (2014) also observed improved soil chemical properties including higher pH due to application of dolomite. The decrease in soil pH at harvest is a clear indication of temporary effect of liming materials on soil pH which warrants liming during every crop season.

In general, soil EC increased during the cropping period (but below critical limit of 1 dS m^{-1}) with a drastic increase at harvest (Table 3 and 17).

5.1.5.2 Dehydrogenase Enzyme Activity

Dehydrogenase enzyme activity, an indicator of microbial activity, showed a decreasing trend from seedling to harvest stage similar to the trend in soil pH (Fig 8). Dehydrogenase activity was improved by lime and dolomite treatments at all stages due to better microbial activity consequent to increase in pH. The control plots showed a drastic reduction in enzyme activity from seedling to harvest stage which

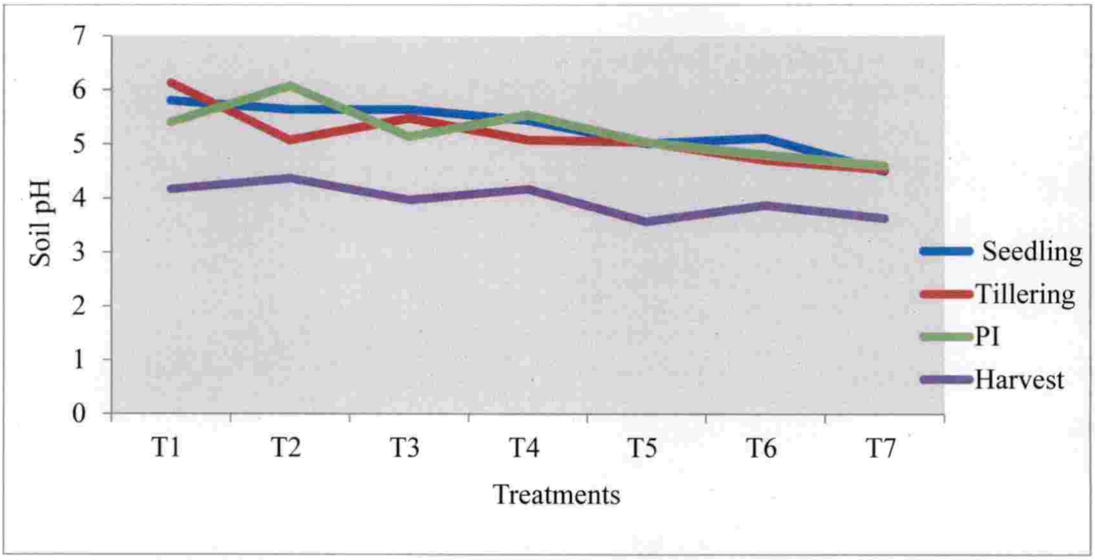

Fig.7 Effect of acidity amelioration practices on soil pH

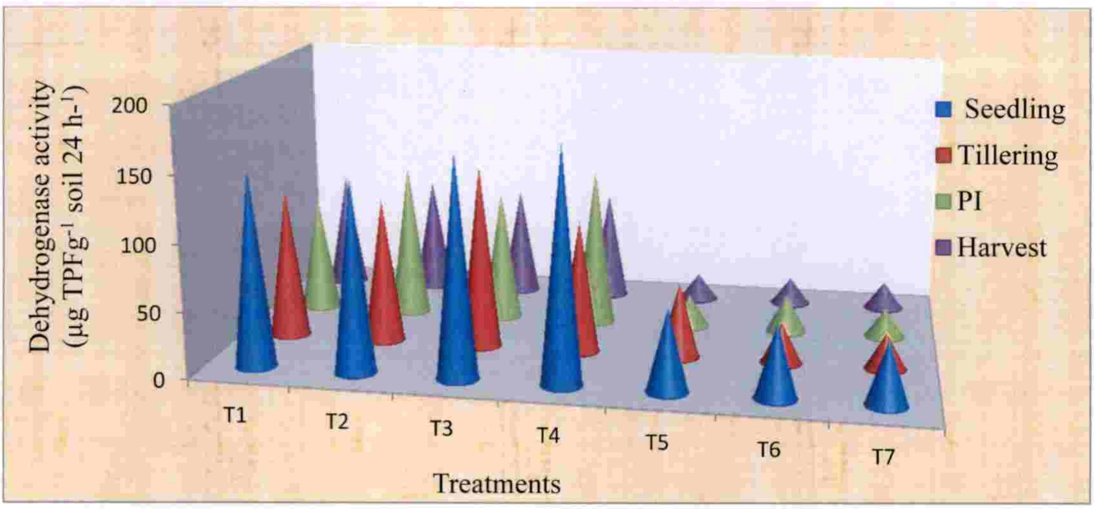

Fig.8 Effect of acidity amelioration practices on dehydrogenase enzyme activity, µg TPF g^{-1} soil 24 h^{-1}

indicated reduced microbial activity due to low soil pH. This is in accordance with the reports of Padmaja *et al.* (1994) who observed that low pH and anaerobic soil conditions affected microbial activity resulting in low availability of nutrients to plants.

5.1.5.3 Organic Carbon Status

High organic carbon status is observed in kari soil. Thampatti (1997) recorded higher OC content of 10 to 30% in kari soil. In this experiment also, organic carbon status was high (3.18 to 4.89%). A slight increase in OC content from initial status (Table 3) from seedling to tillering stage and a decrease at harvest was noticed (Table 18). The treatments had significant effect only at PI stage when higher OC content was shown by lime and RHA treatments.

5.1.5.4 Availability of Primary Nutrients

Among the primary nutrients, initial N and P status in the soil was low and K status was medium (Table 3). Although the kari soil has higher OC content, available N status is generally low due to poor microbial activity (Koruth *et al.* 2013). This corroborates with the findings of the present experiment. Compared to the initial status, N and P availability improved in the soil at all stages of experimentation (Table 19) but K availability decreased at seedling stage and increased at tillering stage but showed a drastic reduction at PI and harvest stages over the initial status. Marykutty (1986) observed that application of lime increased soil pH and available N and P but decreased available of K in the soil.

Available N decreased from seedling to tillering stage which showed a slight increase at PI stage and again decreased at harvest stage but above the initial status. A sharp increase in available P status was observed from seedling to tillering stage in all the treatments (Fig. 9) which was maintained at PI stage and reduced drastically at harvest stage which might be due to the reduction in soil pH at harvest. The low availability of P initially in the soil (Table 3) could be due to P fixation by Fe and Al sesquioxides which is a consequent of extreme soil acidity which was also reported by

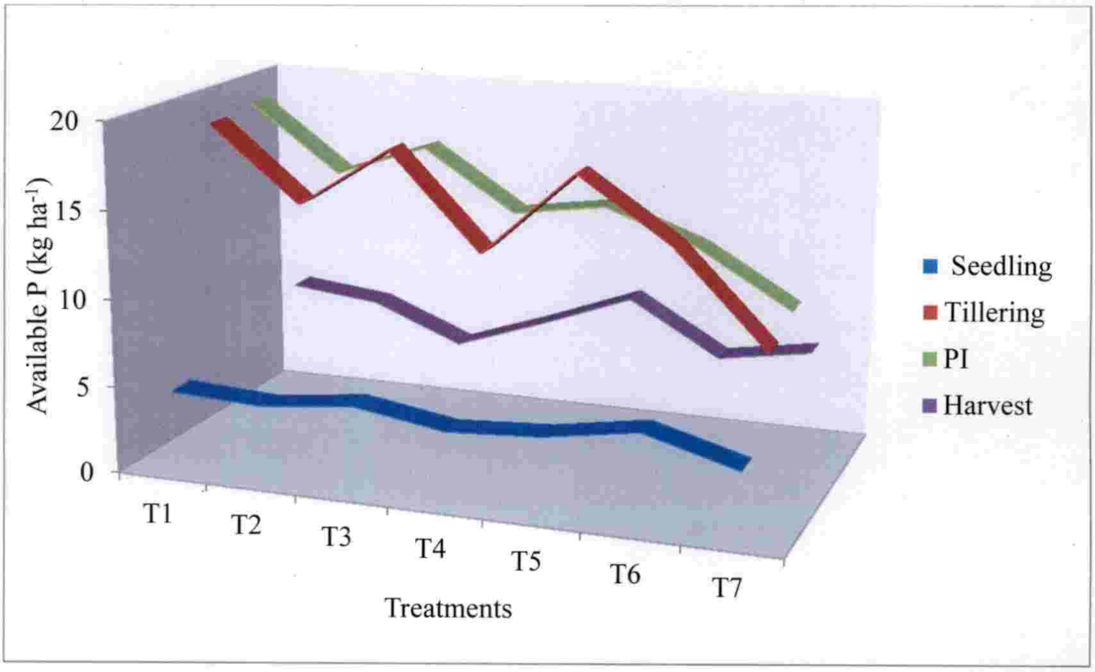

Fig.9 Effect of acidity amelioration practices on soil available P, kg ha^{-1}

Tisdale *et al.* (1993), Audebert and Sahrawat (2000) and Dixit (2006). Available K status increased from seedling to tillering stage but declined at PI and harvest stages.

With respect to primary nutrients significant effect of treatments was observed only on N and P status. All the ameliorated plots had higher N and P contents than the control plots (no liming). This point to the fact that amelioration practices can improve the availability of N and P in the soil. Significant and positive correlation of soil pH with available N at seedling and tillering stages was observed (Table 27). Ono (2012) and Alexander (1977) reported that flooding and liming increased the pH and promoted N mineralization in soils. Soil pH also had significant and positive correlation with available P at tillering and PI stages. Rastija *et al.* (2014) also established enhancement of P availability by dolomite application. However, the treatments failed to express significant effect on soil available K during the cropping period. A drastic reduction in available K compared to the initial status was observed at harvest which might be due to toxic levels of available Fe in the soil. Ottow *et al.* (1983), Yamauchi (1989) and Sahrawat *et al.* (1996) have proved the occurrence of several nutrient disorders and deficiencies in soil including that of K due to Fe toxicity. In acid sulphate soils, K deficiency is associated with the formation of the sulfide mineral oxidation product jarosite, which acts as an infinite sink for K in the upper sulfuric horizon and reduces available K for plant growth (Keene *et al.* 2004). Malvi (2011) reported that under high Na level, Na competes with K ions leading to K deficiency which was also observed in this experiment. The results necessitate elimination of Fe toxicity by liming and application of recommended dose of K for realizing higher yield of rice in acid sulphate soils.

5.1.5.5 Availability of Secondary Nutrients

Regarding secondary nutrients, the initial status of Ca and Mg were low whereas that of S was very high (Table 3). The deficiency of Ca and Mg might be due to higher Fe status in the soil. Ottow *et al.* (1983), Yamauchi (1989) and Sahrawat *et al.* (1996) have reported the deficiency of Ca and Mg due to Fe toxicity. The deficiency of Ca could be corrected by the application of lime and dolomite upto PI stage but was reduced at harvest stage (Fig. 10). The Ca content again went below the critical level of sufficiency (Appendix II) at harvest for all the treatments. Among the treatments the control plots followed by RHA treatments registered lower available Ca status. Significant and Positive correlation of pH with available Ca was observed at all stages (Table 27).

Considerable improvement in the status of available Mg above the level of sufficiency (Appendix II) was observed at all stages of experimentation in dolomite applied plots. With regard to other ameliorants, a slight increase above the initial status in available Mg was observed upto tillering stage which was maintained upto PI stage but it declined at harvest (Fig. 11). The decline in Ca and Mg availability at harvest stage might be due to the removal of these nutrients by the crop and due to reduction in soil pH at harvest. Marykutty (1986) observed that application of lime decreased exchangeable H^+ and Al^{3+} and increased soil pH and exchangeable Ca and Mg in the soil.

Available S was reduced from the initial status at all stages of experimentation. The reduction in S availability might be due to the low redox potential of submerged rice soils resulting in reduction of sulphates to sulphides, some of which are toxic (H_2S) and others low in solubility (FeS and ZnS) as reported by Ramasamy (2014). Moreover, slower mineralization of organically bound S decreases the availability of S to rice in submerged soils. Higher soil available S was recorded with the control (no liming) during all stages of the crop which might have been due to high acidity in the control. Soil amelioration practices could bring down the availability of S in the soil at all stages of experimentation. However, available S content showed an increase at harvest stage over the level at PI stage irrespective of treatments. Drying of soil at harvest might have resulted in oxidation of S to available SO_4 increasing the availability as observed in the present experiment. Soil pH was negatively and significantly correlated with available S at tillering and PI stages (Table 27).

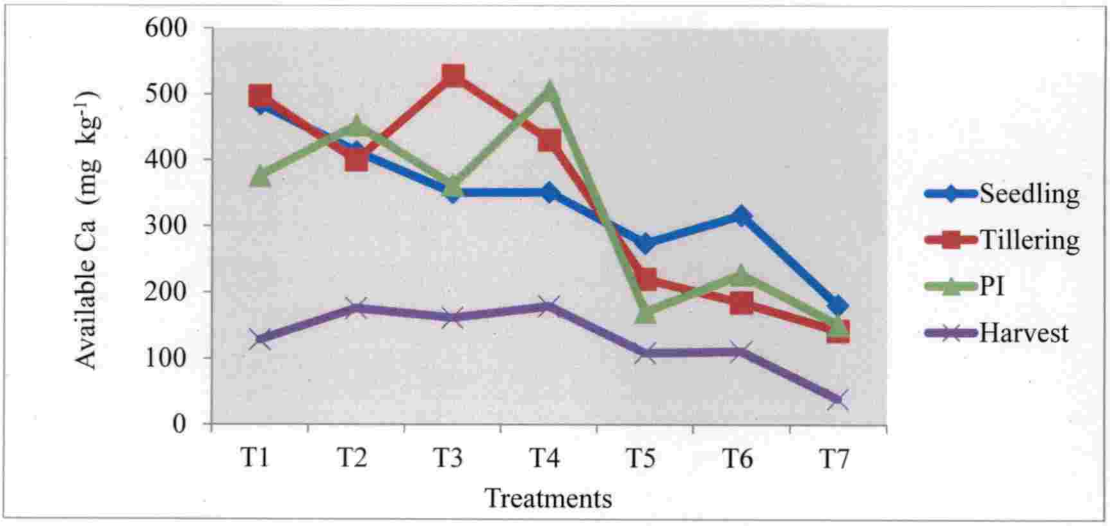

Fig.10 Effect of acidity amelioration practices on soil available Ca, mg kg^{-1}

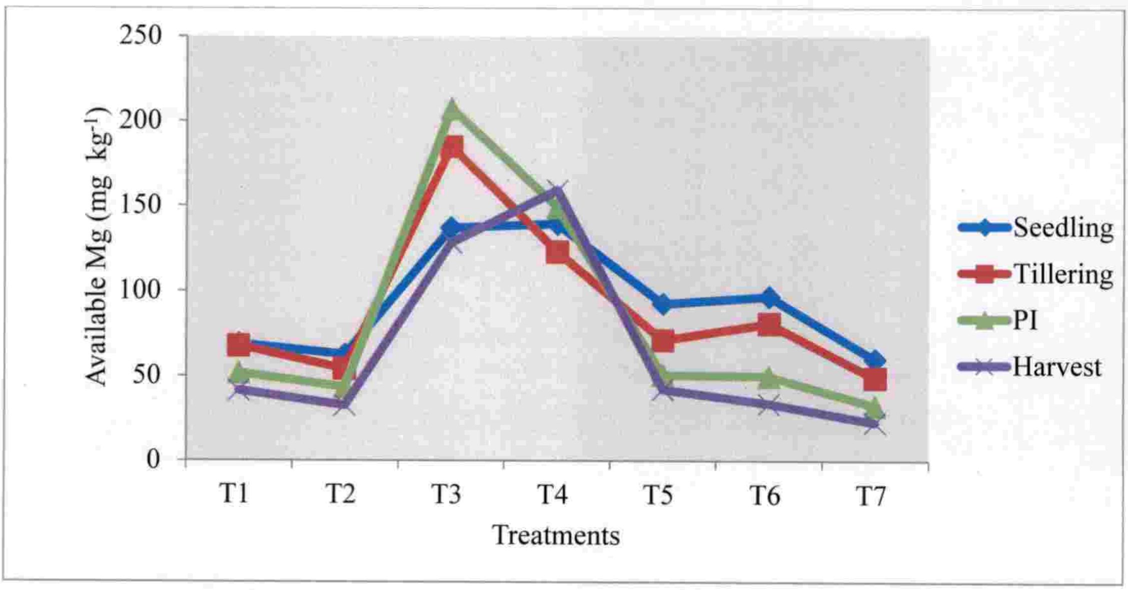

Fig.11 Effect of acidity amelioration practices on soil available Mg, mg kg^{-1}

5.1.5.6 Availability of Micronutrients

Among the micronutrients, available Fe was very high initially and above the critical level of toxicity but during the experimentation, it was reduced in all the treatments. The control recorded significantly higher content of soil available Fe (Fig. 12) which was above the toxicity level at all stages which might be due to low pH noticed in the control. Lime treatments were found superior for reducing the availability of Fe in the soil below the toxic level. Increased availability of Fe at harvest than other stages with all the treatments which again could be due to the reduced soil pH or increased acidity owing to the diminishing effect of ameliorants at the end of crop as well as due to drying of soil at harvest. Significant but negative correlation of soil pH with available Fe was noticed at all stages of sampling (Table 27).

Similar to Fe, soil available Mn content was also high initially (Table 3) which went below the initial value during the cropping period (Table 21) but above the deficiency level (Appendix II). Lime or dolomite application markedly increased available Mn in the soil. Soil pH had positive and significant correlation with available Mn at seedling, tillering and PI stages (Table 27). A decrease in the availability of Mn at harvest than that at PI stage might have been due to the antagonistic effect of higher Fe content (Table 21) due to lower soil pH (Table 17).

Available Zn status in the soil was above the deficiency level initially (Table 3 and Appendix II). No marked variation in the availability of Zn was noticed between treatments at any of the stages (Table 21). Although Zn availability decreased from initial status during the cropping period irrespective of treatments, the status was maintained above the deficiency level.

Initial status of soil available Cu was also sufficient which decreased during the cropping period but was well above the deficiency level (Table 3 and Appendix II). It is evident from the results that Cu availability which is usually higher at low pH was not badly affected due to soil amelioration (Table 22). This is evident from higher Cu status above the deficiency level in both the ameliorated and control plots. The

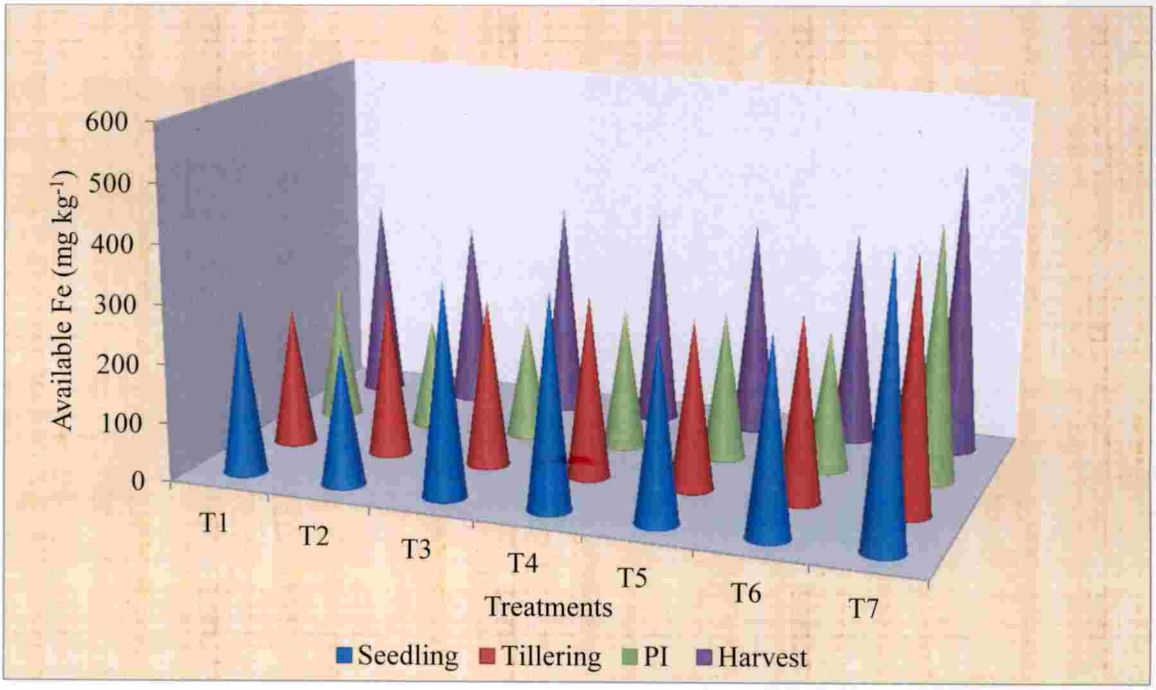

Fig.12 Effect of acidity amelioration practices on soil available Fe, mg kg^{-1}

treatments had profound influence on Cu only at tillering and PI stages when the control and dolomite as basal + PI recorded higher values at tillering and PI stages respectively.

Initially, the status of B was deficient in the soil (Table 3 and Appendix II). Soil amelioration practices improved the availability of B but a decrease in B status was noticed at harvest (Table 22) which might be due to the crop removal and low soil pH. Application of dolomite, lime or RHA as basal and at 30 DAS recorded higher B status which came above the level of sufficiency during initial crop stages. Lime or dolomite applied as basal and one week before PI increased the availability of B at PI stage. Significant and positive correlation of soil pH with available B at seedling and PI stages was noticed (Table 27).

5.1.5.7 Na and Al Status

The initial soil available Na (Table 3) was below the critical level of toxicity (Appendix II). Although there was an increase in the availability of Na over the initial status at all stages of experimentation (Table 23), the content was below the critical level of toxicity. The location of the experimental field away from Vembanad Lake had reduced sea water intrusion to the field leading to low salinity (Plate 1). Dolomite treatments and the control recorded higher Na in the soil at seedling stage and the control registered the higher Na at tillering stage.

Initially as well as during experimentation, the status of exchangeable Al in the soil (Table 3 and 23) was below the critical level of toxicity (Appendix II). Reduction in exchangeable Al in acid soils containing high organic matter has been reported earlier by Zysset *et al.* (1999) and Muhrizal *et al.* (2003). Under low pH and high Al conditions, organic matter acts as a buffer forming complex of Al which may limit Al activity from developing phytotoxicity (Brown *et al.* 2007). Among the treatments, soil exchangeable Al was significantly higher for the control (Table 23). It was reported by Rajput (2012) that Al, Fe, Mn and Zn are more soluble and accumulate in toxic concentrations in the rhizosphere when pH goes below 5.0. The liming materials could raise the pH above 5.0 (Table 17) which reduced the Al content in the treatments other than control. Significant and negative correlation of soil pH with exchangeable Al was observed in the present study (Table 27). Lime increased soil pH (Moschler *et al.* 1973; Arshad and Gill, 1996) and decreased extractable Al^{3+} (Moschler *et al.* 1973; Wildey, 2003) in direct seeded rice systems. Shamshuddin *et al.* (2013) also recommended the application of ground magnesium lime stone for rice in acid sulphate soil to reduce soil acidity and Al^{3+} and Fe^{2+} toxicity.

5.1.6 Pest and Disease Incidence

Incidence of stem borer (*Scirpophaga incertulas*) noticed at tillering stage could be brought under control by the application of Fertera (chlorantraniliprole 0.4% GR) in the soil. The treatments involving RHA had lower incidence of stem borer (Table 24). High silica content (83% in the RHA (Table 4) might have given resistance to the crop against pest and diseases as earlier reported by Savant *et al.* (1997) and Ma *et al.* (1989).

5.1.7 Economics of Cultivation

The economics of cultivation was worked out in terms of net income and BCR. Net income and BCR varied markedly with the treatments (Table 25).The results pointed out the significance of acidity amelioration for realizing higher yield and income from rice cultivation. Higher net income (Fig. 13) and BCR (Fig. 14) could be generated by the application of lime, dolomite or RHA in split doses as basal and at 30 DAS. The highest net income and BCR were given by dolomite applied as basal and at 30 DAS. The lowest net income and BCR were registered by the control. Lime, dolomite or RHA tried in split doses as basal and at 30 DAS produced 53%, 69% and 56% increase in net income respectively over the control. It was conclusively proved that split application of liming material in two equal splits as basal + 30 DAS is economically superior to application as basal + one week before PI stage.

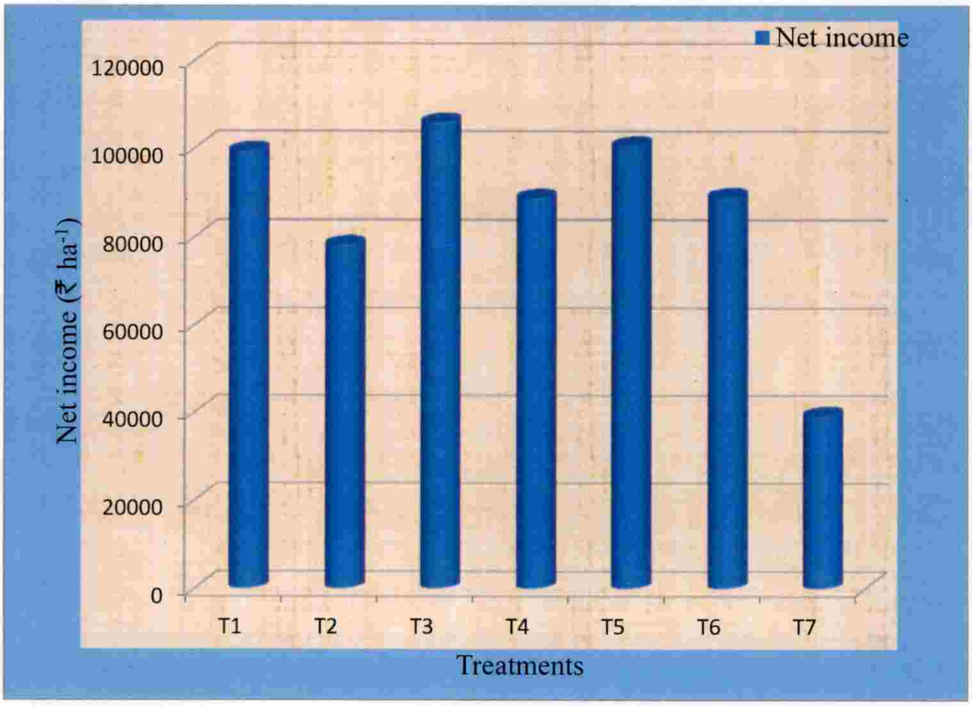

Fig.13 Effect of acidity amelioration practices on net income, ₹ ha^{-1}

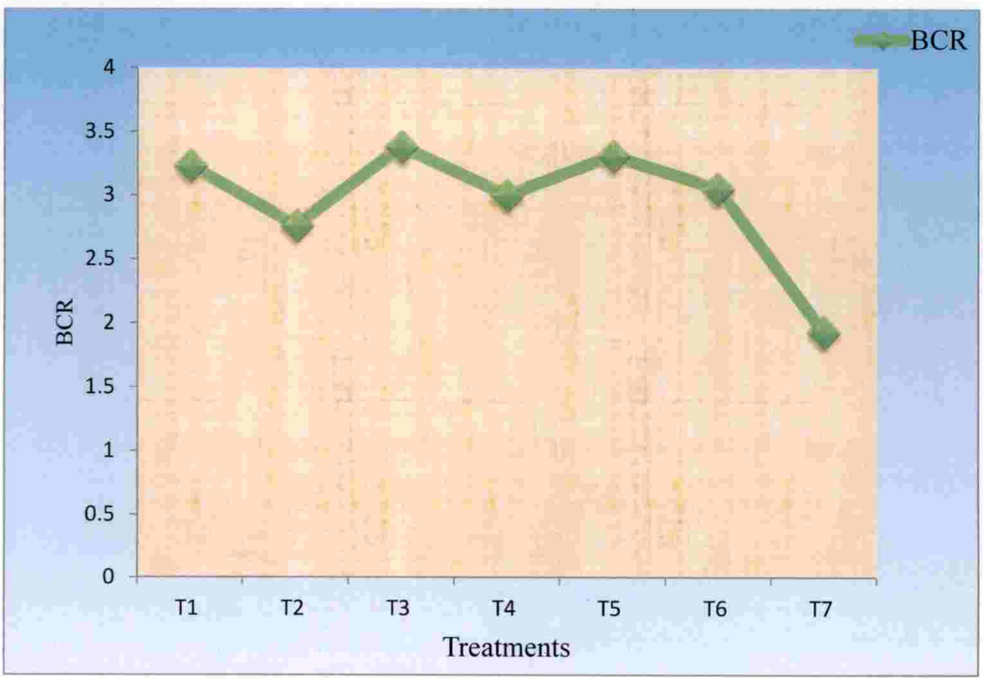

Fig.14 Effect of acidity amelioration practices on benefit cost ratio

5.2. Experiment II - Standardization of nutrient management practices for rice in Vaikom Kari

5.2.1 Growth Characters

Nutrient management practices profoundly influenced the growth characters *viz.* plant height, tiller number and LAI at all stages except tiller number at MT stage during first year and LAI at harvest during second year (Table 28, 29 and 30). The treatments involving dolomite or lime with or without $MgSO_4$ along with 100% POP produced taller plants while the treatments involving RHA produced comparatively shorter plants during both the years. The same trend was also observed in the case of number of tillers m^{-2} and LAI. Lower values of growth attributes recorded by the treatments involving 75% POP warrants that dose of primary nutrients cannot be compromised upon for rice in Vaikom Kari soil. In general, higher growth attribute recorded by dolomite or lime + $MgSO_4$ treatments proved the significance of Mg application in Mg deficient soils. According to Bose *et al.* (2011), Mg is essential for many physiological and biochemical processes affecting plant growth and development and can also ameliorate Al phytotoxicity possibly through over-expression of Mg-dependent mechanisms that alleviate Al toxicity in plants.

5.2.2. Yield Attributes and Yield

The yield attributes *viz.* panicle number, 1000 grain weight and sterility percentage also followed the same trend as that of growth attributes (Table 31). The treatments involving dolomite or lime with or without $MgSO_4$ along with 100% POP recorded higher panicle number m^{-2} and 1000 grain weight and lower sterility percentage during both the years. Reduction in NPK dose from 100% POP to 75% POP affected yield attributes as evident from lower panicle number m^{-2} and 1000 grain weight and higher sterility percentage with the treatment involving 75% POP (T_{13}) compared to similar treatment but with 100% POP (T_8) .The RHA treatments (T_9 to T_{12}) were inferior in their effect on yield attributes.

The grain yield was significantly influenced by nutrient management practices during both the years (Table 32). The highest grain yield of 5.42 and 5.57 t ha^{-1} during I and II year respectively were produced by dolomite + POP + 13:0:45 (T_2) followed by dolomite + POP + 13:0:45 + borax (T_4 - 5.33 t ha^{-1}) and lime + POP + $MgSO_4$ + 13:0:45 (T_6 - 5.1 t ha^{-1}) during first year (Table 32). During second year, T_2 (5.57 t ha^{-1}) was followed by T_4 (5.48 t ha^{-1}), T_8 – lime + POP + $MgSO_4$ + 13:0:45 + borax (5.37 t ha^{-1}) and T_6 (5.32 t ha^{-1}). The treatment involving lime + $MgSO_4$ + 100% POP (T_8) was superior to that involving 75% POP (T_{13}) during both the years. Lower yields were produced by the treatments involving RHA (T_9 to T_{12}).

The pooled analysis of two years` data (Fig.15) also proved the significance of the treatments involving dolomite + POP or lime + $MgSO_4$ + POP along with a foliar spray of 13:0:45 or a combined spray of 13:0:45 and borax on grain yield (Fig.15). The highest yield of 5.49 t ha^{-1} was recorded by the treatment T_2 - dolomite + POP + 13:0:45 followed by dolomite + 13:0:45 + borax (T_4), lime + $MgSO_4$ + POP + 13:0:45 (T_6), lime + $MgSO_4$ + POP + 13:0:45 + borax (T_8) and dolomite + POP + borax (T_3) which excelled among the 16 treatments tried in the present experiment. The year wise data also showed no conspicuous variation in grain yield due to the treatments T_2, T_4 and T_6 during both the years.

Higher growth and yield attributes of dolomite or lime with $MgSO_4$ contributed to higher yield. The higher grain yield of dolomite or lime + $MgSO_4$ treatments might have been due to the supply of Mg in addition to the correction of acidity. According to Koruth *et al.* (2013) and Biswas (2013), application of Mg as basal dose was effective in giving a significant increase in grain yield and straw yield of rice in Mg deficient soils. Suriyagoda *et al.* (2016) opined that dolomite application to lowland rice fields, affected by Fe^{2+} toxicity, could improve plant height, shoot and root dry weight and grain yield by increasing plant P and K contents and decreasing Fe content. The treatments involving RHA registered significantly lower grain yield in the pooled data. The poor performance of RHA regarding growth and yield attributes could be due to its lower efficiency compared to dolomite or lime to ameliorate acidity in extremely acidic soil condition in Experiment II. The treatment

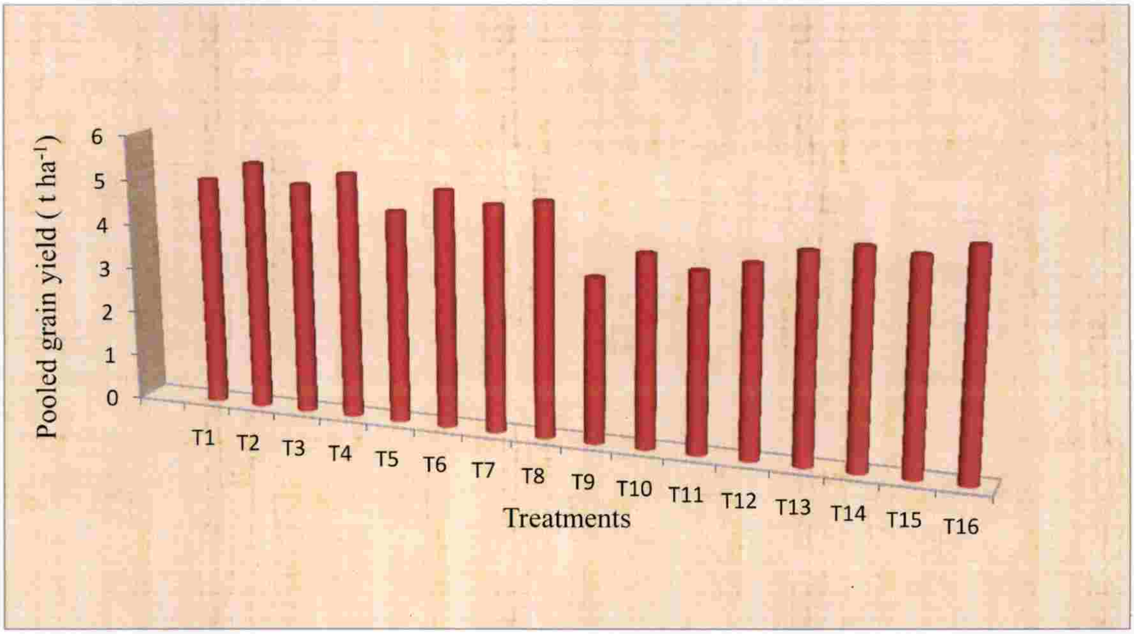

Fig.15 Effect of nutrient management practices on pooled grain yield, t ha^{-1}

involving 75% POP (T_{13}) registered lower growth attributes and markedly reduced grain yield compared to similar treatment with 100% POP (T_8) which might be due to insufficient supply of primary nutrients. Higher yield of treatments involving foliar spray of 13:0:45 or combined spray of 13:0:45 and borax might be due to the timely foliar nutrition of N, K and B and effective absorption and utilization of the nutrients. Application of N and K through foliar spray is especially important in kari soils which is deficient in available N and high in Fe and Ca status that are antagonistic to K. The antagonistic effect of Ca on K was reported by Tisdale *et al.* 1993. The foliar nutrition is particularly beneficial for the rice crop, with damaged roots, especially from MT to PI stage when nutritional demand for the crop is at peak. The root damage is caused by several factors such as Fe toxicity (Bridgit *et al.* 1993; Bridgit and Potty, 2002), Al toxicity (Foy, 1988; Famoso, *et al.* 2010) or excess H_2S accumulation on root surface that decrease root respiration and causes reduced nutrient uptake resulting in deficiencies of K, P, Ca, or Mg in soil (Ramasamy, 2014). Son *et al.* (2012) had reported the beneficial effect of foliar applied K as KNO_3 in improving grain yield when K uptake *via* the root zone is limited. Hussain *et al.* (2012) noticed substantial improvement in rice growth and yield due to application of B at transplanting, tillering, flowering and grain formation stages either by foliar or soil application.

Nutrient management practices had profound influence on straw yield (Table 32). During first year, dolomite + POP + 13:0:45 registered the highest straw yield of 6.58 t ha^{-1}. However, no conspicuous variation in the straw yield was observed between this treatment and other dolomite treatments or treatment involving 75% POP or lime treatments without $MgSO_4$ (lime + POP + 13:0:45 and lime + POP + 13:0:45 + borax). During second year, the highest straw yield was produced by lime + $MgSO_4$ + POP + 13:0:45 followed by treatments involving dolomite and lime + $MgSO_4$ along with 100% POP and foliar sprays. The treatments involving RHA recorded markedly lower straw yield during both the years.

Significant influence of the treatments on HI was observed only during first year (Table 32). Higher harvest indices were obtained for treatments involving dolomite + POP, lime + $MgSO_4$ + POP and RHA + $MgSO_4$ + POP + 13:0:45 or

13:0:45 + borax. The treatments involving 75% POP and lime without $MgSO_4$ recorded lower HI, the lowest being registered by 75% POP. These treatments also registered lower grain yield during both the years as well as in the pooled data.

The TDMP also followed the trend of grain yield. During first year, higher dry matter production was observed with dolomite + POP along with 13:0:45 (14.15 t ha^{-1}) or combined spray of 13:0:45 and borax (14.17 t ha^{-1}) (Table 33). During second year, dolomite and lime + $MgSO_4$ treatments with 13:0:45 or combined spray of 13:0:45 and borax along with 100% POP recorded higher dry matter production. Similar to growth attributes, yield attributes and yield, the treatments involving RHA and 75% POP registered lower dry matter yield of grain and straw as well as total dry matter production.

5.2.3 Plant Nutrient Content

As in the case of Experiment I, the plant parts were analyzed in Experiment II also to assess the nutrient content, which is an index of nutrient availability in the soil, to overcome yield constraints in the *kari* soil.

5.2.3.1 Nutrient Content of Flag Leaf

The data on the nutrient content of the flag leaf (Table 35 and 36) were compared with CNC presented in Appendix III. Higher N, P, and K contents was recorded in the flag leaf during second year than that during first year (Table 35) which might be due to higher initial soil available N, P, and K resulting in higher uptake. The flag leaf N and P contents were above CNC during both the years (Appendix III). The P content was near to optimum during first year and slightly higher during second year. The K content was very low during both the years which might be due to higher Fe and Ca uptake by the crop. In general, RHA treatments recorded lower N, P, and K contents and dolomite with combined spray or lime with or without $MgSO_4$ along with combined spray had higher N, P and K contents in the flag leaf. Higher N and K contents in these treatments with combined spray might be due to foliar nutrition of these nutrients at PI stage of the crop. However, higher content of P in these treatments could be attributed to the reduction in soil acidity resulting in release of fixed P and increasing availability.

The Ca content in the flag leaf was higher than CNC during both the years (Table 35 and Appendix III) and it was comparatively higher during second year which might have further lowered the K uptake. The Mg content of the flag leaf was lower than CNC during both the years which might probably be due to the deficiency of the nutrient in the soil. The flag leaf S content was near optimum during first year and slightly higher during second year. As in the case of N, P, and K, the treatments involving ameliorants other than RHA showed higher contents of Ca and Mg in the flag leaf whereas the RHA treatments registered higher S content. Comparatively lower pH in RHA applied plots might have resulted in lower Ca and Mg and higher S contents in the flag leaf.

The Fe content of flag leaf was above the critical level of toxicity during both the years, Mn content was below CNC and Zn, Cu and B contents agreed with CNC (Table 36 and Appendix II). Higher Fe content in the flag leaf might be due to higher available Fe status in the soil which was markedly above the toxic limit (Table 3). Even though, there was high availability of Mn in the soil prior to the experiment, soil available Mn went below detectable limit at PI stage of the crop during second year which reflected in lower Mn content in the flag leaf. The treatments involving dolomite or lime + $MgSO_4$ registered lower Fe which might be due to the effect of Mg in reducing Fe uptake and toxicity in plants. These treatments also recorded higher Zn status. The RHA treatments recorded higher Mn and Cu contents in the flag leaf. This could be due to comparatively acidic soil condition in RHA treated plots which favoured Mn and Cu uptake. The treatments could produce marked variation in B content in the flag leaf only during first year when dolomite + POP + borax and lime + $MgSO_4$ + POP with borax or 13:0:45 + borax recorded higher B content.

Sodium content of flag leaf during second year was much higher than that during first year (Table 36) which could be due to higher available Na status in the soil (Table 3). Very low K content in flag leaf could also be a reason for higher flag leaf Na content which is substantiated by Slaton (2011). He found that the plant Na concentration tend to be very high (>2,000 to 3,000 ppm) when K is low or deficient. In general, Na content in the flag leaf was higher for the treatments involving lime + $MgSO_4$ and RHA + $MgSO_4$. The content of Al went above CNC for some treatments during first year and for all the treatments during second year but was below critical level of toxicity. This was in accordance with the exchangeable Al status in the soil which was also below the level of toxicity. Among the treatments, those involving dolomite or lime + $MgSO_4$ registered lower Al content in the flag leaf during first year and dolomite + POP with or without 13:0:45 as well as the treatments involving lime without $MgSO_4$ showed lower Al content.

Significant and positive correlation of grain yield with P and Ca contents of flag leaf but negative correlation with S, Fe and Mn were observed during both the years (Table 63). Negative correlation of grain yield with Na and Al contents was also noticed but significance was observed only for Al content during first year.

5.2.3.2 Nutrient Content in Grain and Straw at Harvest

5.2.3.2.1 Macronutrient Content in Grain and Straw

The N content in the grain was higher than CNC during both the years (Table 37) and straw content was near optimum during first year and was higher than CNC during second year (Appendix III). Grain and straw P contents were higher than CNC during both the years. Grain and straw K contents were below CNC during first year and above CNC during second year. Low K content in leaves (<1%) and low K : Fe (17 to 18:1) in straw is also an indication of physiological effect of Fe toxicity in rice (Ramasamy, 2014). However, the effect of Fe toxicity on K uptake could be alleviated by acidity amelioration, soil application of recommended dose of K and foliar spray of 13:0:45 at PI stage in the present study. The treatments involving dolomite and lime + $MgSO_4$ generally showed higher N, P and K contents in the grain and straw (Table 37). Higher N and K contents in the grain and straw registered by the treatments with foliar spray of 13:0:45 showed the positive effect of foliar nutrition of N and K on plant nutrient concentration.

In general, grain and straw showed Ca content markedly higher than CNC, Mg content lower than CNC and S content within CNC during both the years (Table 38 and Appendix III). High initial status of available Ca and S and low status of Mg in the soil were reflected in the content of respective nutrients in the grain and straw. Ca even in high concentrations is a non toxic mineral nutrient and is very effective in detoxifying high concentrations of other mineral elements in plants (Marschner, 1995). The treatments involving RHA generally showed lower Ca and Mg contents in the grain and straw compared to dolomite or lime with or without $MgSO_4$ treatments. Generally, higher Mg content in the grain and straw were observed with treatments involving dolomite or lime with $MgSO_4$. In the case of S content in the grain and straw, RHA treatments were found equally effective as other ameliorants. No marked variation was between the treatments involving lime with or without $MgSO_4$ with respect to plant S content.

5.2.3.2.2 Micronutrient Content in Grain and Straw

Iron content in the grain was two times higher than CNC during first year except for dolomite treatments and was lower than CNC during second year (Table 39 and Appendix III). The straw Fe content was three to six times higher than CNC during first year and was slightly higher than CNC during second year. Lower content of Fe in the grain and straw during second year could be attributed to the high content of Ca in them. This is in consonance to Tisdale *et al.* (1993). Among the treatments, those involving RHA registered higher Fe content in the plant (Table 39) due to lower pH in RHA applied plots. Lower Fe content due to dolomite application was pronounced during first year only. Addition of nutrient amendments such as Ca, Mg or K was found to reduce the plant uptake of Fe compared to untreated plants (Benckiser *et al.*, 1984).

During first year, the grain and straw Mn content was markedly above the CNC and it was drastically reduced below CNC during second year. At PI stage during second year, the available soil Mn content was below detectable limit which was reflected in lower Mn content in the plant. The yield of rice in this study was not affected by Mn deficiency as rice is tolerant to low levels of available Mn in the soil as reported by Tisdale *et al.* (1993). The Zn content in the grain agreed with CNC during both the years while the straw Zn content was markedly below the toxic level. Although Zn availability and uptake is reduced due to liming acid soil and raising pH above 6.0 as reported by Tisdale *et al.* 1993, such an effect was not observed in the present study since the pH was not above 6.0 at different stages of experimentation.

Grain Cu content was above CNC during first year which was markedly below CNC during second year (Appendix III and Table 39). The straw Cu content was above CNC during first year which also reduced drastically below the CNC during second year. Prior to the experiment, the soil was low in available Cu during both the years (Table 3). Hence, seed treatment with 0.25% $CuSO_4$ was done during both the years. However, the available Cu content in the soil increased above sufficiency level from tillering stage onwards during first year whereas it was reduced to even below detectable limit for most of the treatments from tillering stage onwards during second year (Table 57). This was reflected in the Cu content in the grain and straw. Tisdale *et al.* (1993) also pointed out that higher available Fe in the soil suppresses Cu absorption by rice.

Grain B content was only $1/10^{th}$ of CNC during first year and even below that during second year (Appendix III). The straw B content was lower than CNC during first year but increased sharply by two to five times the CNC during second year. In general, dolomite treatments registered higher B content in the plant (Table 39).

5.2.3.2.3 Na and Al Content in Grain and Straw

Compared to first year, there was a two fold increase in Na content in the grain and a ten fold increase in Na content in the straw during second year (Table 40). The ratio between grain and straw Na content was approximately 1:6 during first year and 1:3 during second year. Dolomite + POP + 13:0:45 registered the lowest Na content in the grain while the same treatment along with dolomite + POP + 13:0:45 + borax recorded the lowest Na content in the straw during both the years. Generally, the RHA treatments showed higher Na content during both the years.

The Al content in both grain and straw (Table 40) was above CNC but below critical level of toxicity during both the years (Appendix III). The grain Al content was comparatively lower and straw Al content was markedly lower during second year than those during first year. Dolomite treatments registered lower Al content in the grain and straw. Higher Al content in both grain and straw was mostly observed with RHA treatments. The results reflected the efficiency of soil ameliorants in reducing soil acidity.

5.2.3 Uptake of Nutrients

In general, the uptake of nutrients except Fe was comparatively higher during second year especially with respect to K, Ca and B uptake which was reflected in higher content of these nutrients in the crop during second year (Table 41 to 45). In the case of Fe, the uptake was drastically reduced during second year which showed lower content of Fe in the grain and straw during second year. The reason might be the higher availability and higher uptake of Ca by the crop as reported by Tisdale *et al*. (1993).

Nutrient management practices had profound influence on the uptake of macronutrients, micronutrients, Na and Al by the crop during both the years (Table 41 to 45). In general, higher uptake of macro and micronutrients was observed with dolomite or lime + $MgSO_4$ treatments during both the years (Fig. 16a and 16b). This could be attributed to higher efficiency of these soil ameliorants in correcting soil acidity as well as due to their supply of Mg in the soil which was initially deficient in Mg (Table 3). The treatments involving RHA and 75% POP recorded lower uptake of macronutrients and micronutrients during both the years and it was reflected in lower grain yield with these treatments (Table 32).

Application of dolomite + POP + 13:0:45 + borax (T_4) and lime + POP + $MgSO_4$ + 13:0:45 (T_6) registered comparatively higher N uptake, dolomite + POP + 13:0:45 with (T_4) or without borax (T_2) recorded higher K uptake and dolomite + POP alone (T_1) could register the highest P uptake (Fig. 16a and 16b). It was observed that the treatments involving foliar spray of 13:0:45 recorded higher N and K uptake. Son *et al.* (2012) also reported higher uptake of N and K in rice along with higher grain yield by one to three foliar application of potassium nitrate than soil application. Higher uptake of Ca, Mg, S, Cu and B were observed with dolomite + POP + 13:0:45 with or without borax (Fig. 17a and 17b). Dolomite or lime + $MgSO_4$ along with POP + 13:0:45 with or without borax registered higher uptake of Fe, Mn and Zn (Table 43). Uptake of Na was the highest with RHA + POP + $MgSO_4$ + 13:0:45 during first year and with dolomite + POP during second year (Table 45). Higher Al uptake was observed with lime + POP + 13:0:45 with or without $MgSO_4$ (Table 45).

The antagonistic relationship of Ca, Mg, and K with each other had been reported by Malvi (2011) by which the presence of any one of them might reduce the uptake rate of the other two nutrients. Mossor-Pietraszewska (2001) had proved that Ca uptake and translocation in plants in acid soils ($pH < 5.5$) was affected by Ca-Al interactions which is strongly associated with growth and development in a wide variety of plants (Schaberg *et al.* 2006). Watanabe and Osaki, (2002) and Silva *et al.* (2005) have shown that excess Al in soil with low pH competes or inhibits Ca and/or Mg absorption capacity and affects normal plant development.

Significant but positive correlation of grain yield with uptake of P, K, Ca, Mg, S, Mn, Zn, Cu and B and negative correlation with Fe was observed during first year (Table 63). However, the yield was positively and significantly correlated with the uptake of all nutrients except Na and Al during second year. The results indicated that amelioration of soil acidity is a crucial management practice for improving the availability and uptake of nutrients resulting in higher yield. Selection of suitable ameliorant and adoption of optimum dose and time of application are particularly important. In the present study, dolomite @500 kg ha^{-1} in two split doses, 300 kg ha^{-1} as basal and 200 kg ha^{-1} at 30 DAS was found effective for ameliorating soil acidity and realizing higher rice yield in Vaikom Kari soil.

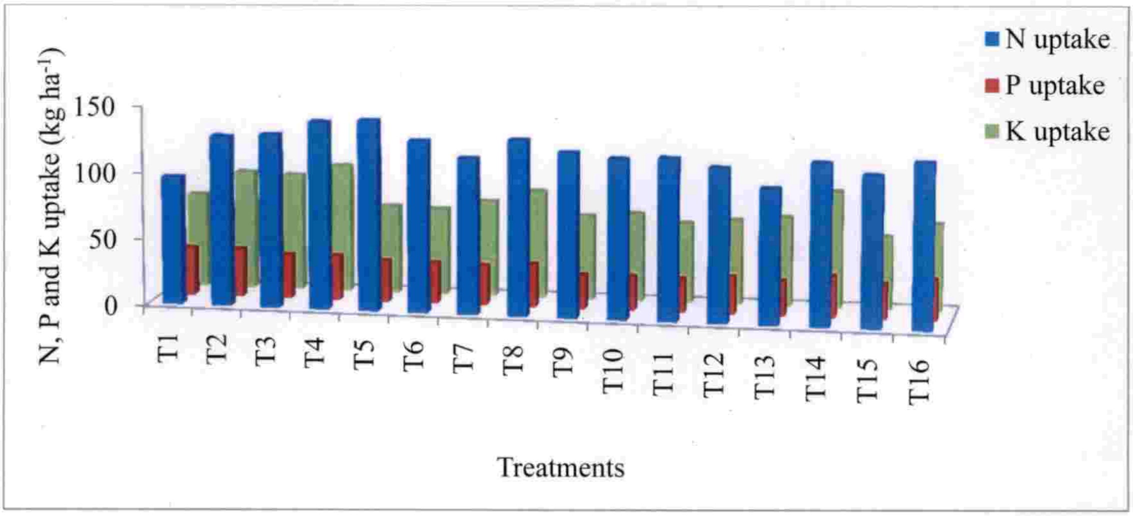

Fig.16a Effect of nutrient management practices on N, P and K uptake during 2015, kg ha^{-1}

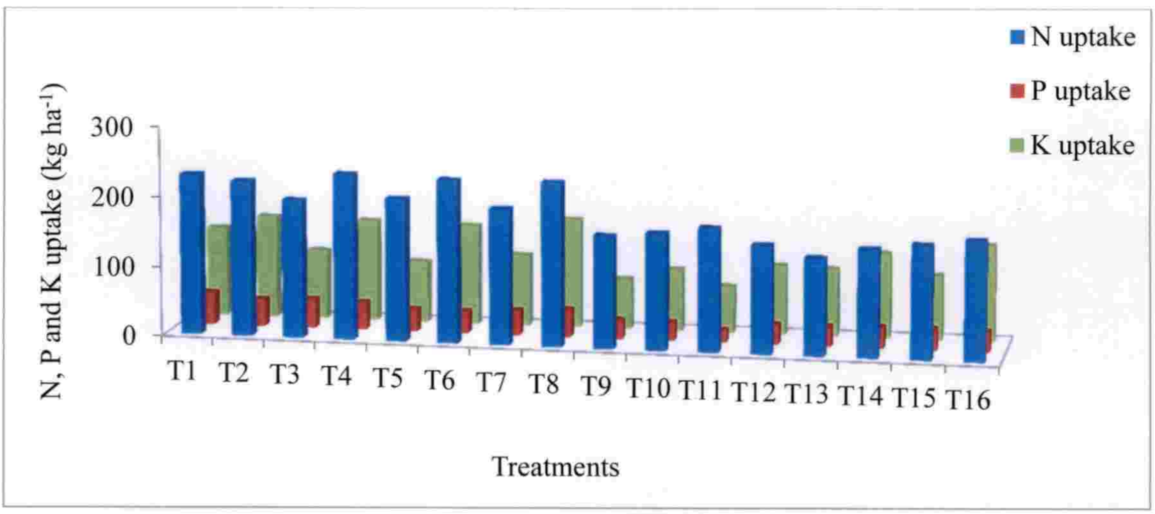

Fig. 16b. Effect of nutrient management practices on N, P and K uptake during 2016, kg ha^{-1}

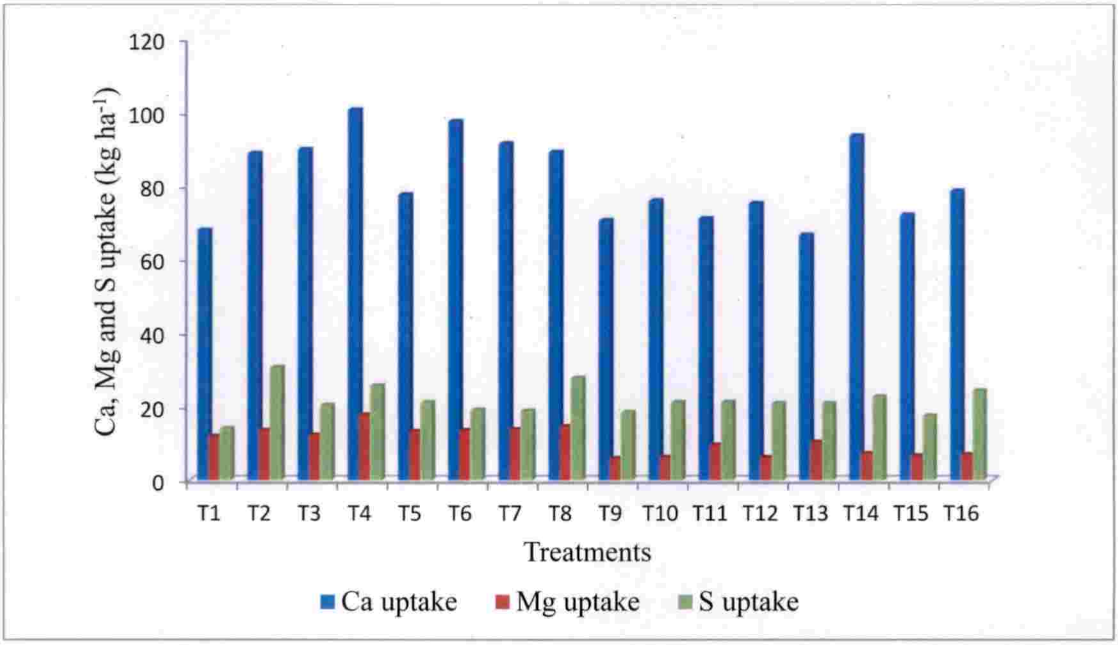

Fig. 17a. Effect of nutrient management practices on Ca, Mg and S uptake during 2015, kg ha^{-1}

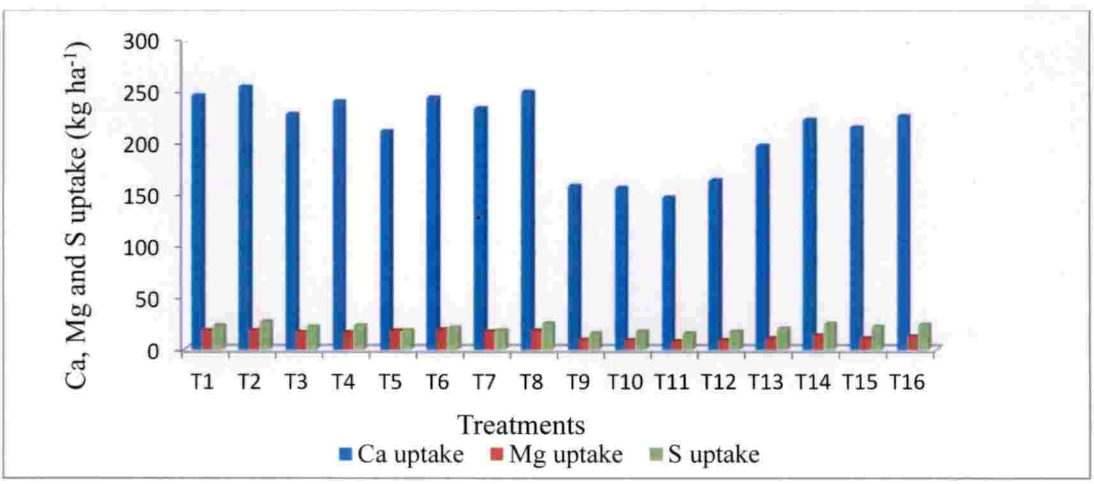

Fig. 17b. Effect of nutrient management practices on Ca, Mg and S uptake during 2016, kg ha^{-1}

5.2.4 Soil Chemical Properties and Nutrient Availability

5.2.4.1 Soil pH and EC

Initially, the soil was extremely acidic in nature (Table 3) as per classification of soil acidity (KAU, 2011). During both the years, the soil acidity was reduced below the initial status by the application of ameliorants throughout the cropping period except at harvest (Table 46). Soil pH showed an increasing trend upto tillering stage which decreased afterwards irrespective of treatments during both the years (Fig 18a and 18b). Considerable reduction in soil pH was observed at harvest during both the years with all the treatments, similar to the result of Experiment I. The reason might be the drying of soil at harvest and temporary effect of liming. It is evident from the data that the effect of liming materials applied as basal and at 30 DAS did not last after the crop. Hence the results of the present experiment also necessitate application of liming materials during every crop season.

Significant influence of the treatments on soil pH was observed during both the years (Table 46). Among the treatments, dolomite or lime with or without $MgSO_4$ performed better in ameliorating acidity than RHA treatments at all stages during both the years. Rice can grow well in a pH of 5.5 to 6.5 (Singh, 1999) but the soil pH was below 5.0 at all stages in the case of RHA treatments during both the years. Only a slight rise in soil pH (from the initial value of 4.23 to a maximum of 4.58 during 2015 and from 4.29 to 4.69 during 2016) could be brought about by the application of RHA compared to dolomite and lime. Hence RHA proved ineffective in ameliorating soil acidity in extremely acidic soil (pH 3.5 to 4.5) such as the kari soil in this study for improving growth and yield of rice. As soil ameliorant, RHA may be effective in moderately (pH 5.5 to 6) or slightly acid (pH 6 to 6.5) soils.

The initial status of soil EC was below the critical level of crop tolerance (Table 3). The values of EC ranged from 0.37 to 1.63 dS m^{-1} during first year and from 0.28 to 2.13 dS m^{-1}during second year (Table 46). Although a sharp increase in EC was noticed at harvest during both the years of experimentation, it was below the critical level for all the treatments excluding RHA during first year. Marked increase

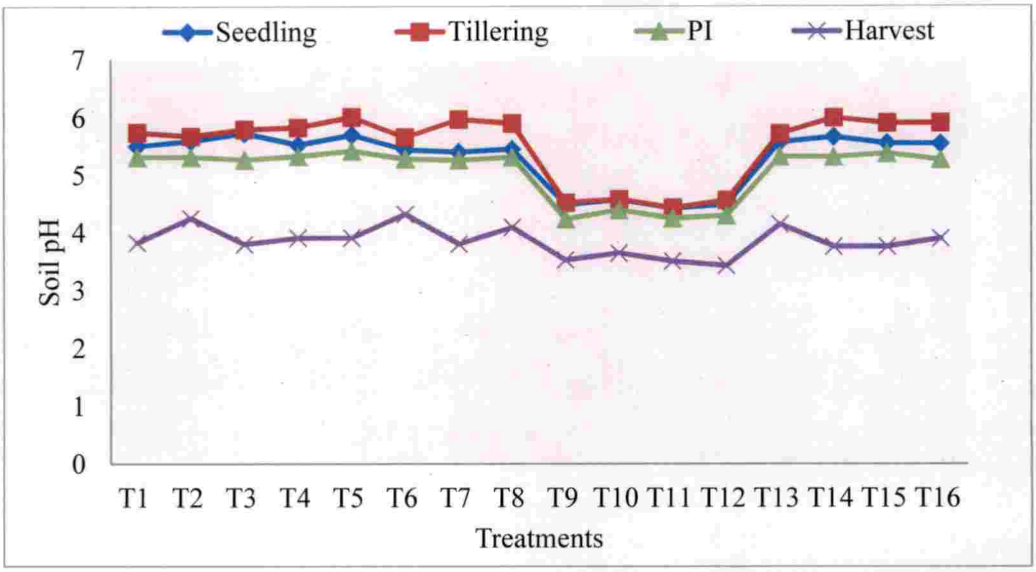

Fig.18a Effect of nutrient management practices on soil pH during 2015

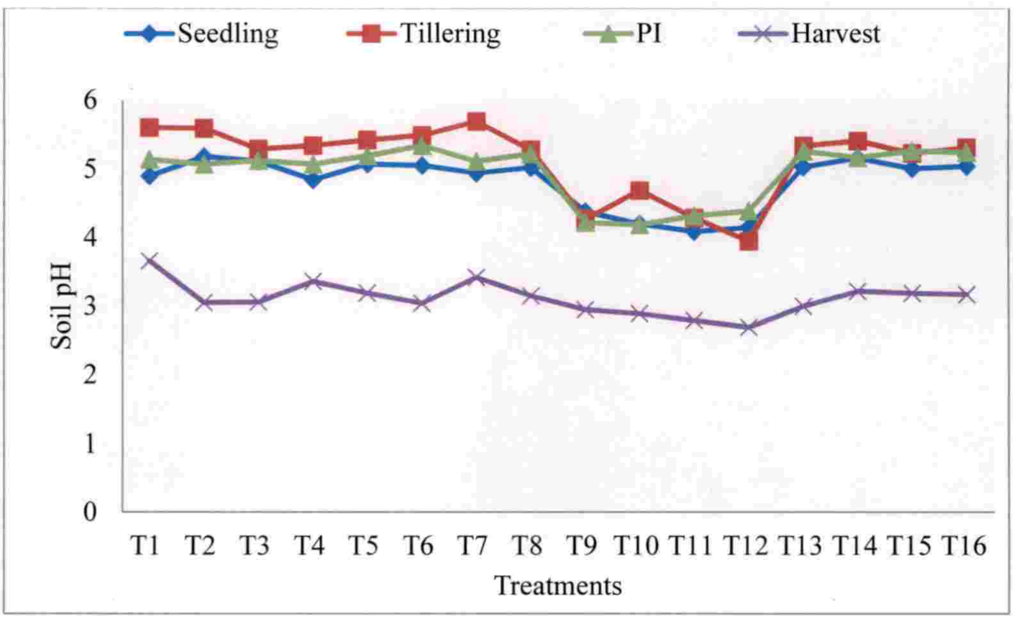

Fig.18b Effect of nutrient management practices on soil pH during 2016

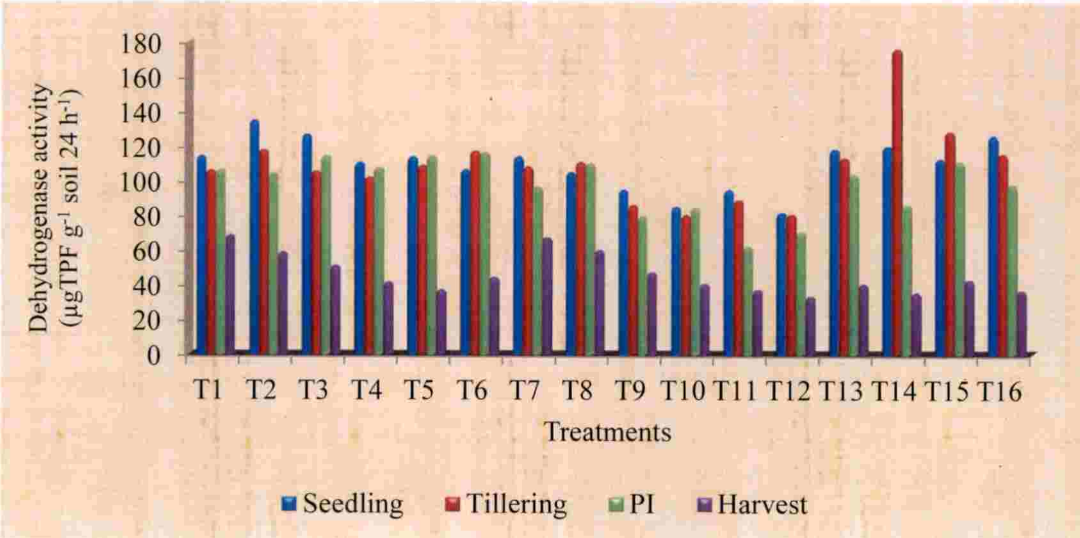

Fig.19a Effect of nutrient management practices on dehydrogenase enzyme activity during 2015, µg TPF g^{-1} soil 24 h^{-1}

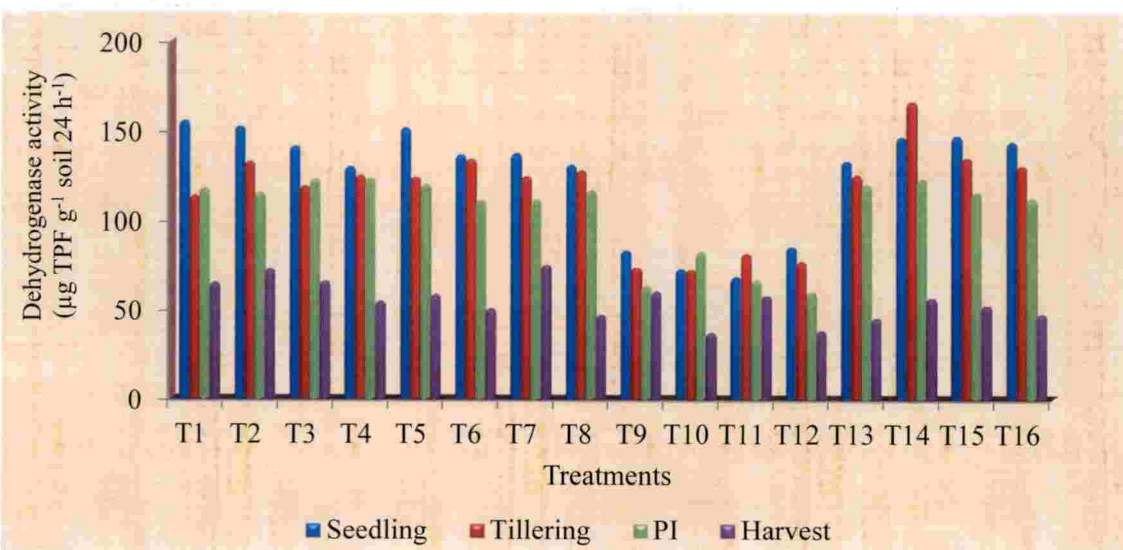

Fig.19b Effect of nutrient management practices on dehydrogenase enzyme activity during 2016, µg TPF g^{-1} soil 24 h^{-1}

in EC at harvest might be due to increased Na content in the surface soil at harvest due to capillary rise of Na salt present in subsurface soil upon drying.

5.2.4.2 Dehydrogenase Enzyme Activity

The dehydrogenase enzyme activity was very low initially during both the years (Table 3). The activity was improved at all stages by nutrient management practices except RHA treatments (Table 47). At harvest stage, however, a decrease in dehydrogenase activity even below the initial status was noticed with all the treatments (Fig 19a and 19b) which could be due to lower pH at harvest as in the case of Experiment I. Similarly, the enzyme activity was profoundly influenced by the nutrient management practices at all stages except at harvest during both the years. All the treatments except those involving RHA helped in improving dehydrogenase enzyme activity in the soil during the cropping period. Lower pH in RHA treatments resulted in lower microbial activity and showed lower enzyme activity.

5.2.4.3 Organic Carbon Status

The soil OC content was initially high (Table 3) which was maintained throughout the crop season by all nutrient management practices (Table 47). In general, dolomite treatments showed higher OC status. A slight reduction in OC status was observed at harvest during both the years with all the treatments.

5.2.4.4 Availability of Primary Nutrients

The soil was initially low in available N (Table 3) as in the case of Experiment I. Although it increased over the initial value at all stages of the crop, the status remained low or deficient during both the years (Table 48). The values showed a decreasing trend from tillering to harvest during first year. Soil ameliorants had significant effect on available N only during first year when the dolomite treatment (T_2) at seedling stage and lime without $MgSO_4$ at other stages recorded higher values. Though the effect of treatments was not significant, available N during second year showed an increasing trend upto PI stage and thereafter decreased below the initial value at harvest. Though the soil was high in OC, the available N status was low due to poor microbial activity in extremely acidic soil condition of the experimental field. Amelioration of acidity increased available N status in soil during the cropping season probably by improving microbial activity as evident from the data on dehydrogenase activity (Table 46). The decrease in available N towards the harvest stage might be due to the reduced pH and microbial activity as a result of the diminishing effect of ameliorants as well as due to the crop removal. Koruth *et al.* (2013) also observed reduced availability of N under low pH which affected microbial activity.

Initially, availability of P in the soil was in the low range (Table 3) which might be due to P fixation by Fe and Al sesquioxides which is a consequent of extreme soil acidity. Available P status increased even to high level during the cropping period but dropped at harvest during both the years (Fig 20a and 20b) (Table 49). During second year, the availability was reduced at harvest to even below the initial level especially for the RHA treatments. The RHA treatments recorded poor available P status in the soil at all the stages due to higher soil acidity in RHA applied plots compared to dolomite and lime that leads to higher P fixation.

Soil available K was medium during both the years (Table 3) and the status was maintained throughout the crop period which declined to low range at harvest during first year (Table 50). The probable reasons might be the antagonistic effect of high Ca and Fe content of soil (Table 51 and 54) on K availability and heavy leaching loss of K due to higher rainfall during the period (Fig. 1b). Higher values of available K were registered by the treatments involving RHA and lime with or without $MgSO_4$.

5.2.4.5 Availability of Secondary Nutrients

The soil belonged to Vechoor series and had high deposits of $CaCO_3$ shells (GoK, 1999). High acidity in spite of large accumulation of lime shells is a peculiar characteristic of the kari soils (Nair and Iyer, 1948; Subramoney, 1958; 1959; Money, 1961; Money and Sukumaran, 1973; Chattopadhyay and Sidharthan, 1985). Hence the initial available Ca content was high (Table 3). During first year, the value was maintained near initial status at seedling stage and increased over the initial status at

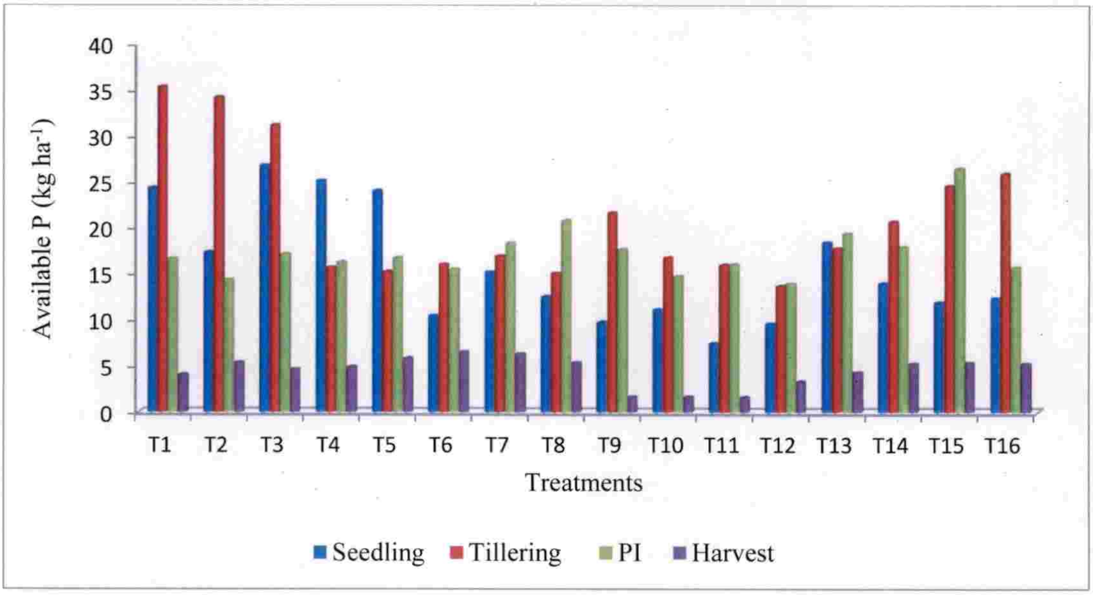

Fig. 20a Effect of nutrient management practices on soil available P during 2015, kg ha^{-1}

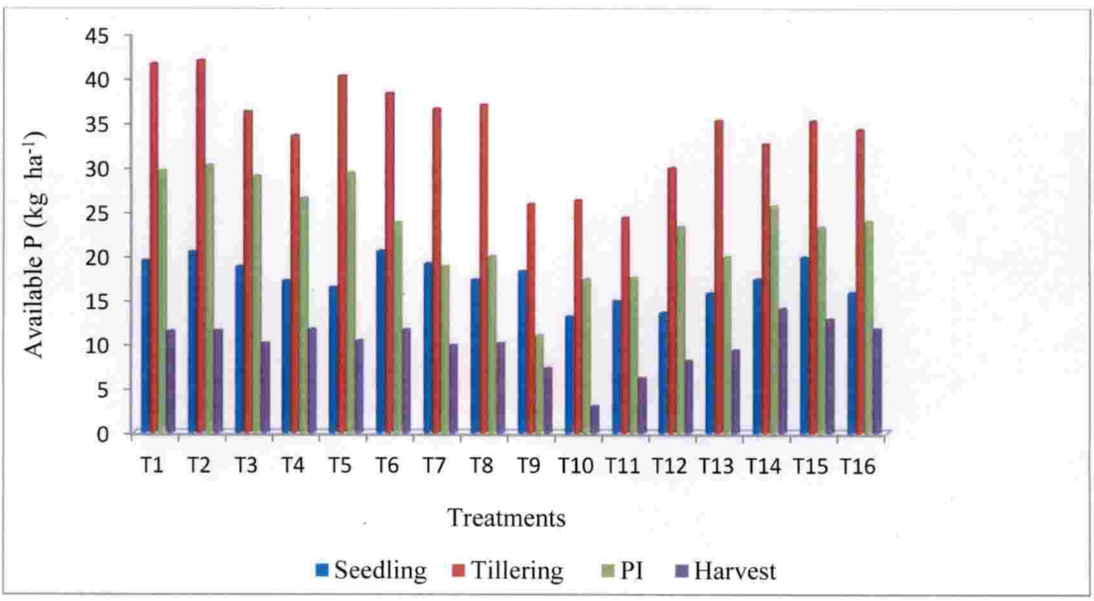

Fig. 20b Effect of nutrient management practices on soil available P during 2016, kg ha^{-1}

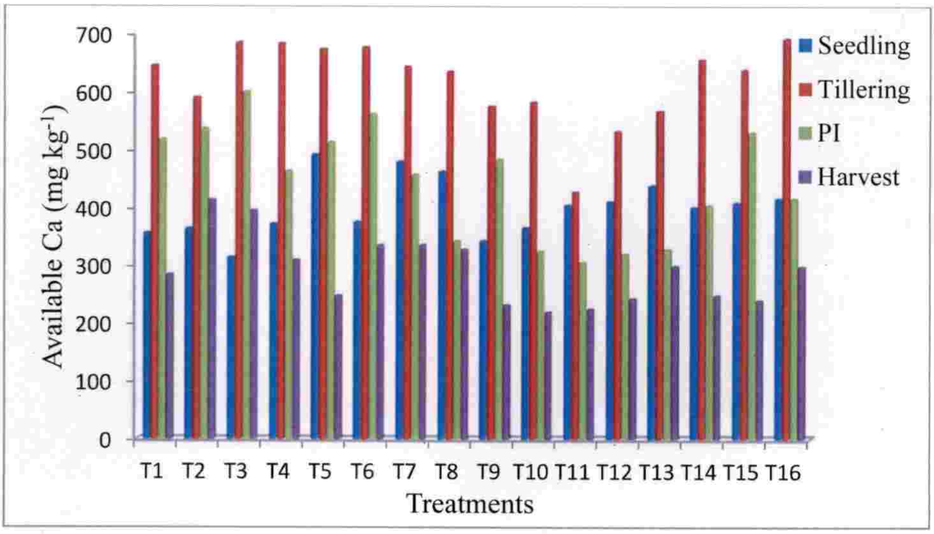

Fig.21a Effect of nutrient management practices on soil available Ca during 2015, mg kg^{-1}

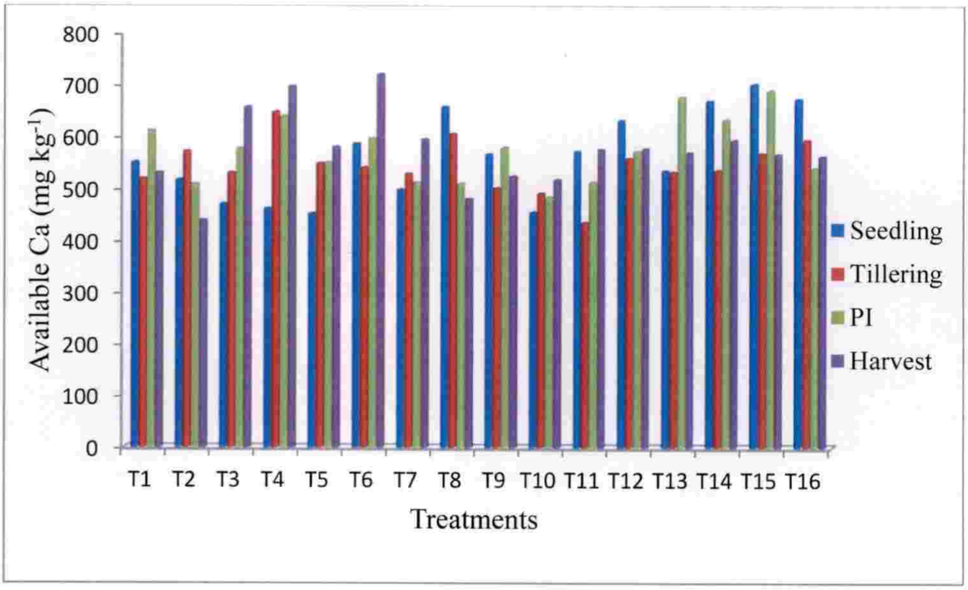

Fig.21b Effect of nutrient management practices on soil available Ca during 2016, mg kg^{-1}

tillering and PI stages with a decrease at harvest (Fig. 21a). As Ca is highly liable to leaching, the reduction in available Ca even below the initial status at harvest could be attributed to higher rainfall during the period (Fig. 1b) causing leaching of the nutrient as well as a drop in pH at harvest (Table 46). During second year, the status was maintained throughout the crop season for most of the treatments (Fig. 21b). Lime with or without $MgSO_4$ and dolomite treatments registered higher values of soil available Ca at different stages of sampling (Table 41).

Initially, the availability of Mg in the soil was much below the critical limit (Table 3 and Appendix II). Availability of Mg increased above the initial value at all stages during both the years. However, during first year, there was a slight decrease in Mg content at harvest stage whereas there was a sharp increase at harvest during second year (Fig. 22a & 22b). The decrease in Mg at harvest during first year could be due to the occurrence of rainfall and subsequent leaching loss of Mg at the end of crop period similar to that of Ca (Fig. 1b). Edmeades *et al.* (1985) and Myers *et al.* (1988) have shown that with increasing soil acidification, less amount of Mg remain in exchangeable form. Since it is a poor competitor with Al and Ca for the exchange sites, more Mg remain in solution and is liable to leaching loss. The available Mg status remained deficient in lime without $MgSO_4$ treatments throughout the cropping period. The treatments involving dolomite or lime + $MgSO_4$ recorded higher availability of Mg in the soil during both the years.

The soil available S was initially (Table 3) very high due to the acid sulphate nature of the kari soil but it decreased sharply at all stages of crop during both the years of experimentation (Table 53) as observed in Experiment I. Hegde *et al.* (1980) reported available S to the range of 571 to 1500 ppm in kari soil. It could also be observed that the available S status decreased after tillering stage but showed an increase at harvest. Availability of S decreased during the cropping period due to the formation of sulfides under flooded condition as well as application of soil ameliorants *viz.* dolomite, lime or RHA. Drying of soil at harvest might have enabled oxidation of sulfides leading to higher available S status. Though there is high S content in Kuttanad soil, there is no H_2S toxicity observed due to high Fe content

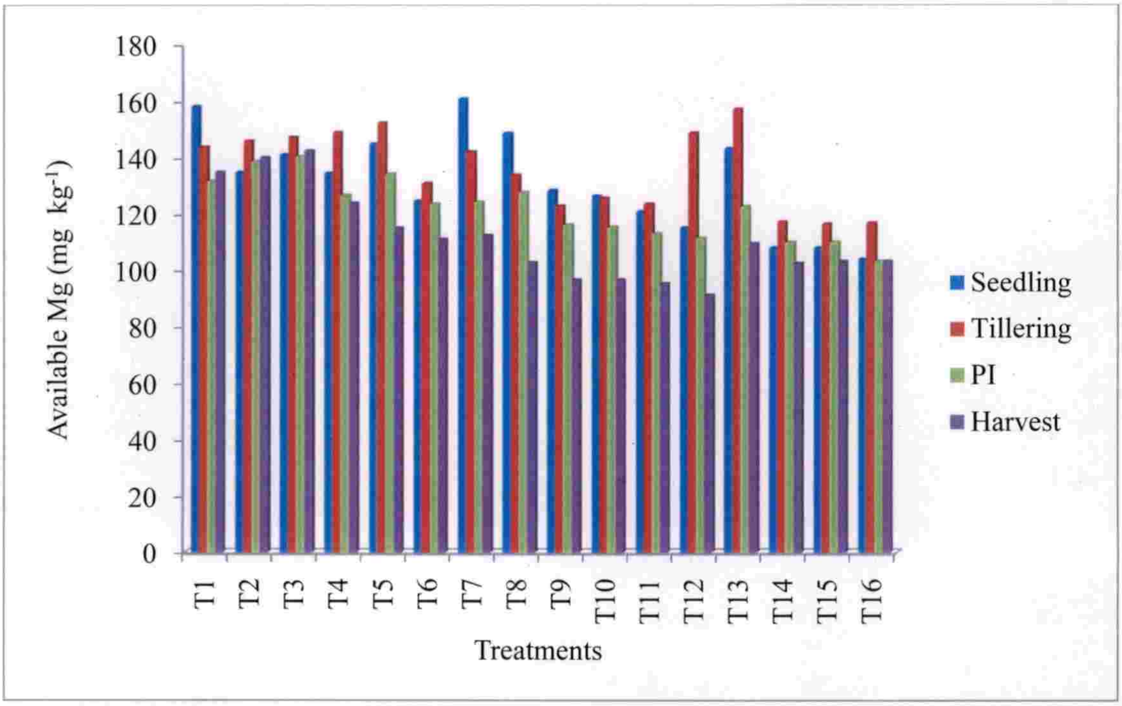

Fig.22a Effect of nutrient management practices on soil available Mg during 2015, mg kg^{-1}

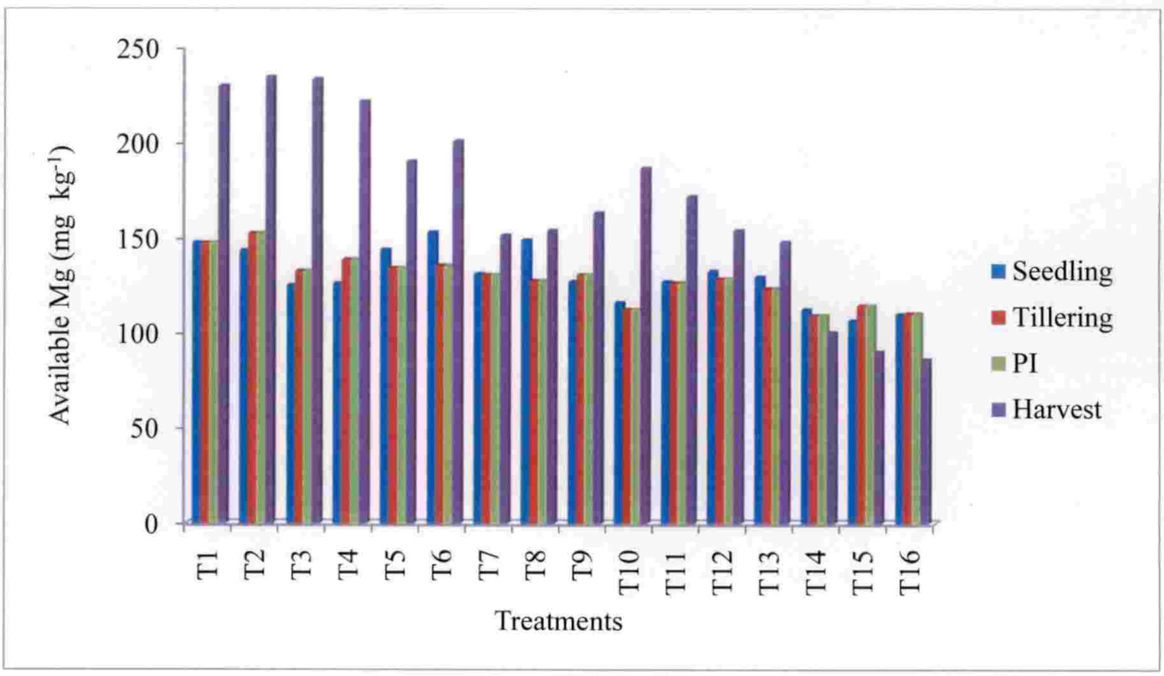

Fig. 22b Effect of nutrient management practices on soil available Mg during 2016, mg kg^{-1}

leading to more FeS formation. Ramasamy (2014) also reported toxicity of sulphide occurs in soils low in active Fe.

5.2.4.6 Availability of Micronutrients

Initially, the availability of Fe in the soil was very high (Table 3) which was much above the toxic limit (Appendix III). Though the availability of Fe was brought down by nutrient management practices during the cropping period (Table 54), it was always well above the toxic limit. A decreasing trend of available Fe content from seedling to tillering stage and an increasing trend upto PI stage during first year (Fig. 23a & 23b) and upto harvest stage during second year were observed. Drying of soil at harvest and diminishing effect of soil ameliorants leading to lowering of soil pH might have increased the availability of Fe in the soil. The decrease in Fe content at harvest during first year might be due to the rainfall towards end of crop season (Fig 1b). Among the treatments, those involving dolomite and lime + $MgSO_4$ registered lower content of available Fe. Higher availability of Fe was noticed with RHA treatments at all stages of the crop which could be attributed to comparatively high soil acidity in RHA applied plots. Reduction in root growth in RHA treatment compared to the dolomite treatment due to Fe toxicity could be seen in Plate 5. This is in conformity with the findings of Bridgit *et al.* (1993) who observed very few long roots in rice due to Fe toxicity.

The initial available Mn status in soil was sufficient which was comparatively higher during second year (Table 3 and Appendix II). Available Mn content increased from the initial status during first year upto PI stage and decreased at harvest (Table 55). The leaching loss of Mn due to higher rainfall during the period might have reduced the content of available Mn (Fig. 1b). During second year, available Mn content decreased from the initial value, declined at PI stage to deficiency level for many treatments even below the detectable limit but increased sharply at harvest. The reduction in available Mn status during the PI stage could be due to very high Ca and Fe contents in the soil (Table 51 and 54) showing antagonism with Mn (Tisdale *et al.* 1993). The sharp increase in Mn availability at harvest might be due to higher soil

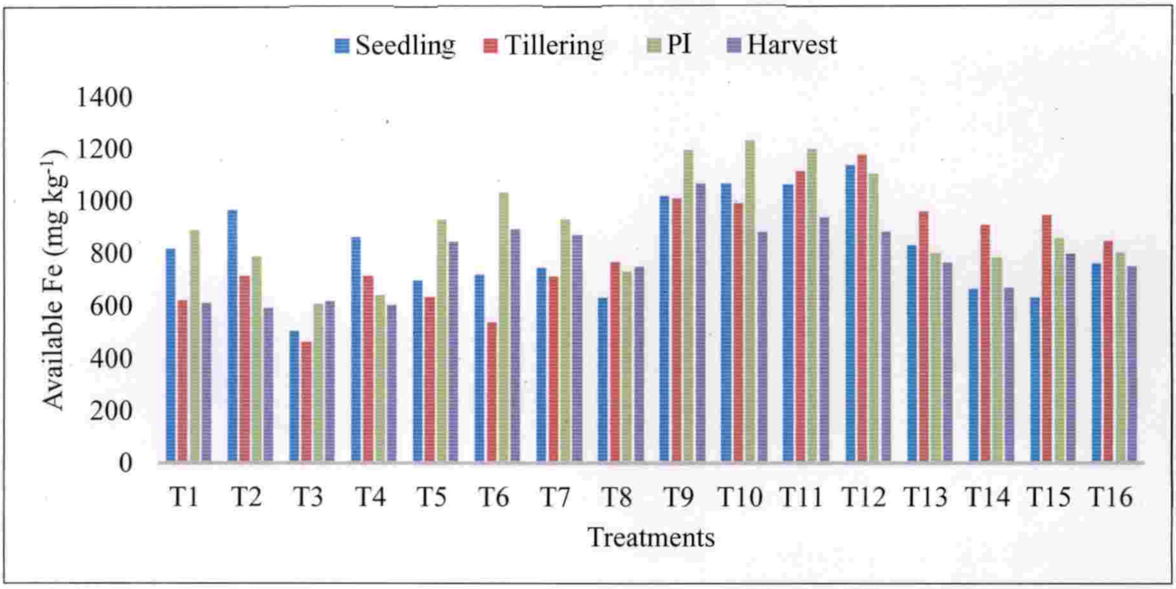

Fig. 23a Effect of nutrient management practices on soil available Fe during 2015, mg kg^{-1}

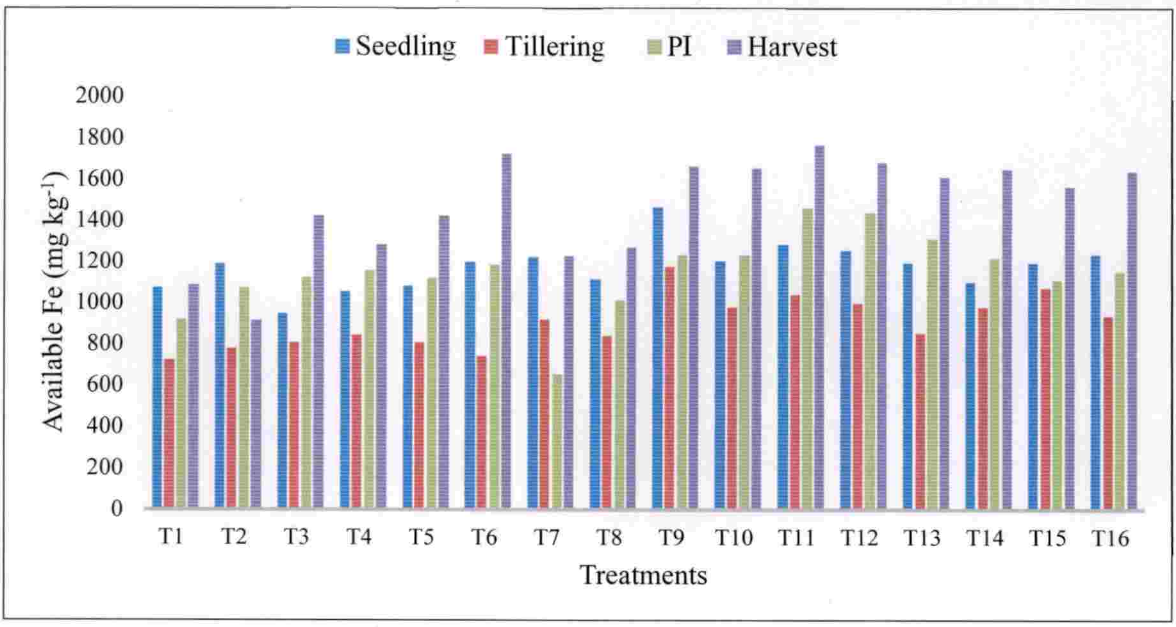

Fig. 23b. Effect of nutrient management practices on soil available Fe during 2016, mg kg^{-1}

Dolomite treatment RHA treatment

Plate 6. Root growth of rice as affected by Fe toxicity

acidity induced by the dry soil condition at harvest. In general, higher status of available Mn was registered by dolomite treatments.

Similar to available Mn, the initial available Zn was above sufficiency level during both the years but was much higher during second year (Table 3 and Appendix II). During the cropping period, the soil available Zn content increased upto tillering stage decreased at PI stage and further increased at harvest for most of the treatments during first year (Table 56). During second year, an increasing trend upto PI stage and a decline at harvest were observed. In general, dolomite and lime + $MgSO_4$ treatments registered higher available Zn in the soil.

The soil was deficient in available Cu during both the years initially (Table 3) which could be due to the organic matter content in *kari* soil which binds Cu and makes it less available. Acute Cu deficiency due to chelation with insoluble organic matter that reduces the nutrient availability in peat soils has been reported by Sanyal and Majumdar (2009). Cu is more strongly bound to the organic matter and slow rate of decomposition of organic matter in acid soils decreases the release of Cu that cause deficiency (Cavallaro and McBride, 1980; Jeffery and Uren, 1983; FAO 1983). The high S content of the soil (Table 3) could also reduce the availability of Cu by forming CuS which is less soluble. Upon flooding, as the redox potential decreased, insoluble or unavailable sulfides of Cu might have formed which upon draining increased Cu availability to rice plant (Harmsen and Vlek, 1985). During first year, the Cu availability was raised to sufficiency level at PI and thereafter increased further at harvest stage (Table 57) which might be due to the mineralization of organic matter towards the later stages of crop. The Cu status increased at seedling stage from initial status but went even below detectable level at tillering, PI and harvest stages for many treatments during second year. Generally, the treatments involving dolomite, lime + $MgSO_4$ or RHA + $MgSO_4$ along with 100% POP registered higher available Cu in the soil.

Initially, the soil was deficient in available B during both the years (Table 3). Deficiency of B (0.21 to 0.3 mg kg^{-1}) in kari soils has also been reported by

Sasidharan and Ambikadevi (2013). The deficiency can be corrected with the soil application of borax @ 10 kg ha^{-1} or foliar spray with 0.5% boric acid (KAU, 2011). During first year, available B content was higher than the initial status at all stages but remained deficient throughout the cropping period. However, during second year available B content increased sharply from the initial status at seedling stage irrespective of treatments, maintained the increase upto tillering stage. Afterwards, the availability of B decreased below detectable limit for most of the treatments. In general, higher available B status was recorded by dolomite treatments.

5.2.4.7 Na and Al status

Comparatively higher status of available Na was found initially in the soil than in Experiment I (Table 3) which is due to the proximity of the field of Experiment II to the Vembanad Lake which makes it more prone to sea water inundation during summer. There was plot to plot variation in available Na during both the years where second year status was higher and above the level of toxicity. In general, the Na status was reduced below the initial value during both the years and the reduction being more pronounced during second year (Fig. 24a and 24b). A sharp decrease of available Na status observed at tillering and PI stages of second year followed by a rise in the Na level at harvest could be due to the capillary rise of subsoil Na upon drying of the soil at harvest. This rise in Na status was not observed during first year which might be due to higher rainfall towards the end of the crop season that prevented further rise of Na from the subsurface soil (Fig 1b).

Though the soil was high in exchangeable Al status initially (Table 3), it was below the critical limit of toxicity (Appendix II). This could be due to the high available Fe content in the soil which is antagonistic to Al. The Al content decreased from the initial value during the cropping period at all stages during both the years. Merino *et al.* (2010) has reported that Ca plays a fundamental role in the amelioration of pH and Al toxicity and improving physiological and biochemical processes in plants through Al-Ca interactions. Ca deficiency triggers Al toxicity in plants whereas addition of Ca alleviates Al toxicity (Rout *et al.* 2001; Rengel and Zhang, 2003).

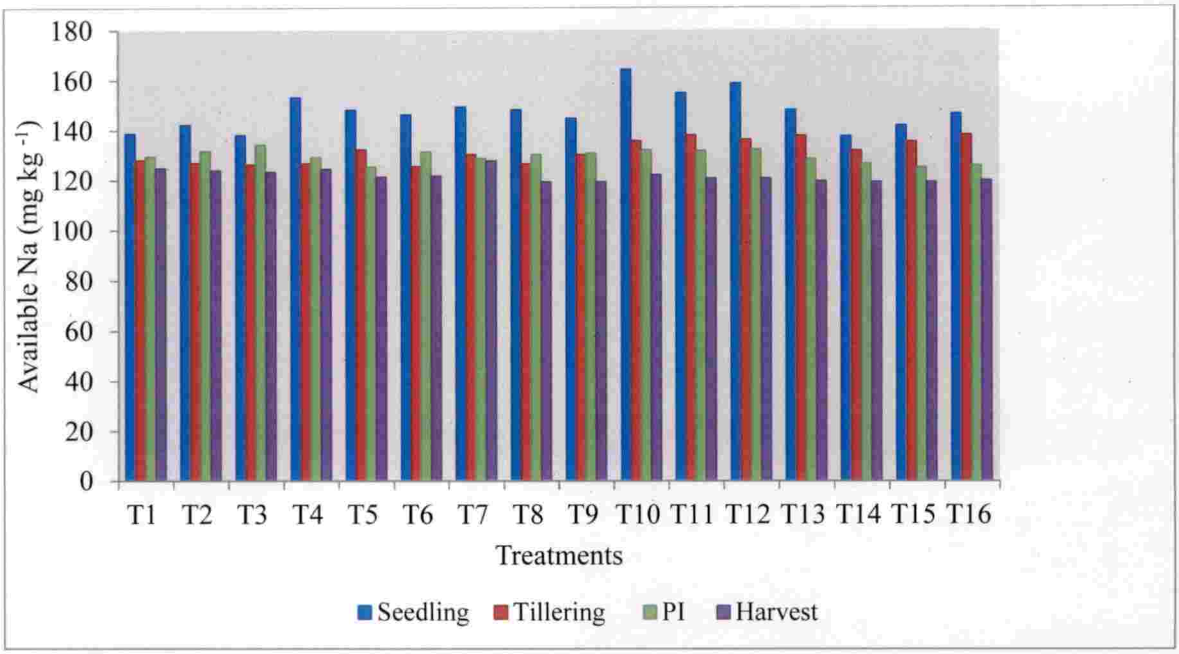

Fig.24a Effect of nutrient management practices on available Na during 2015, mg kg $^{-1}$

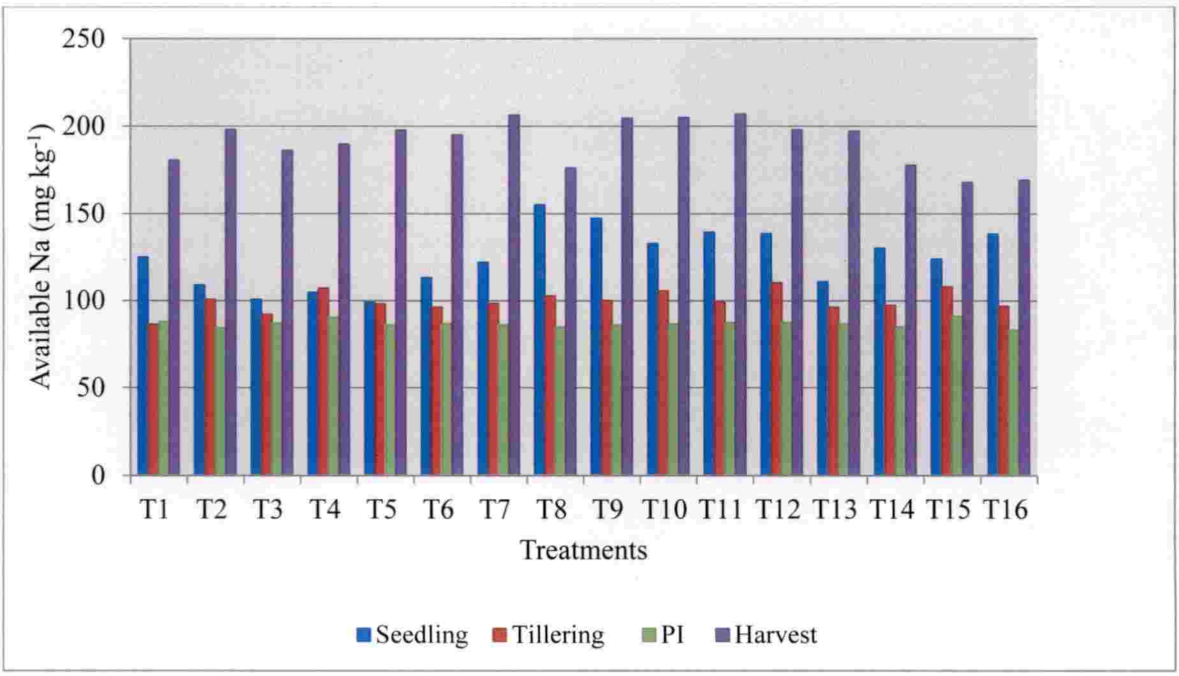

Fig.24b Effect of nutrient management practices on available Na during 2016, mg kg $^{-1}$

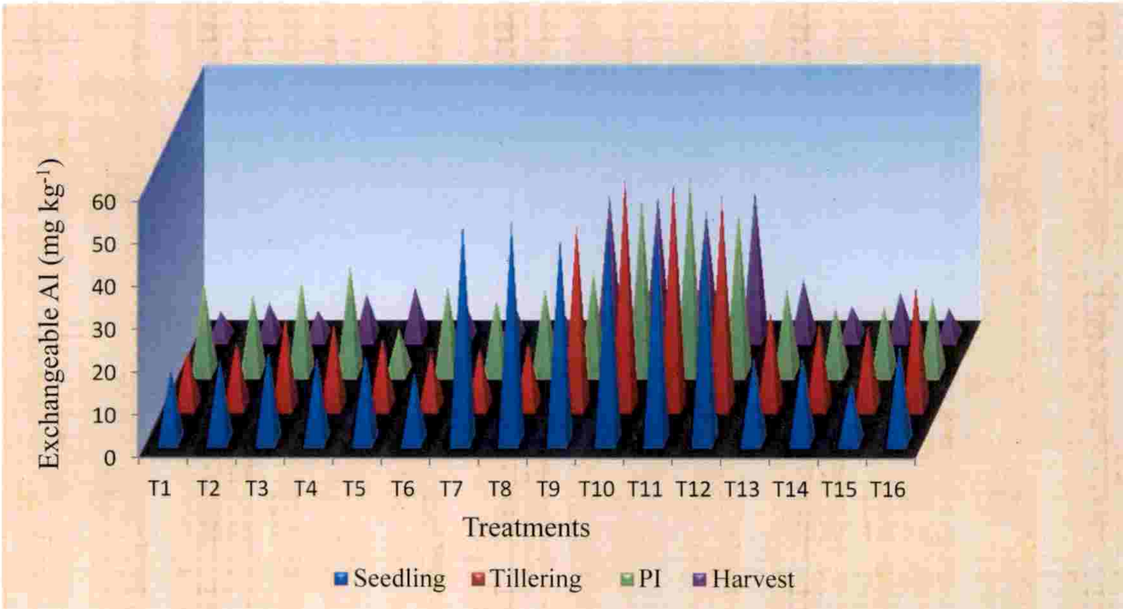

Fig. 25a Effect of nutrient management practices on exchangeable Al during 2015, mg kg^{-1}

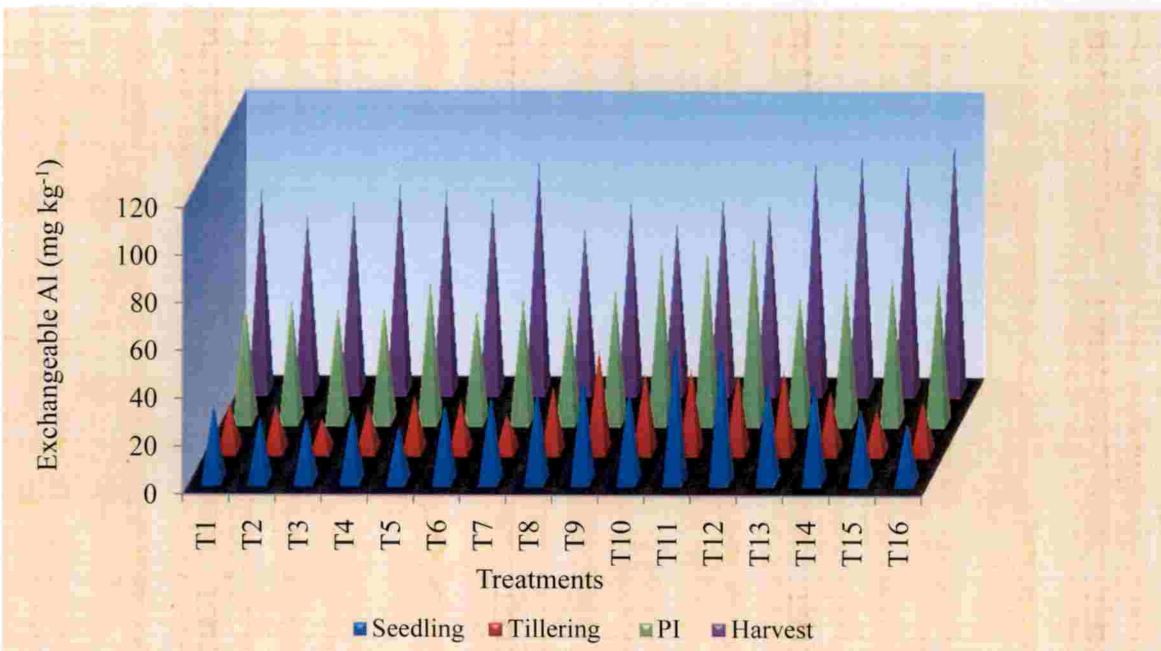

Fig. 25b Effect of nutrient management practices on exchangeable Al during 2016, mg kg^{-1}

During first year, the Al content was reduced at harvest whereas during second year, it was increased (Fig. 25a & 25b). This could be due to higher rainfall at harvest during first year (Fig. 1b) that resulted in a dilution effect of Al whereas the dry condition at harvest during second year increased acidity and exchangeable Al.

5.2.5 Pest and Disease Incidence

At tillering stage of the crop during both the years, there was stem borer (*Scirpophaga incertulas*) incidence but the incidence was lower during second year as revealed from the scores given in Table 61 (9.33 to 17.33% during 2015 and 3.33 to 12% during 2016). The pest was controlled by the application of Fertera (chlorantraniliprole 0.4% GR) in the soil. The treatments involving RHA had lower incidence of stem borer during both the years as in the case of Experiment I which might be due to the resistance provided by high silica content (83%) in the RHA as observed by Savant *et al.* (1997) and Ma *et al.* (1989).

5.2.6 Economics of Cultivation

The economics of cultivation was worked out in terms of net income and BCR (Table 62). The effect of nutrient management practices on net income and BCR followed the same trend during both the years. The treatments involving dolomite generated higher net income and BCR (Fig. 26 and 27 respectively) compared to treatments involving lime and RHA. The results proved the superiority of dolomite for acidity amelioration in extremely acidic soils to which the typical kari soil belongs. Among the treatments, dolomite + POP + 13:0:45 (T_2) generated the highest net income (₹ 65108 ha^{-1} during 2015 and ₹ 70475 ha^{-1} during 2016) followed by dolomite + POP + 13:0:45 + borax (T_4) (₹ 63067 ha^{-1} during 2015 and ₹ 68125 ha^{-1} during 2016). The same trend was observed with BCR also. The highest BCR of 2.27 during 2015 and 2.28 during 2016 were recorded by T_2 followed by T_4 (2.22 during 2015 and 2.24 during 2016). Higher grain yield obtained with these treatments has reflected in their economics also and hence they can be recommended for economic rice cultivation in kari soil. The higher yield of dolomite compounded with lower cost proved to be economically efficient. Foliar nutrition of 13:0:45 alone or in combination with borax not only produced higher yield but was also economically viable. This is supported by Fageria *et al.* (2009) who have reported reduced cost of production in addition to increased efficiency of nutrient uptake by foliar fertilization along with soil fertilization. Son *et al.* (2012) also obtained higher net income from rice due to one to three foliar application of potassium nitrate.

Higher net income and BCR were obtained with lime + $MgSO_4$ + 13:0:45 + borax along with 100% POP (T_8) compared to similar treatment with 75% POP (T_{13}). Hence, it can be inferred that even 25% reduction in the recommended dose of NPK cause reduction in the grain yield and affect the economics of rice cultivation in kari soil. The lime + POP treatments without $MgSO_4$ recorded higher net income and BCR compared to lime + POP + $MgSO_4$ treatments. Although higher grain yield was realized due to lime + POP + $MgSO_4$ treatments, the high cost of $MgSO_4$ resulted in lower net income and BCR with these treatments. The treatments involving RHA registered lower net income and BCR which was due to lower grain yield obtained from these treatments.

The results of Experiment II revealed the superiority of soil acidity amelioration with dolomite @ 500 kg ha^{-1} (300 kg as basal dose and 200 kg ha^{-1} at 30 DAS) and soil application of 90:45:45 kg NPK ha^{-1} (full P as basal and N and K in three equal splits at 20 DAS, 35 DAS and PI stage) along with foliar spray of 13:0:45 (1%) or combined spray of 13:0:45 (1%) and borax (0.5%) at panicle initiation stage for realizing higher productivity and profitability from rice cultivation in Vaikom Kari soil.

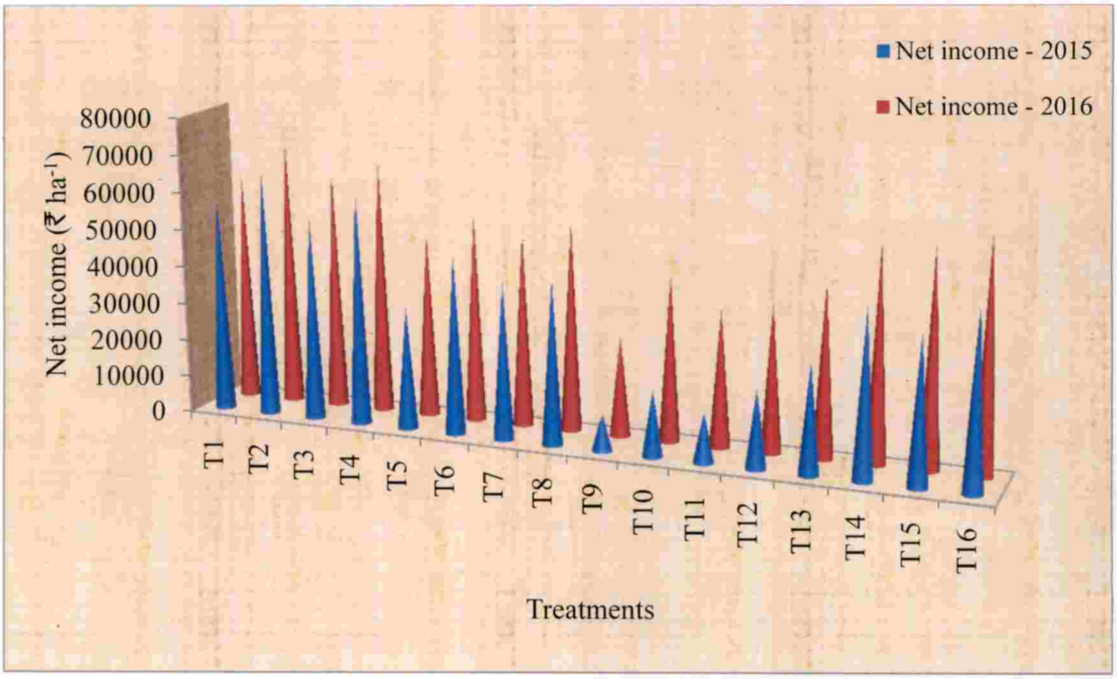

Fig. 26 Effect of nutrient management practices on net income, ₹ ha^{-1}

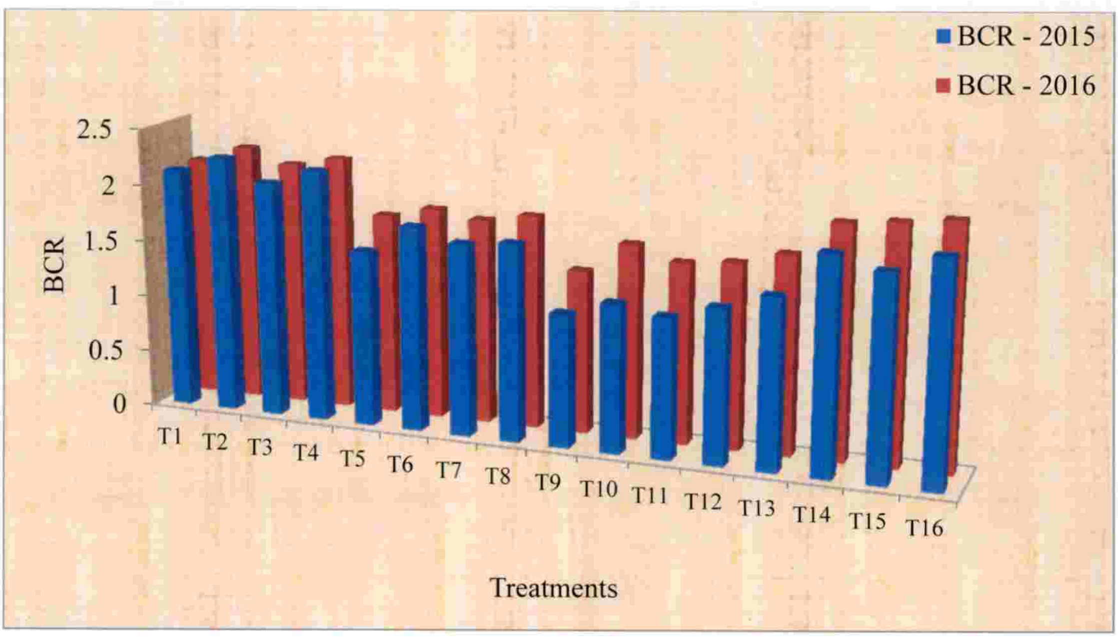

Fig. 27 Effect of nutrient management practices on benefit cost ratio

Summary

6. SUMMARY

The investigation entitled “Acidity amelioration and nutrient management practices for mitigating yield constraints of rice in Vaikom Kari” was carried out as two field experiments in Vaikom Kari soils of Kuttanad from 2014 to 2017 to standardize acidity amelioration and nutrient management practices for rice to overcome yield constraints in Vaikom Kari and to work out the economics of cultivation.

Field experiment I entitled “Evaluation of acidity amelioration practices for rice in Vaikom Kari” was conducted in farmer’s field in Vaikom Kari soils of Kallara panchayat in Kottayam district during November 2014 to March 2015. The experiment was laid out in RBD with seven treatments in three replications with rice var. Uma. The treatments included lime, dolomite and rice husk ash (RHA) applied as two splits one as basal and 30 DAS and the other as basal and one week before third dose of fertilizer application and a control without ameliorants.

Acidity amelioration practices had significant effect on growth characters of rice *viz.* plant height, tiller number m^{-2} and LAI at MT, PI and harvest stages. Any liming material irrespective of time of application could improve plant height over control at all stages with the tallest plants at each stage produced by RHA treatments. Higher number of tillers was produced by lime or dolomite or RHA as basal + 30 DAS at MT stage and these treatments along with RHA as basal + PI at PI stage. All treatments except control were on a par at harvest with respect to tiller number. Lime or dolomite or RHA as basal + 30 DAS produced higher LAI at MT stage while all treatments except lime as basal + PI and control were on a par at PI stage. At harvest, significantly higher LAI was produced by RHA or dolomite as basal + 30 DAS.

With regard to yield attributes, higher number of panicles m^{-2} and 1000 grain weight and lower sterility percentage were recorded by lime, dolomite and RHA over control irrespective of time of application.

Lime or dolomite or RHA as basal + 30 DAS were effective in producing significantly higher grain yield. Grain yield was significantly and positively correlated with LAI at MT and PI stages and panicle number m^{-2}. Higher straw yield could be produced by lime or dolomite as basal + 30 DAS and RHA treatments. Though not significant, higher values of HI were recorded by dolomite treatments. Application of lime or dolomite or RHA as basal + 30 DAS resulted in higher dry matter production at harvest.

Higher Na content in three youngest leaves one week before PI was observed with control which registered the lowest K/Na_{Leaves}. Positive correlation was observed between grain yield and K/Na_{Leaves}, but was not significant.

The contents of N, P, Mn, Zn, Cu and B in the flag leaf agreed with CNC as reported in rice. However, the contents of K, Ca and Mg in the flag leaf were below CNC and those of S, Fe and Al were above CNC. Acidity amelioration practices improved the nutrient status in the flag leaf. The control plot registered lower contents of macronutrients except S and B and higher contents of S, Fe, Mn, Zn, Cu, Na and Al in the flag leaf. Grain yield was also significantly and positively correlated with P, Mg and B contents of the flag leaf and significantly and negatively correlated with S, Fe, Mn, Cu, Na and Al contents.

The contents of primary nutrients in the grain and straw was near or within CNC. No variation in the contents of primary nutrients in the grain and straw due to treatments was noticed except grain P content. The control plots registered the lowest grain P content and dolomite as basal + 30 DAS the highest value. However, Ca content in the grain was slightly higher whereas that in the straw was slightly lower than CNC. The content of Mg in both the grain and straw was lower than CNC. The S content agreed with CNC in the grain but was higher in the straw. Among the treatments, the control registered the lowest Ca and Mg and the highest S contents.

Amelioration practices could reduce Fe content in both the grain and straw below the level of toxicity. Concentration of Mn in the grain and straw was below CNC. The grain and straw Zn and Cu contents were near CNC. Content of B in the grain was below CNC whereas that in the straw was near CNC. Higher Mn content was recorded by the control as well as dolomite as basal + PI in the grain and dolomite as basal + PI and lime treatments in the straw. Higher content of Zn in the grain was also observed in the control as well as with dolomite as basal + PI. Lime or dolomite as basal + 30 DAS and RHA as basal + PI registered higher straw Zn content. No pronounced variation in the Cu content in the grain and straw was observed between ameliorated and control plots. Higher content of B in the grain and the straw was observed with lime or dolomite or RHA as basal + 30 DAS.

No marked variation in Na content in the grain and straw was observed due to treatments. Higher Al content in the grain was observed with control and the lowest with dolomite as basal + 30 DAS. The straw Al content was higher than CNC and near to the toxic limit. The control, the RHA treatments and lime as basal + PI recorded higher straw Al content.

Soil ameliorants improved the uptake of macronutrients and micronutrients. Uptake of N and K were significantly higher for lime or dolomite or RHA applied as basal + 30 DAS while dolomite as basal + 30 DAS recorded the highest P uptake. The highest uptake of Ca was found with lime as basal + 30 DAS, that of Mg and S with dolomite as basal + 30 DAS and the lowest recorded by the control for these nutrients. The highest uptake of Mn and Zn were observed with lime as basal + 30 DAS, that of Cu with RHA as basal + 30 DAS and that of B with lime or dolomite or RHA as basal + 30 DAS. The control treatment and RHA as basal + PI recorded significantly lower Na uptake and both the RHA treatments registered higher Al uptake. Grain yield was significantly and positively correlated with uptake of nutrients except Fe, Zn and Al.

Soil pH increased over the initial status in the ameliorated plots which decreased at harvest. Lime and dolomite treatments were more effective in reducing soil acidity. Soil EC increased in general during the cropping period (but < 1 dS m^{-1}) with a sharp increase at harvest.

Lime and dolomite treatments improved dehydrogenase activity at all stages with a decreasing trend from seedling to harvest stage. The control plots showed a drastic reduction in the enzyme activity from seedling to harvest stage.

A reduction in soil OC content after the crop was observed but the treatments had significant effect only at PI stage when the lime treatments, dolomite as basal + PI and RHA as basal + 30 DAS showed higher OC contents. Though the soil was high in OC, available N status was low.

In general, soil ameliorants improved nutrient availability in the soil. Lime or RHA as basal + PI recorded the highest soil available N at seedling and tillering stages and dolomite as basal + PI and RHA as basal + 30 DAS registered higher values at PI stage. In general, application of lime or dolomite or RHA as basal + 30 DAS improved soil available P. The treatments failed to express significant effect on available K status. Lime or dolomite treatments gave higher soil available Ca content in the soil while dolomite treatments registered significantly higher soil available Mg. Lime treatments showed significantly lower values of available Fe. Significant and positive correlation of pH with available Ca and negative correlation with available Fe was observed at all stages. Higher soil available Mn was recorded by lime treatments. Available Zn was not influenced by the treatments at any of the stages. Soil available Cu status was the highest with control at PI stage and with dolomite as basal + PI at harvest stage. Dolomite treatments recorded higher B in the soil. The control plots recorded significantly lower status of available N, P, Ca, Mn and B and higher status of available S and Fe in the soil. There was an increase in the availability of Na at all stages of experimentation but the content was below the critical level of toxicity. Soil exchangeable Al status was significantly higher in the control.

Lower incidence of stem borer was observed with RHA treatments and the highest with the control.

Lime, dolomite or RHA applied as basal + 30 DAS were found economically superior while the control recorded the lowest net income and BCR.

A critical analysis of the results of Experiment I proved the superiority of lime, dolomite or RHA for ameliorating acidity and realising higher yield and income from rice cultivation in strongly acidic soil in Vaikom Kari. The results have clearly indicated the superiority of split application of ameliorants as basal + 30 DAS over as basal + one week before PI stage.

Field experiment II entitled "Standardization of nutrient management practices for rice in Vaikom Kari was conducted during August to December 2015 and repeated during the same season of 2016 in farmer's field in Vaikom Kari soils of Thalayazham panchayat in Vaikom Thaluk in Kottayam district. The experiment was laid out in RBD with 16 treatments (formulated based on the results of Experiment I) in three replications with rice variety Uma. The treatments were dolomite, lime + $MgSO_4$ or RHA + $MgSO_4$ along with 100% POP alone or with 100% POP + foliar spray of 13:0:45 (1%) or borax (0.5%) or 13:0:45 + borax at PI stage. Lime + $MgSO_4$ + 75% POP + 13:0:45 + borax as well as lime without $MgSO_4$ + 100% POP combined with 13:0:45 or borax or both were also included as treatments.

Nutrient management practices had profound influence on growth characters *viz.* plant height, tiller number and LAI at all stages during both the years except tiller number at MT during first year and LAI at harvest during second year. The treatments involving dolomite and lime with or without $MgSO_4$ along with 100% POP produced taller plants, higher tiller number m^{-2} and higher LAI during both the years.

Regarding yield attributes, dolomite + POP + 13:0:45 produced the highest number of panicles m^{-2}. Higher test weight and lower sterility percentage were observed with dolomite + POP + 13:0:45 or dolomite + POP + 13:0:45 + borax.

The grain yield was significantly influenced by the nutrient management practices during both the years. The highest grain yield of 5.42 and 5.57 t ha^{-1} during 2015 and 2016 respectively were produced by dolomite + POP + 13:0:45. This treatment was followed by dolomite + POP + 13:0:45 + borax and lime + POP + $MgSO_4$ + 13:0:45 during both the years. Lower yields were produced by the treatments involving RHA and 75% POP. The grain yield was significantly and positively correlated with LAI at MT and PI stages and with panicle number.

The pooled analysis of two years' data also proved the significance of the treatments involving dolomite + POP or lime + POP + $MgSO_4$ on grain yield. The highest yield of 5.49 t ha^{-1} was recorded by dolomite + POP + 13:0:45 followed by dolomite + POP + 13:0:45 + borax and lime + $MgSO_4$ + POP + 13:0:45. The treatments involving RHA and 75% POP registered significantly lower grain yield in the pooled data.

Higher straw yields were produced by dolomite treatments, lime + POP + $MgSO_4$ + 13:0:45, treatment involving 75% POP and lime + POP without $MgSO_4$ combined with 13:0:45 or 13:0:45 + borax during first year. During second year, all treatments were on a par except lime + POP + $MgSO_4$ alone and RHA treatments. The treatments involving RHA recorded significantly lower straw yield during both the years. Significant influence of the treatments on HI was observed only during first year. Higher values of HI were recorded by dolomite or lime + $MgSO_4$ treatments and RHA + $MgSO_4$ along with13:0:45 or 13:0:45 + borax combined with 100% POP.

Higher dry matter yield of grain as well as straw were produced by dolomite + POP or lime + $MgSO_4$ + POP along with 13:0:45 alone or 13:0:45 + borax during both the years. The TDMP at harvest was significantly higher with dolomite + POP along with 13:0:45 or 13:0:45 + borax during first year and with dolomite treatments except the one with borax and lime + $MgSO_4$ + POP treatments with 13:0:45 or with 13:0:45 + borax during second year. The treatments involving RHA and 75% POP registered lower values of TDMP at harvest.

Analysis of three youngest leaves one week before PI for K/Na_{Leaves} revealed the superiority of treatments involving 100% POP and dolomite during both the years. Lower ratios were registered by RHA treatments.

The flag leaf N, P, Ca and S contents were above CNC during both the years. However, K and Mg contents were lower than CNC. The Fe content was above the critical level of toxicity during both the years, Mn content below than CNC and Zn, Cu and B contents agreed with CNC. The treatments involving ameliorants other than RHA showed higher contents of N, P, K, Ca and Mg in the flag leaf whereas the RHA treatments registered higher S content. The treatments involving dolomite + POP or lime + $MgSO_4$ + POP recorded comparatively lower Fe content and higher Zn content. Higher Mn and Cu contents were observed with those treatments involving RHA. The effect of treatments on B content was significant only during first year when dolomite + POP + borax and lime + $MgSO_4$ + POP with borax or 13:0:45 + borax registered higher B content. Significant and positive correlation of grain yield with P and Ca contents of flag leaf but negative correlation with S, Fe and Mn contents were observed during both the years. The grain yield was also negatively correlated with available Na and exchangeable Al contents in the soil.

The contents of the primary nutrient in the grain and straw were higher than CNC except grain and straw K content which was below CNC during first year. The treatments involving dolomite and lime + $MgSO_4$ generally showed higher NPK content in the grain and straw. In general, the grain and straw showed Ca status markedly higher than CNC, Mg status lower than CNC and S status within CNC during both the years. The treatments involving RHA generally showed lower Ca and Mg contents in the grain and straw. Generally, higher Mg content in the grain and straw was observed with treatments involving dolomite or lime + $MgSO_4$. But in the case of S content in the grain and straw, RHA treatments were found equally effective as other ameliorants.

The grain Fe content was more than two times higher than CNC during first year except for dolomite treatments and was lower than CNC during second year. The straw Fe content was three to six times higher than CNC during first year whereas slightly higher than CNC during second year. Among the treatments, those involving RHA registered higher Fe content in the plant. During first year, the grain and straw Mn contents were markedly above the CNC and it drastically reduced below CNC during second year. The Zn content in the grain agreed with CNC during both the years while the straw Zn content was markedly below the CNC. Grain and straw Cu contents were above CNC during first year which was markedly below CNC during second year. Grain B content was only 1/10th of CNC during first year which further decreased during second year. The straw B content was lower than CNC during first year but increased sharply by two to five times the CNC during second year. In general, dolomite treatments registered higher B content in the plant.

Compared to first year, there was a two fold increase in Na content in the grain and a ten fold increase in Na content in the straw during second year. Dolomite + POP +13:0:45 registered the lowest Na status in the grain while the same treatment along with dolomite + POP +13:0:45 + borax recorded the lowest Na status in the straw during both the years. Generally, the RHA treatments showed higher Na status.

The Al content in both grain and straw were above CNC but below critical level of toxicity during both the years. Dolomite treatments registered lower Al content in the grain and straw.

Regarding nutrient uptake, higher uptake of N was noticed with dolomite + POP + 13:0:45 + borax and lime + POP + $MgSO_4$ + 13:0:45. Dolomite + POP alone could register the highest P uptake. Higher uptake of K, Ca, Mg and S were observed with dolomite + POP + 13:0:45 with or without borax. Dolomite or lime + $MgSO_4$ along with POP + 13:0:45 with or without borax registered higher uptake of Fe, Mn and Zn while dolomite + POP + 13:0:45 with or without borax recorded higher uptake of Cu and B. The treatments involving RHA and 75% POP recorded lower uptake of macronutrients and micronutrients during both the years. Uptake of Na was the highest with RHA + POP + $MgSO_4$ + 13:0:45 during first year and with dolomite + POP during second year. Higher Al uptake was observed with lime + POP + 13:0:45 with or without $MgSO_4$.

The grain yield was significantly and positively correlated with the uptake of P, K, Ca, Mg, S, Mn, Zn, Cu and B and significantly and negatively correlated with Fe during first year. During second year, the yield was significantly and positively correlated with uptake of nutrients except Na and Al.

Soil acidity showed a reducing trend upto tillering stage due to the application of soil ameliorants which thereafter showed a marked increase after the crop. Among the treatments, dolomite and lime with and without $MgSO_4$ performed better in ameliorating soil acidity than RHA treatments at all stages during both the years.

Similar to the soil acidity, a sharp increase in EC was recorded after the crop. In general, the RHA treatments showed higher EC values.

Nutrient management practices had profound influence on the dehydrogenase enzyme activity at all stages except at harvest during both the years. All treatments except those involving RHA helped in improving dehydrogenase enzyme activity in the soil during the cropping period. However, the enzyme activity declined at harvest stage, even below the initial status, during both the years, irrespective of the treatments.

No marked variation in soil organic carbon content was observed during the cropping period compared to the initial value. In general, nutrient management practices were effective in maintaining soil organic carbon status.

Although the availability of N in the soil increased over the initial status at all crop stages during both the years, the values were in the low range as in the case of the initial status. A reduction in available N was noticed after the crop during both the years. Significant influence of the treatments on soil available N was observed only during first year when the treatments involving dolomite + POP recorded higher available N status during seedling stage and those involving lime + POP without $MgSO_4$ at other stages.

There was a sharp increase in soil available P from the low initial value upto tillering stage which further showed a decreasing trend towards harvest. The treatments involving dolomite + POP and lime + POP with or without $MgSO_4$ recorded higher available P during all crop stages.

Initial medium status of available K in the soil was maintained throughout the cropping period during both the years except a sharp decline at harvest during first year. The treatments involving RHA and lime + POP with or without $MgSO_4$ showed higher status of available K during both the years.

An increase in available Ca over the initial status was observed upto PI stage during first year while the initial status was maintained throughout the crop season during second year. The treatments involving lime or dolomite registered higher soil available Ca during both the years.

Availability of Mg in the soil showed an increase over the initial status throughout the season during both the years with higher status at tillering stage during first year and at harvest during second year. The treatments involving dolomite + POP or lime + $MgSO_4$ + POP recorded higher availability of Mg in the soil.

The initial high availability of S reduced sharply due to treatments during the cropping period. Available S status decreased after tillering stage but showed an increase at harvest but below the initial status.

Availability of Fe in the soil decreased from the initial high status due to application of soil ameliorants. Available Fe content showed a decreasing trend from seedling to tillering stage and an increasing trend upto PI stage during first year and upto harvest stage during second year. Lower Fe contents were registered in general by dolomite and lime + $MgSO_4$ treatments while RHA treatments recorded higher status.

An increase in available Mn content over the initial value at all stages of sampling was observed during first year. During the cropping period, there was a reduction in available Mn content at harvest. During second year, available Mn increased upto tillering stage, dropped to deficiency level for some of the treatments at PI stage and underwent a sharp increase at harvest. Dolomite treatments registered higher status of available Mn in the soil.

An increase in available Zn status compared to the initial status at all stages during first year and a reduction but not below the sufficiency level during second year was noticed. An increasing trend in available Zn status from seedling to tillering and then decrease at PI stage were observed which further increased at harvest during first year. However, an increasing trend upto PI stage and a decline at harvest were noticed during second year. In general, dolomite and lime + $MgSO_4$ treatments registered higher available Zn in the soil.

Availability of Cu in the soil was below CNC before and during the cropping period except at PI and harvest stages of the crop during first year. The treatments involving dolomite, lime + $MgSO_4$ or RHA + $MgSO_4$ along with 100% POP were found superior.

Initially, the soil was deficient in available B during both the years. During first year, available B content was higher than the initial status at all stages but remained deficient throughout the cropping period. However, during second year available B content increased sharply from the initial status at seedling stage, irrespective of treatments, maintained the increased level upto tillering stage and decreased below detectable limit for most of the treatments. In general, higher available B status was recorded by dolomite treatments.

Initially, available Na status was below toxic level during first year and above toxic level during second year. In general, the Na status was reduced below the initial value during both the years, the reduction being more pronounced during second year. Dolomite treatments showed lower status of available Na in the soil.

Though the soil was high in exchangeable Al status initially, it was below the critical limit of toxicity. The Al content decreased from the initial value during the cropping period at all stages during both the years. The treatments involving dolomite registered lower status of exchangeable Al in the soil.

Soil pH was significantly and positively correlated with available P and significantly and negatively correlated with available Fe and exchangeable Al in the soil.

The incidence of stem borer (*Scirpophaga incertulas*) noticed at tillering stage was lower during 2016 than during 2015. The treatments involving RHA registered significantly lower incidence of stem borer during first year and the same treatments and the lime treatments without $MgSO_4$ recorded significantly lower incidence during second year.

During both the years, higher net income and BCR could be obtained with dolomite treatments. The highest net income (Rs. 65108 ha^{-1} during 2015 and Rs. 70475 ha^{-1} during 2016) and BCR (2.27 during 2015 and 2.28 during 2016) were recorded by dolomite + POP + 13:0:45 (T_2) followed by dolomite + POP + 13:0:45 + borax (T_4). The treatments involving RHA and 75% POP registered lower net income and BCR during both the years.

The results of the study revealed the superiority of soil acidity amelioration with dolomite @ 500 kg ha^{-1} (300 kg as basal dose and 200 kg ha^{-1} at 30 DAS and soil application of 90:45:45 kg NPK ha^{-1} (full P as basal and N and K in three equal splits at 20 DAS, 35 DAS and PI stage) along with foliar spray of 13:0:45 (1%) or combined spray of 13:0:45 (1%) and borax (0.5%) at panicle initiation stage for realizing higher productivity and profitability from rice cultivation in Vaikom Kari soil.

Future line of work

- The results of the study conducted during *virippu* season can be verified in farmer's field where *puncha* crop is cultivated.
- Additional foliar spray of 13:0:45 at tillering stage can also be experimented.
- Nutrient management experiment may be repeated including foliar nutrition of P at tillering stage along with basal soil application.

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Abstract

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ACIDITY AMELIORATION AND NUTRIENT MANAGEMENT PRACTICES FOR MITIGATING YIELD CONSTRAINTS OF RICE IN VAIKOM KARI

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ABSTRACT

An investigation entitled "Acidity amelioration and nutrient management practices for mitigating yield constraints of rice in Vaikom Kari" was carried out as two field experiments in Vaikom Kari soils of Kuttanad during the period from 2014 to 2017 to standardize acidity amelioration and nutrient management practices for rice to overcome yield constraints in Vaikom Kari and to work out the economics of cultivation.

Experiment I entitled "Evaluation of acidity amelioration practices for rice in Vaikom Kari" was conducted in farmer's field in Kallara panchayat in Kottayam district during November 2014 to March 2015. The experiment was laid out in RBD with seven treatments in three replications with rice var. Uma. The treatments included lime, dolomite and rice husk ash (RHA) applied as two splits- as basal + 30 DAS or as basal + one week before third dose of fertilizer application and a control without ameliorants.

Lime, dolomite or RHA, irrespective of time of application, could produce taller plants with higher LAI and tiller number at maximum tillering (MT), panicle initiation (PI) and harvest stages. The same treatments recorded higher number of panicles m^{-2} and 1000 grain weight and lower sterility percentage. Lime, dolomite or RHA as basal + 30 DAS produced significantly higher grain yield over control. Grain yield was significantly and positively correlated with LAI at MT and PI stages and panicle number m^{-2}. Higher straw yield was obtained with lime or dolomite as basal + 30 DAS and RHA treatments. Application of lime, dolomite or RHA as basal + 30 DAS resulted in higher dry matter production at harvest.

Soil ameliorants improved the uptake of macronutrients and micronutrients. Uptake of N and K were significantly higher for lime, dolomite or RHA applied as basal + 30 DAS while dolomite as basal + 30 DAS recorded the highest P uptake. The highest uptake of Ca was found with lime as basal + 30 DAS and that of Mg and S with dolomite as basal + 30 DAS. The highest uptake of Mn and Zn were observed

with lime as basal + 30 DAS, Cu with RHA as basal + 30 DAS and that of B with lime, dolomite or RHA applied as basal + 30 DAS. The control treatment and RHA applied as basal + one week before PI registered lower Na uptake and both RHA treatments registered higher Al uptake. There was significant and positive correlation of grain yield with uptake of nutrients except Fe, Zn and Al.

Lime and dolomite treatments were more effective in reducing soil acidity and improving dehydrogenase activity and nutrient availability in the soil. The ameliorated plots showed higher organic carbon status compared to control. Lime as basal + one week before PI and dolomite treatments recorded higher soil available N at seedling stage and at tillering and PI stages, any treatment except control could register higher available N in the soil. Any liming material applied as basal + 30 DAS improved soil available P status. No significant effect of treatments on available K was observed. Lime or dolomite treatments resulted in higher availability of Ca while dolomite treatments registered higher availability of Mg in the soil. At all stages except harvest, the control plots recorded significantly higher status of available S and Fe and lower status of Mn in the soil. Significant and positive correlation of pH with available Ca and negative correlation with available Fe was observed at all stages of crop growth. Soil available Cu status was the highest with control at PI stage and with dolomite at harvest stage. Dolomite treatments recorded higher available B in the soil. The highest Na content in the soil was registered by dolomite treatments at seedling stage and by control at tillering stage. There was an increase in the availability of Na at all stages of experimentation but the content was below the critical level of toxicity. Soil exchangeable Al status was significantly higher in the control.

Lime, dolomite or RHA applied as basal + 30 DAS gave higher net income and BCR while the control recorded the lowest net income and BCR.

Experiment II entitled "Standardization of nutrient management practices for rice in Vaikom Kari" was conducted during August to December 2015 and 2016 in farmers` fields in Thalayazham panchayat in Kottayam district. The experiment was laid out in RBD with 16 treatments (formulated based on the results of the Experiment

I) in three replications with rice var. Uma. The treatments were dolomite, lime + $MgSO_4$ or RHA + $MgSO_4$ along with 100% POP alone or with 100% POP + foliar spray of 13:0:45 (1%) or borax (0.5%) or 13:0:45 + borax at PI stage. Lime + $MgSO_4$ + 75% POP + 13:0:45 + borax as well as lime without $MgSO_4$ + 100% POP combined with 13:0:45 or borax or both were also included as treatments.

The treatments involving dolomite and lime with or without $MgSO_4$ produced taller plants, higher tiller number m^{-2} and higher LAI during both the years. Dolomite + POP + 13:0:45 produced the highest number of panicles m^{-2}. Higher test weight and lower sterility percentage were observed with dolomite + POP + 13:0:45 and dolomite + POP + 13:0:45 + borax. Higher grain yield of 5.42 and 5.57 t ha^{-1} during 2015 and 2016 respectively were produced by dolomite + POP + 13:0:45 followed by dolomite + POP + 13:0:45 + borax and lime + $MgSO_4$ POP + 13:0:45. Grain yield was significantly and positively correlated with LAI at MT and PI stages and with panicle number m^{-2}. Pooled analysis also proved the significance of the above treatments in producing higher grain yield. Lower yields were produced by the treatments involving RHA and 75% POP during both the years and in the pooled data. In general, higher straw yields were noticed with the treatments involving dolomite or lime along with foliar spray of 13:0:45 or 13:0:45 + borax. Higher dry matter production was noticed with dolomite + POP along with 13:0:45 or borax during first year and with dolomite + POP or lime + $MgSO_4$ + POP along with 13:0:45 or 13:0:45 + borax during second year.

In general, higher uptake of macronutrients and micronutrients was observed with dolomite or lime + $MgSO_4$ treatments along with 100% POP during both the years. Uptake of Na was the highest with RHA + $MgSO_4$ + POP + 13:0:45 during first year and with dolomite treatments during second year. Higher Al uptake was observed with lime + POP + 13:0:45 with or without $MgSO_4$. Significant and positive correlation of grain yield with uptake of P, K, Ca, Mg, S, Mn, Zn, Cu and B and negative correlation with Fe was observed during first year. During second year, the yield was significantly and positively correlated with uptake of nutrients except Na and Al.

The treatments involving dolomite, lime with or without $MgSO_4$ performed better in ameliorating soil acidity than RHA treatments during both the years. The treatments involving RHA showed higher EC values. All the treatments except those involving RHA helped in improving dehydrogenase enzyme activity in the soil during the cropping period. The initial soil organic carbon status was maintained during the cropping period due to nutrient management practices. Availability of N in the soil improved due to treatments involving dolomite + POP during seedling stage and due to those involving lime + POP without $MgSO_4$ at other stages. The treatments involving dolomite + POP and lime + POP with or without $MgSO_4$ recorded higher available P during all crop stages. In general, higher status of available K was registered by the treatments involving RHA or lime without $MgSO_4$. All treatments involving lime or dolomite registered higher soil available Ca and those involving dolomite or lime + $MgSO_4$ showed higher availability of Mg in the soil. In general, available S in the soil decreased from initial status during the cropping period. The treatments involving dolomite registered lower status of soil available Fe and higher status of available Mn and B. Higher status of available Zn was registered by the treatments involving dolomite or lime + $MgSO_4$. The treatments involving dolomite, lime + $MgSO_4$ or RHA + $MgSO_4$ along with POP registered higher available Cu in the soil. Dolomite treatments recorded lower status of Na and exchangeable Al in the soil. Soil pH was significantly and positively correlated with available P and significantly and negatively correlated with available Fe and exchangeable Al in the soil.

The economics of cultivation in terms of net income and BCR were the highest with dolomite + POP + 13:0:45 during both the years which was closely followed by dolomite + POP + 13:0:45 + borax. The treatments involving RHA and 75% POP registered lower net income and BCR.

The results of the study revealed the superiority of dolomite for ameliorating soil acidity in Vaikom Kari soil compared to lime or rice husk ash. Split application of dolomite as basal dose and at 30 DAS proved more effective than application as basal dose and one week prior to fertilizer application at panicle initiation stage. Soil acidity amelioration with dolomite @ 500 kg ha^{-1} (300 kg as basal dose and 200 kg ha^{-1} at 30 DAS) and soil application of 90:45:45 kg NPK ha^{-1} (full P as basal and N and K in three equal splits at 20 DAS, 35 DAS and PI stage) along with foliar spray of 13:0:45 (1%) or combined spray of 13:0:45 (1%) and borax (0.5%) at panicle initiation stage resulted in higher productivity and profitability from rice cultivation in Vaikom Kari soil.

സംഗ്രഹം

"വൈക്കം കരിനിലങ്ങളിലെ നെല്ലിൻെറ വിളവിനെ ബാധിക്കുന്ന പ്രശ്നങ്ങളെ നേരിടുന്നതിനായി മണ്ണിൻെറ അമ്ലത നിവാരണവും, സസ്യപോഷണരീതികളും" എന്ന വിഷയത്തിൽ വെള്ളായണി കാർഷിക കോളേജിൻെറ ആഭിമുഖ്യത്തിൽ കുട്ടനാട്ടിലെ വൈക്കം കരിനിലങ്ങളിൽ 2014 മുതൽ 2017 വരെയുള്ള കാലയളവിൽ രണ്ട് കൃഷിയിടപരീക്ഷണങ്ങൾ നടത്തുകയുണ്ടായി.

ഒന്നാമത്തെ പരീക്ഷണം "വൈക്കം കരിനിലങ്ങളിലെ മണ്ണിൻെറ അമ്ലത നിവാരണം", ഉമ എന്ന അത്യുൽപാദനശേഷിയുള്ള നെല്ലിനം ഉപയോഗിച്ച് നവംബർ 2014 മുതൽ മാർച്ച് 2015 വരെയുള്ള കാലയളവിൽ കോട്ടയം ജില്ലയിലെ കല്ലറ പഞ്ചായത്തിൽ നടത്തുകയുണ്ടായി. കുമ്മായം (ഹെക്റ്ററൊന്നിന് 600 കിലോഗ്രാം), ഡോളൊമൈറ്റ് (500 കിലോഗ്രാം) ഉമിച്ചാരം (500 കിലോഗ്രാം) എന്നീ മൂന്നു തരം കുമ്മായ വസ്തുക്കൾ രണ്ട് തവണകളായി (നിലം ഒരുക്കുന്ന സമയത്തും പിന്നെ വിതച്ച് മുപ്പതാം ദിവസത്തിലും അല്ലെങ്കിൽ മുന്നാം വളത്തിനു ഒരാഴ്ച്ച മുൻപായും) നൽകുന്നതിനോടൊപ്പം കുമ്മായവസ്തുക്കൾ ഇല്ലാത്ത ഒരു ട്രീറ്റ്മെൻറും ഉൾപ്പെടെ ഏഴു ട്രീറ്റ്മെൻറുകൾ മൂന്നു റെപ്ലിക്കേഷനുകളിലായി റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പരീക്ഷണ രീതി അവലംബിച്ച് പരീക്ഷിച്ചു. ഇവയിൽ ഏതെങ്കിലും ഒരു കുമ്മായവസ്തു നിലം ഒരുക്കുന്ന സമയത്തും പിന്നെ വിതച്ച് മുപ്പതാം ദിവസത്തിലും നൽകിയപ്പോൾ മികച്ച വിളവും, ആദായവും ലഭിച്ചു.

"വൈക്കം കരിനിലങ്ങളിൽ നെല്ലിന് സസ്യപോഷണരീതികൾ" എന്ന രണ്ടാമത്തെ കൃഷിയിടപരീക്ഷണം ആഗസ്റ്റ് മുതൽ ഡിസംബർ വരെ 2015ലും, 2016ലും തലയാഴം പഞ്ചായത്തിൽ നടത്തുകയുണ്ടായി. ഉമ നെല്ലിനം ഉപയോഗിച്ച് 16 ട്രീറ്റ്മെൻറുകൾ മൂന്നു റെപ്ലിക്കേഷനുകളിലായി റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈനിൽ പരീക്ഷിച്ചു. ഡോളൊമൈറ്റ്,

കുമ്മായം+മഗ്നീഷ്യംസൾഫേറ്റ് (ഹെക്റ്ററൊന്നിന് 80 കിലോഗ്രാം മണ്ണിൽ ചേർക്കൽ), ഉമിച്ചാരം+മഗ്നീഷ്യംസൾഫേറ്റ്, എന്നിവയ്ക്കൊപ്പം ഹെക്റ്ററൊന്നിന് 90:45:45 കിലോഗ്രാം എൻ.പി.കെ (ശുപാർശ ചെയ്തിട്ടുള്ള അളവിൽ) രാസവളങ്ങളും, അടിക്കണ പരുവത്തിനു മുൻപായി പത്രപോഷണത്തിനായി 1% വീര്യത്തിൽ 13:0:45, 0.5% വീര്യത്തിൽ ബൊറാക്സ് എന്നിവ ഒറ്റയ്ക്കോ, ഇവ രണ്ടുമൊരുമിച്ചോ നൽകിയും, പത്രപോഷണമില്ലാതെയും, പരീക്ഷിച്ചു. മഗ്നീഷ്യംസൾഫേറ്റ് ഇല്ലാതെ കുമ്മായവും, ഹെക്റ്ററൊന്നിന് 90:45:45 കിലോഗ്രാം എൻ.പി.കെ രാസവളങ്ങളും ഒപ്പം 13:0:45, ബൊറാക്സ് എന്നിവ ഒറ്റയ്ക്കോ, ഇവ രണ്ടുമൊരുമിച്ചോ പത്രപോഷണം നൽകിയും പരീക്ഷണം നടത്തി. കൂടാതെ, കുമ്മായം+മഗ്നീഷ്യംസൾഫേറ്റും, 13:0:45+ബൊറാക്സും പത്രപോഷണം നൽകിയതോടൊപ്പം ശുപാർശയുടെ 75% എൻ.പി.കെ രാസവളങ്ങൾ ഉൾപ്പെടുത്തിയും പരീക്ഷിച്ചു. ഇവയിൽ, ഹെക്റ്ററൊന്നിന് 90:45:45 കിലോഗ്രാം എൻ.പി.കെ രാസവളങ്ങളോടൊപ്പം ഡോളൊമൈറ്റ്+13:0:45 അല്ലെങ്കിൽ ഡോളൊമൈറ്റ്+13:0:45+ബൊറാക്സ് അല്ലെങ്കിൽ കുമ്മായം+മഗ്നീഷ്യംസൾഫേറ്റ്+13:0:45 എന്നീ ട്രീറ്റ്മെൻറുകൾക്ക് മികച്ച വിളവും, വർദ്ധിച്ച അറ്റാദായവും, വരവു ചിലവ് അനുപാതവും ലഭിക്കുകയുണ്ടായി.

വൈക്കം കരിനിലങ്ങളിൽ മണ്ണിൻെറ അമ്ലത നിവാരണത്തിനായി ഹെക്റ്ററൊന്നിന് 300 കിലോഗ്രാം ഡോളൊമൈറ്റ് നിലം ഒരുക്കുമ്പോഴും 200 കിലോഗ്രാം ഡോളൊമൈറ്റ് വിതച്ച് ഒരു മാസത്തിനു ശേഷവും മണ്ണിൽ ചേർത്ത് കൊടുക്കണം. മികച്ച വിളവും ആദായവും ലഭിക്കുന്നതിനായി ഹെക്റ്ററൊന്നിന് ശുപാർശ ചെയ്തിട്ടുള്ള എൻ.പി.കെ. രാസവളങ്ങൾ മണ്ണിൽ ചേർത്ത് കൊടുക്കുന്നതിനോടൊപ്പം 1% വീര്യത്തിൽ 13:0:45 മാത്രമോ, 0.5% വീര്യത്തിൽ ബൊറാക്സും കൂടി ചേർത്തോ അടിക്കണ പരുവത്തിന് മുൻപായി പത്രപോഷണം വഴി നൽകണമെന്ന് ശുപാർശ ചെയ്യാവുന്നതാണ്.

Appendices

APPENDIX Ia

Weather data during the cropping period of Experiment I (29 October 2014 to 25 March 2015)

Standard week	Temperature (^0C)		Rainfall (cm)	Relative humidity (%)		Bright sunshine (h)
	Maximum	Minimum		Maximum	Minimum	
44	31.6	23.1	18.2	89.6	50.7	5.4
45	31.9	23.1	49.7	93.7	54.0	5.3
46	32.5	22.8	56.9	89.0	61.8	6.3
47	31.9	23.1	5.2	91.2	65.6	5.4
48	28.9	22.9	1.7	92.9	83.7	5.6
49	32.4	22.3	0.2	91.6	64.9	6.2
50	31.8	22.5	14.9	95.3	77.7	6.5
51	32.1	22.6	18.5	90.7	80.5	7.2
52	32.1	23.1	0.7	87.0	63.5	7.9
1	32.2	21.5	0.3	93.9	61.5	5.9
2	31.7	21.4	-	89.1	62.0	6.2
3	31.7	20.5	-	86.4	47.7	6.7
4	32.0	21.7	-	90.0	54.7	6.7
5	32.6	21.6	-	92.8	61.7	6.4
6	32.3	22.4	-	92.2	68.7	5.5
7	32.2	22.3	-	92.4	75.2	5.6
8	32.9	22.3	-	93.5	79.7	5.6
9	33.6	22.7	2.0	93.7	86.4	8.8
10	33.9	23.2	19.0	92.8	85.3	6.7
11	33.6	22.9	45.2	93.9	80.7	6.1
12	33.9	23.3	-	92.8	76.0	8.9

APPENDIX Ib

Weather data during the cropping period of Experiment II (30 July to 31 December 2015)

Standard week	Temperature (^{0}C)		Rainfall (cm)	Relative humidity (%)		Bright sunshine (h)
	Maximum	Minimum		Maximum	Minimum	
31	31.6	23.3	27.8	92.2	64.5	6.7
32	31.7	23.0	58.6	91.0	70.2	6.0
33	32.0	23.0	54.6	91.8	54.1	6.3
34	32.3	23.5	40.3	90.1	72.9	4.6
35	32.7	23.7	1.4	90.3	67.7	7.4
36	32.0	23.4	42.0	91.1	76.1	6.2
37	31.8	22.7	59.5	89.3	72.1	5.7
38	32.2	23.1	91.5	88.4	77.0	4.3
39	32.8	22.6	146.9	90.9	74.1	3.1
40	30.1	22.8	97.1	91.1	83.4	4.4
41	31.7	23.1	115.3	92.6	77.9	4.4
42	32.7	23.4	7.7	91.5	66.6	7.9
43	31.8	23.2	65.9	91.4	76.3	5.3
44	31.5	22.9	62.6	90.1	71.3	5.8
45	32.6	23.0	58.6	92.3	77.4	6.8
46	32.7	23.2	10.5	92.1	70.6	7.2
47	33.2	23.2	24.9	90.9	70.4	6.0
48	33.5	23.0	18.0	88.0	72.0	7.6
49	32.6	23.0	27.4	90.0	76.0	7.0
50	32.9	23.0	22.6	92.5	70.0	7.6
51	32.7	22.3	3.4	90.4	71.4	6.5
52	32.6	20.7	-	89.5	73.5	8.1

APPENDIX Ic

Weather data during the cropping period of Experiment II (30 July to 31 December 2016)

Standard week	Temperature (^{0}C)		Rainfall (cm)	Relative humidity (%)		Bright sunshine (h)
	Maximum	Minimum		Maximum	Minimum	
32	32.2	22.1	31.7	89.7	73.7	4.3
33	32.0	21.7	11.8	90.3	74.6	4.8
34	31.9	21.9	44.0	89.7	73.4	4.8
35	31.6	22.2	15.2	92.6	76.3	6.5
36	31.7	21.9	5.0	91.9	79.0	7.8
37	32.0	22.0	3.0	89.6	75.6	7.8
38	32.0	21.7	17.0	90.0	76.7	7.3
39	32.0	21.0	28.7	90.1	78.1	7.7
40	31.6	21.7	2.1	89.4	80.1	7.9
41	32.5	21.2	44.0	90.0	75.0	7.1
42	32.4	21.3	22.3	91.6	76.6	7.8
43	31.7	21.4	96.0	91.4	78.1	7.2
44	32.3	21.4	59.2	92.4	73.3	8.1
45	33.1	21.7	-	90.7	65.7	7.5
46	32.4	20.8	-	89.9	66.6	8.0
47	32.6	20.8	-	90.3	71.1	7.5
48	31.2	20.8	0.8	87.3	73.4	6.5
49	33.0	21.7	-	91.4	64.9	7.4
50	32.9	20.9	-	90.4	63.3	7.5
51	32.8	20.0	-	90.6	63.4	8.5
52	33.2	20.8	-	90.3	58.5	7.7

APPENDIX II

Rating of nutrient availability in the soil

Nutrient	Deficiency	Sufficiency	Toxicity
Available N (kg ha^{-1})	<280	280-560	-
Available P (kg ha^{-1})	<10	10-25	-
Available K (kg ha^{-1})	<110	110-270	-
Available Ca (mg kg^{-1})	<300	>300	-
Available Mg (mg kg^{-1})	<120	>120	-
Available S (mg kg^{-1})	<5	5-10	-
Available Fe (mg kg^{-1})	<5	>5	>300
Available Mn (mg kg^{-1})	<1	>1	-
Available Zn (mg kg^{-1})	<1	>1	-
Available Cu (mg kg^{-1})	<1	>1	-
Available B (mg kg^{-1})	<0.5	>0.5	-
Available Na (mg kg^{-1})	<80	80-120	>160
Exchangeable Al (mg kg^{-1})	-	-	>120

Source: Venugopal *et al.* (2013)

APPENDIX III

Critical nutrient concentration in rice

Nutrient	Critical nutrient concentration			Critical level of toxicity
	Flag leaf	Straw	Grain	
N (%)	2.0 - 2.5	0.6 - 0.8	1.1	>1.0 % (straw)
P (%)	0.2 - 0.3	0.1 - 0.15	0.20	-
K (%)	1.4 - 2.0	1.5 - 2.0	0.29	-
Ca (%)	0.3 - 0.6	0.3 - 0.5	0.05	-
Mg (%)	0.15 - 0.3	0.2 - 0.3	0.15	-
S (%)	0.10 - 0.15	-	0.10	-
Fe (mg kg^{-1})	75 – 100	60 – 100	0.025	>300 (leaf blade)
Mn (mg kg^{-1})	40 – 700	50 – 150	0.01	>7,000 (shoot)
Zn (mg kg^{-1})	25 – 50	-	0.002	>1500 (straw)
Cu (mg kg^{-1})	7 – 15	-	0.004	>30 (straw)
B (mg kg^{-1})	6 – 15	15 – 18	0.01	>100 (straw)
Al (mg kg^{-1})	-	15 - 18 (shoot)	-	>300 (shoot)

Source: Dobermann and Fairhurst (2000)

APPENDIX IV

Score chart for stem borer (*Scirpophaga incertulas*) incidence

Scale	Dead hearts
0	No damage
1	1-10%
3	11-20%
5	21-30%
7	31-60%
9	61% and above

Source: IRRI (1981)

APPENDIX V

Cost of inputs and price of produce

Input	Cost (₹ unit^{-1})		
	Experiment I 2014	Experiment II 2015	Experiment II 2016
Paddy seed (kg^{-1})	40	40	40
Lime (kg^{-1})	6	6	6
Dolomite (kg^{-1})	4	4	4
RHA (kg^{-1})	2	2	2
Urea (kg^{-1})	6	6	6
Rajphos (kg^{-1})	10	10	10
Potash (kg^{-1})	16	17	12
$MgSO_4$ (kg^{-1})	-	120	120
Borax (kg^{-1})	-	200	200
13:0:45 (kg^{-1})	-	140	140
$CuSO_4$ (50 g^{-1})	25	25	25
Tiller charge (h^{-1})	500	500	500
Labour charge (man^{-1})	500	550	600
Fertera (4 kg^{-1})	950	950	950
Almix (8g^{-1})	200	200	200
Output	Minimum support price (₹ kg^{-1})		
Rice grain	19	21.5	22.5