CRITICAL ANALYSIS OF THE SOIL PLANT ATMOSPHERE CONTINUUM FOR INCREASING THE PRODUCTIVITY OF RICE IN LATERITIC SOILS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Critical analysis of the soil plant atmosphere continuum for increasing the productivity of rice in lateritic soils**" is a bona-fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis, entitled **"Critical analysis of the soil plant atmosphere continuum for increasing the productivity of rice in lateritic soils"** is a record of research work done independently by **Ms. M.S. Sailaja Kumari** 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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EXTERNAL EXAMINER

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Introduction

INTRODUCTION

Laterisation is a soil forming process occurring in the humid tropical climate with alternate wetting and drying conditions. Under appropriate drainage conditions silica and bases are removed and there is accumulation of less mobile constituents of iron, alumina and manganese. Laterite soils of the state often referred to as middle valley laterites occupy 23,500 km^2 of the land area of the state. It accounts for more than 60 per cent of the rice soils in Kerala. These soils are characterized by low pH, CEC, WHC and low status of nutrients and toxicity of Fe and Al.

Iron toxicity is a wide spread nutrient disorder that reduces the rice yields in rain fed and irrigated low land systems. Large amounts of ferrous ion in soil solution mobilized in situ or accumulated via interflow, cause iron toxicity symptoms in the lower leaves of rice plant as a result of uptake of excessive amount of Fe. The prerequisite for iron toxicity to occur is reduced state of the soil (soil redox potential less than 150 mv) and thus iron toxicity is exclusively a disorder of the wetland rice grown under rainfed and irrigated conditions. This disorder is complex because of the interactions with hydrology, availability and requirement of other plant nutrients and rice plant tolerance mechanism involved. About 42 percent of the rice paddies of India showed bronzing symptoms.

Laterite soils are potential soils which respond well to management practices. Reduction of Fe toxicity can be achieved by planting tolerant rice var and correcting multiple nutrient deficiencies. Low K often induces Fe toxicity in lowland rice while K fertilization alleviates this unfavourable condition. The experiments undertaken to find out factors limiting rice production in these soils have shown deficiency of P, K and Ca and toxicity of Fe, Al and Mn. The elements Fe and Mn in excess have some toxic effects on rice and it may affect absorption, translocation and metabolism of other elements affecting the yield expression of rice in lateritic soils. However the application of P, K and lime is reported to have reduced the toxicity problems of these elements and enhanced the rice yield. Gupta and Singh (1989) observed that the application of P repressed the toxic effects of Fe and Al resulting in increased yield. Sahu (1993) reported direct correlation between increasing dose of K application and decreasing intensity of Fe toxicity enhancing the yield. It is suggested that yield increased and Fe toxicity decreased by application of K at a level of 120 kg ha^{-1} or more (Bridgit, 1999). The role of lime in decreasing the Fe toxicity in soil as well as plant has been reported by Devi *et al.* (1996). Thus a study was undertaken in the lateritic soils to evaluate the feasibility of P, K and lime in correcting toxicities and deficiencies of nutrients, for sustained productivity. Experiments were conducted at two locations of Palakkad district for two seasons;

1. to find the role of P in decreasing the Fe toxicity problem
2. to find out the response of P levels on yield
3. to find out the role of K and lime in decreasing the Fe toxicity in soil and plant
4. to evaluate importance of K and lime in enhancing the rice yield potential
5. to fix the optimum dose of P, K and lime for maximum yield at the two locations viz. Koyalmannam and Ottappalam
6. to find the correlation pattern of nutrient ratios of soil and plant with yield
7. to evaluate the role of weather parameters on yield

Review of Literature

2. REVIEW OF LITERATURE

The problem of low yield expression in rice is of particular significance in lateritic soils of Kerala. Average yield of rice in the state is only 2032 kg ha^{-1}. The researches conducted have shown that rice yield can be improved through a balanced supply of nutrients particularly P, K and Ca. Back up of adequately supplied nutrients helps the plants in surviving under adverse situations of nutrient deficiencies and toxicities. Literature pertaining to this aspect is reviewed hereunder.

2.1 PHOSPHORUS

Phosphorous is one of the most crucial elements for crop production in general and for acid soils in particular. Phosphorous from native source itself is generally considered to be ample to meet the P requirement of rice crop grown under submerged condition. Submergence is known to increase the P availability through reduction. However response to P application by rice has been observed in all types of soils irrespective of initial available P contents. (Dedatta, 1983; Pillai *et al.*, 1986; Bhaskar *et al.*, 1998)

Phosphorous is associated with root development, active tillering, early flowering and ripening (Degeus, 1954). Verma (1960) observed marked increase in the rice yield with higher level of P application. Mahapatra (1961) obtained no response to P in the main seasons in Orissa. An excess of P over actual requirement was suggested to depress the rice yield (Russel, 1961). Very little effect of P on grain and straw yield was noted by Enyi (1964). Venkatachalam (1969) observed that grain yield as well as P uptake increased due to P application. Significant increase in number of productive tillers and a high test weight due to P nutrition was reported by Nair *et al.* (1972) and Gupta and Gautam (1988). Kalyanikutty and Morachen (1974) and Suseelan *et al.* (1977) have reported lack of any response to P application in rice tillering. Phosphorous manuring increases early tiller formation and stimulates early synchronous flowering (Bhattacharya and Chatterjee, 1978). A field study with rice in an iron toxic Haplaquent showed that grain yield could be increased by applying P fertilizer at 20 kg ha^{-1} (Sahu, 1993).

Davide (1960) reported that beneficial effects of flooding on phosphate availability depend on the intensity of reduction and on the iron content of soil. Kalam *et al.* (1966) reported that the magnitude of response to P was much lower than that of N due to high status of P in the soil. Patrick and Mahapatra (1968) observed that drying of soil decreased availability of P content since the P content depends up on the available moisture content. The status of soil P is changeable, it may vary significantly in a short time or with in a limited distance.

A combination of high P in presence of Mn in soil proved to reduce translocation of Fe to roots. Precipitation of manganese phosphate occurs at higher level of P (Vander and Van, 1979). Toxic effects of Fe and Al decreased by the application of phosphorous (Gupta and Singh, 1989). Rosmini and Mukhlis (1989) reported that increased levels of P offset iron toxicity. In a P deficient soil absorption of N and K decreased significantly and thus yield (Yoshida, 1981). Application of P was found to decrease the content of DTPA extractable Cu, Zn and Fe (Patra, 1981). Frageria *et al.* (1982) found that the content and uptake of N, P, K increased with higher level of P. Ismunadj and Ardjasa (1989) reported that Fe toxicity decreased and yield increased by P, K and Ca application. Alan and Azmi (1989) reported that P application increased the content of N, P, K, Cu, Mn and Fe and decreased P uptake. Munda and Patel (1989) found greater effect of P fertilizer on plant N, P and K uptake than K fertilizer. Potassium uptake was higher at the higher rate of P application. Increasing rates of each nutrient of N, P and K increased the yield and uptake of N, P and K in rice and wheat (Singh *et al.*, 1989).

2.2 POTASSIUM (K)

Potassium exists solely as K^+ ion either in solution or bonded to negatives. As a result of its strictly ionic nature K^+ has functions particularly related to the ionic strength of the solutions within the plant cells (Tisdale *et al.*, 1997). Potassium apparently does not form an integral part of any plant component and its function is catalytic in nature.

Potassium is indispensable for growth and grain production of rice. Tanaka *et al.* (1976) reported that rice plant was characterized by its high capacity of absorbing as well as exhausting K and thereby tended to maintain the K in a plant at a constant level. A positive response of rice to K application was observed by Su (1976).

Significant increase in rice plant height with increase in levels of K was observed (Vijayan and Sreedharan, 1972 and Venkatasubbiah *et al.*, 1982). Potassium application positively influence the yield attributes in rice. K absorbed at maximum tillering stage increases the number of panicles, spikelets per panicle and weight of grain (Su, 1976 and Mahapatra, 1983). Higher straw and gram yields were observed with increased K rates (Gurumani *et al.*, 1984 and Gosh *et al.*, 1994). Nadgoswami (1981) reported that K application increased the rice yield in lateritic soils under submergence and it was more in soils which were subjected to wetting and drying. According to Venkatasubbiah *et al.* (1982) K application increased grain and straw yield of rice but effect of K was more on grain yield compared to straw yield. Application of K @ 120 and 180 kg ha^{-1} significantly increased the panicle weight, filled grains per panicle and grain weight as compared to 60 kg K_2O ha^{-1}. The grain yield of rice increased with increase in level of K and the effect was linear up to 60 kg ha^{-1} of K_2O (Robinson and Rajagopalan, 1977). Significant increase in the yield of rice by the application of K_2O up to 80 kg ha^{-1} was observed by Agarwal (1980).

Mitra *et al.* (1992) reported that application of K could markedly increase rice yield of both iron tolerant and susceptible varieties. Potassium also decreased iron uptake by the rice plant and created a favourable environment for the absorption of other essential nutrients. Sahu (1993) reported a direct correlation between increasing K application and decreasing intensity of Fe toxicity symptoms. It is suggested that yield increased due to K application and Fe toxicity reduced by K application at a level of 120 $kgha^{-1}$ or more. According to Bridgit (1999) increasing levels of K significantly increased the height of the plant, grain weight and grain yield. However increasing the levels beyond 120 kg ha^{-1} did not have any significant effect.

Alvarenga and Lopa (1988) reported that available K and exchangeable Ca increased with K application in red latosol. Rajdhar (1989) studied the effect of K on the nutrient content. Increasing K concentration increased N, P and K contents but decreased Ca and Mg contents.

Ray and Choudhary (1980) found that K increased the rate of translocation of amino acids to the grain and rate of protein formation. Chakravorti (1989) indicated that grain N content and total N uptake was increased by the application of potassium while P content was little affected.

Applied K decreased Ca and Mg content in plants. N uptake was increased by increasing the application of K from 50 to 100 kg ha^{-1} (Reddy *et al.*, 1978). Datta and Gomez (1982) confirmed that response to P was more when K was applied. The total uptake of N, P and K by rice increased significantly with increasing levels of K (Singh and Singh, 1987). With increasing levels of K, K content and P content was increased while Fe content was decreased drastically indicating K-P synergism and K-Fe antagonism.

A consistent decrease in the Mn content with increase in K application has been reported by Randhawa and Pasricha (1976). According to Dixit and Sharma (1993) addition of K significantly reduced the concentration of Fe. Singh and Kumar (1993) conducted studies on K and Zn relationship in wheat and found that the effect of K and Zn concentration is antagonistic and Zn decreased significantly with K addition. Mandal *et al.* (1996) reported that K application caused an increase in Zn content in soil and the content and uptake of Zn increased with increase in K dose. This was attributed to the increase in water soluble plus exchangeable and organically bound forms of Zn in soil due to K application. Sreemannarayana and Sairam (1995) stated that increasing K levels decreased leaf Fe and Mn contents and increased leaf zinc. Bridgit (1999) reported that increased application of K in laterite soil increased the SiO_2 content in the grain and straw.

Muthuswamy *et al.* (1974) reported that K application increased the uptake of N, P and K by rice. Koch and Mengel (1977) showed the K application increased N uptake of rice and N content in grain. Turner and Barkus (1983) observed that increased K supply increased plant uptake of P while it reduced that of N, Ca, Mg and Cu. Singh and Singh (1987) observed that uptake of N, P and K by rice increased with increasing levels of K.

Baruah *et al.* (1996) observed that high Fe levels decreased N, P, K, Zn and Mn content and increased Fe and Cu contents. Sahrawat (1996) reported that application of N, P, K and zinc in the field decreased the uptake of Fe in rice and this can be a significant factor in the Fe toxicity tolerance of the cultivars.

2.3 CALCIUM

Calcium is a constituent of cementing materials of plant cells. Calcium maintains the turgidity of the cell wall and promotes normal root growth and development. Calcium stimulated the absorption of P and K (Tanaka, 1961; Jacobsen *et al.*, 1961) and accelerated more effectively the translocation of photosynthetic products compared to K and Mg. Kamprath (1967) envisaged lime requirement to overcome toxicities and deficiencies rather than raising the soil pH to neutrality. Application of lime increased the rice yield by rectifying the ill effects of Fe and Al (Sahu, 1968; Laskar, 1990 and Dixit and Sharma, 1993). Padmaja and Varghese (1972) reported an increase in grain and straw yield by the application of lime.

Devi *et al.* (1996) observed considerable reduction in Fe^{2+} concentration in soil as well as plant during the period of panicle initiation when lime was applied entirely as one top dressing @ 600 kg ha^{-1}. Lime application at this rate resulted in significantly higher grain and straw yield of rice as compared with 0, 300 or 900 kg lime ha^{-1}.

Role of lime in decreasing K content of rice has also been reported by so many workers (Mackey and Mac Eachern, 1962; Kalia *et al.*1969). However Mandal and Sinha (1968) could not find any effect of liming on availability of K content in acid red loam soils. Hati *et al.* (1979) reported that Ca did not show any significant influence on iron content of wheat and have negative relation on the availability of plant Mn and Fe. Marykutty (1986) found that Ca application though raised the pH could not bring down Fe content below the critical level of 300ppm in rice in laterite soils. Verma and Tripati (1987) reported that application of lime under flooded condition increased rice yield and increased Mn content and decreased Fe content. Liming of acid soil has been found to be beneficial in increasing the availability of phosphorous and repressing the toxic level of Al, Mn and Fe (Mongia and Bandyopadhyay, 1993; Hati *et al.*, 1979).

2.4 NUTRIENT INTERACTION

Two or more growth factors in combination can result in growth response that is greater than the sum of individual effects, then the interaction is positive and when the combined effect is less, the interaction is negative. Additivity indicates the absence of interaction, the recognition of the importance of nutrient balance in crop production is an indirect reflection of the contribution of the interactions to yield. The highest yields are obtained when nutrients and other growth factors are in a state of balance.

Bridgit (1999) reported that interactions are governed by concentrations of the elements and nature of ions. The influence of interactions at different stages also showed variations with growth phases and previous expressions. Antagonistic effects between mono and divalent cations are reported by Mathew (1993).

Manganese was found to antagonistically affect the content of Fe in both waterlogged and well drained conditions (Singh and Singh, 1975). Singh *et al.* (1978) suggested that the addition of Zn decreased the Mn and Fe concentration indicating the antagonistic effect of Zn on absorption of Mn and Fe by rice plants. Chavan and Banerjee (1980) also observed a decrease in the uptake of Zn with increase in content of Fe. Singh and Sakal (1983) observed that depressing effect of Fe was pronounced than that of Fe on Zn.

2.4.1 Interaction between P and K

Muthuswamy *et al.* (1974) indicated that potassium application was correlated with the uptake of N, P and K by rice. Similar reports were made by Chattopadhyay and Mallik (1977) and Sheela and Aravindakshan (1990) in banana.

Synergism between K and P and antagonism between K and Na was observed by Lahar (1972) in banana. Mello and Kaminski (1990) reported that while applying Ca and Mg as correctors of soil acidity, K and dry matter yield were not affected. But both increased with increase in rate of K applied.

Barber (1986) confirmed the antagonism between K and Ca as well as between K and Mg. Taharieva and Romheld (1991) reported antagonistic interactions between K and Ca, Mg and K and N on low calcareous soils. Yang (1992) observed antagonism by K and Mg while conducting a study on relationship between K and Mg and effect of N and K in different types of soils. Sindhu (1997) reported that in banana with increased level of K, nitrogen content decreased while P showed an increasing trend.

2.4.2 Interaction between K and Ca

Available K status of the soil decreased from a mean value of 85ppm to 39.7 ppm by the application of lime (Marykutty, 1986). Sudhir *et al.* (1987) reported that absorption of K is stimulated by Ca ions at low concentrations and decrease at high concentrations. Applied K decreased Ca and Mg content raised in alluvial soils (Chakravorti, 1989). Daliparthy (1994) reported that Mg or Ca deficiency occurs from ion antagonism in soils with the exchangeable K.

He (1968) observed a decrease in leaf calcium content by K application in banana. Fernandez *et al.* (1973) found that K was negatively correlated with Ca and Mg in all stages. Erdei and Zsoldos (1977) observed stimulatory effect of Ca on uptake of K. Kulkarni *et al.* (1991) while studying the interactions reported that an increase in Fe content of all cultivars was positively associated with Mn content of plant tissues, this association being most noticeable in Mashuri. It is suggested the involvement of Mn in oxidation of Fe may be one of the reasons for differential tolerance of rice cultivars to iron toxicity. Prabhakumari (1992) observed antagonistic relationship between K and Ca in coconut. Calcium and Mg were found to show a decreasing trend with increasing K in banana (Sindhu, 1997). Bridgit (1999) reported that Ca application narrowed K/Ca, K/Mn, K/Fe, K/Zn and K/Cu ratios in plants.

2.4.3 Interaction between P and Ca

Padmaja and Varghese (1972) observed an increase in phosphorous content of grain and straw by the application of Ca. Calcium stimulated the absorption of P and K. An increase in the available N and P content of soil by the application of graded levels of lime has been observed by Marykutty (1986). Synergestic relationship between P and Ca in coconut was reported by Prabhakumari (1992).

Increasing rates of each nutrient N, P and K increased the yield and uptake of N, P and K in rice and wheat (Singh *et al.*, 1989). The uptake on N, P, K, Ca and Mg by rice was significantly increased by liming and P addition (Prakash and Badrinath, 1995).

2.5 IRON IN PLANT NUTRITION

The importance of iron as an essential micronutrient for crops was recognized as early as in 1915.Its nutritional importance for the rice plant suggests one of the beneficial effects of submergence in the increased supply of iron. Rice is known to have a particular capacity to exclude Fe from its metabolic process by either preventing its absorption from the soil or by limiting its accumulation in roots. Ishizuka *et al.* (1961) noticed that Fe or Mn at 0.1 ppm was optimum for rice and above 40 ppm level they are toxic. The yield expression in rice is limited in lateritic soils due to their susceptibility to excess Fe (Bridgit *et al.*, 1993).

Patnaik and Bhadrachalam (1965) from nutrient solution studies found that luxury range for rice was 5-40 ppm and toxic range was above 40 ppm. VanBreemen and Moorman (1978) suggested that rice showed toxic symptoms when dissolved Fe in the rooting medium was in the range of 100-500 ppm range and at low nutrient levels of P and K. It is probably impossible to define a generally applicable critical Fe content in plant. Howeler (1985) reported that severity of Fe toxicity is related to low concentration of P, K and Zn in the plant.

Bulbule and Despande (1989) reported that tolerant varieties maintained high nutrient ratios of N/Fe, P/Fe, K/Fe, Mg/Fe, and Mn/Fe. They also stated that Fe absorption is related with multiple nutritional stress and resulting low P/Fe and K/Fe ratios lead to more serious yield reduction than Ca/Fe and Mg/Fe ratios.

2.6 EFFECT OF SEASONS AND RICE PRODUCTION

In the laterite soils of Kerala rice is grown in two seasons viz., virippu (April-May to September) and mundakan (August-September to December-January). Yields during the first crop are higher than second crop. Lower temperatures during flowering season, withdrawal of monsoon and dry spell in the reproductive phase during second crop have been suggested possible causes for lower yields. Choudhari and Ghildyal (1970) stated that low temperature delay maturity and facilitate better translocation to the ear head and more number of filled grains and grain weight. According to Alexander *et al.* (1990) weather components in the specific growth phases affect productive tillers per unit area, number of grains per panicle, weight of grains and sterility. At mean temperature of 27°C- 28°C sterility will be less according to Choudhari and Sodhi (1979). Rao (1993) reported that the number of days required for crop maturity is proportionately less if the maximum temperature is high.

Rainfall is an important weather parameter affecting crop growth and development of paddy. Pre-monsoon showers during April and May are very important for adequate germination and survival of paddy seedlings in the juvenile phase as paddy is a direct sown crop during kharif. 37 per cent yield variability during kharif can be explained by pre-monsoon and monsoon rain fall. Venkateswarlu *et al.* (1976) attributed higher yield in rabi to higher rainfall. Dry matter production and grain yield were reduced to 50% in wet season compared to dry season according to Sahu and Murty (1976). Lenka and Garnayak (1991) reported that there was an increase in yield corresponding to an increase in moisture content. But a negative correlation between yield and number of rainy days during maturity stage was reported by Viswambaran *et al.* (1989). Watanabe and Takeichi (1991) reported that sterility index increased linearly with increasing N rate and with increasing sunshine. Rice yield increased with increasing N, in the year with greater sunshine but yield increased and then decreased with N in the year with less sunshine.

Samui *et al.* (1998) reported that yield of rice decreases slowly as the sunshine hours during planting to harvesting increases from 300 to 450 h (beyond 450 h the fall is rapid) and there was a decrease in yield with increase in total rainfall during planting to maturity from 900 to 1100 mm. Malabuyue *et al.* (1993) reported that mean daily rainfall during reproductive growth, reproductive stage soil moisture tension and mean solar radiation during grain filling have the strongest effects on grain yield. Therefore, sowing date should be well timed so that panicle initiation and early reproductive growth coincide with periods of high rainfall. Yang and Yang (1994) reported that rice yield increased with increasing solar radiation and decreased with increased water stress but was not significantly affected by total sunshine hours or total rainfall. According to Pamplona *et al.* (1995), grain yield highly correlated with solar radiation and minimum temperature. A prediction model showed that high yield observed especially during dry season was not due mainly to higher solar radiation but also due to lower minimum temperature. Crop responsiveness to nitrogen fertilizer application could be associated with higher solar radiation. It is also reported that the amount of solar radiation received during the period before the harvest is very important on which final crop output depends if the other environmental factors are not limiting (Rao, 1993).

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Critical analysis of the soil plant atmosphere continuum for increasing the productivity of rice in lateritic soil" was carried out for two continuous seasons in Palakkad district of Kerala. The experimental site was selected in such a way that maximum variation in the productivity of rice was observed in the selected sites. Ottappalam and Koyalmannam were the two locations selected for the study and both belong to laterite belt. The materials used and methodology adopted for the study is described hereunder. Soil samples were collected from the two sites and analyzed for the basic characteristics before starting the experiment and the data are presented in the table 3 and table 4.

3.1 CROPPING HISTORY OF THE EXPERIMENTAL SITE

The farmers at Koyalmannam and Ottappalam used to take two crops of paddy and the area belongs to typical double cropped wet land. The farmer of Koyalmannam area selected for the study used to apply farm yard manure and green manures in his field. Manures were mixed and puddled into the field just before transplanting. On the other hand, at Ottappalam the farmer used only nitrogenous fertilizer i.e., urea and no other fertilizers were applied owing to the high costs.

3.2 EXPERIMENTAL METHODS

The experiment was carried out during the first and second crop seasons of 2000-2001 with variety Jyothi. The experiment was laid out in RBD with fifteen treatments in $2^2 \times 3 + 3$ combination with three replications. The plot size was 5 m x 4 m and the spacing adopted was 15 cm x 10 cm. The treatment details are as follows.

Table. 1 Treatment Details

Levels of phosphorus	:2
P_1	17.5 kg ha^{-1}
P_2	35 kg ha^{-1}
Levels of potassium	:3
K_1	35 kg ha^{-1}
K_2	70 kg ha^{-1}
K_3	105 kg ha^{-1}
Levels of lime	:2
L_1	300 kg ha^{-1}
L_2	600 kg ha^{-1}
Controls	:3
C_1	NPK + FYM as per POP of KAU (70:35:35: + 5t FYM) ha^{-1}
C_2	NPK + FYM + lime as per POP of KAU (70:35:35 + 5t FYM + 600 kg lime) ha^{-1}
C_3	Farmers' practice – Nitrogenous fertilizer only

Two crops of rice for the virippu and mundakan season were taken at Koyalmannam and Ottappalam simultaneously with the same treatments and cultivation practices. Date of planting and harvest at the two sites are as follows.

Table 2. Details of the crop

Details	Koyalmannam		Ottappalam	
	First crop	Second crop	First crop	Second crop
Date of sowing	10/6/2000	4/11/2000	8/6/2000	6/11/2000
Date of harvest	30/9/2000	26/2/2001	26/9/2000	22/2/2001

Nitrogen was applied uniformly in all the treatments @ 70 kg ha^{-1} as per POP of KAU (KAU, 1996). Phosphorus, potassium and lime were applied as per the treatments. Nitrogen, phosphorus and potassium were supplied through urea, Rajphos

Fig. 1. Lay out of the experimental plots at Koyalmannam N

R1

$P_2K_3L_1$	$P_1K_1L_1$	$P_2K_2L_1$
$P_1K_2L_1$	$P_2K_1L_1$	$P_1K_3L_1$
$P_2K_3L_2$	$P_1K_1L_2$	C_2
$P_1K_2L_2$	$P_2K_1L_2$	$P_1K_3L_2$
C_1	$P_2K_2L_2$	C_3

R2

$P_2K_2L_1$	$P_2K_3L_1$	$P_2K_1L_1$
$P_1K_3L_1$	C1	$P_1K_3L_1$
$P_1K_3L_2$	$P_1K_1L_2$	$P_1K_2L_2$
$P_2K_3L_2$	$P_2K_2L_2$	$P_2K_1L_2$
$P_1K_2L_1$	C2	C3

R3

$P_2K_3L_1$	$P_1K_2L_1$	$P_1K_3L_1$
P_2K_1L1	$P_2K_2L_1$	P_2K_3L1
$P_1K_1L_2$	$P_1K_2L_2$	P_1K_3L2
$P_2K_1L_2$	$P_2K_2L_2$	P_2K_3L2
C_1	C_2	C_3

Fig. 2. Lay out of the experimental plots at Ottappalam

N ↑

$P_2K_1L_2$	$P_1K_3L_1$	$P_1K_3L_2$
C_1	$P_2K_1L_1$	$P_1K_2L_2$
$P_2K_3L_1$	**$P_1K_2L_1$**	**$P_2K_2L_2$**
P_2K_1L1	$P_2K_3L_1$	C1
$P_1K_1L_2$	$P_2K_2L_1$	C3
P_1K_3L2	$P_1K_3L_1$	$P_2K_2L_1$
P_2K_3L1	C3	$P_2K_3L_1$
$P_1K_3L_1$	C2	$P_1K_1L_2$
P_2K_3L2	$P_2K_3L_2$	$P_2K_1L_1$
C_3	$P_2K_2L_2$	$P_1K_3L_1$
$P_1K_2L_1$	C1	$P_1K_2L_1$
$P_2K_2L_1$	$P_2K_1L_2$	$P_1K_3L_1$
$P_1K_2L_2$	$P_1K_2L_2$	C2
$P_2K_2L_2$	$P_1K_1L_2$	$P_2K_3L_2$
C_2	$P_1K_3L_2$	$P_2K_1L_2$
R1	**R2**	**R3**

and muriate of potash which contained 46, 20 and 60 percent N, P, K respectively. Lime was applied through burnt lime.

Land preparation, cultivation practices and plant protection measures were done as per POP of KAU. FYM and half the quantity of lime were applied in the field five days prior to transplanting. The full quantity of phosphorus, half the quantity of nitrogen and half the quantity of potassium were applied as basal dressing. Twenty two days old rice seedlings of variety "Jyothi" were transplanted in the field at a spacing of 15 cm x 10 cm @ 2-3 seedlings per hill. Half the quantity of lime was applied one month after transplanting. The remaining quantity of nitrogen and potassium were applied as top dressing one week prior to panicle initiation.

The crop was harvested at maturity. Threshing was done on the same day and yields were recorded. Dry weight of grain and straw were recorded .

3.3 OBSERVATIONS RECORDED

3.3.1 Weather parameters

Observations on weather parameters like maximum temperature, minimum temperature, humidity, sunshine hours and rainfall were recorded for Ottappalam area from Pattambi observatory and data for Koyalmannam area was collected from Alathur observatory.

3.3.2 Biometric observations and Yield parameters

Observations on biometric characters like plant height, number of tillers per hill at critical stages viz, maximum tillering stage (MT stage), panicle initiation stage (PI stage), flowering stage (Flg stage) and harvest stage were recorded. Yield contributing characters viz., thousand grain weight and number of grains per panicle after harvest and grain yield and straw yield on dry weight basis were also recorded.

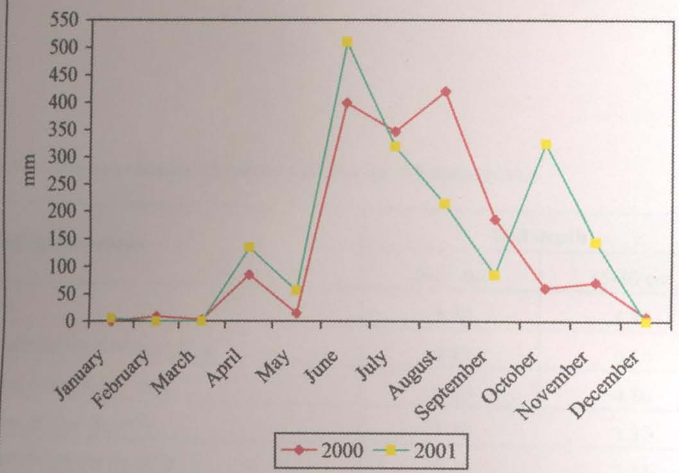

Fig. 3. Monthly average rainfall (Koyalmannam)

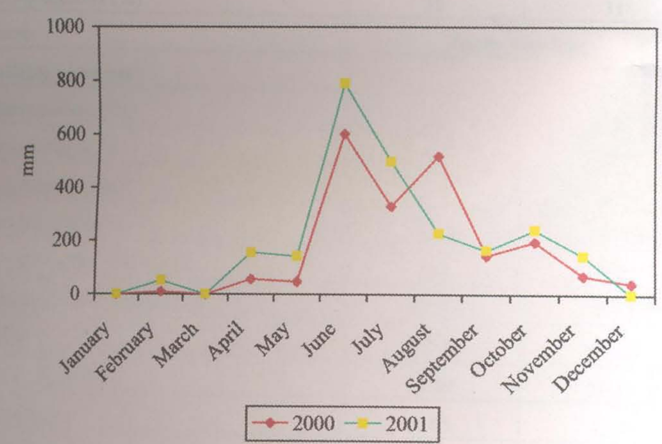

Fig. 4. Monthly average rainfall (Ottappalam)

Table 3. Physico-chemical characteristics of soils of Koyalmannam

Soil characteristics	Soil depth	
	0-15 cm	15-30 cm
pH	5.10	4.85
Electrical conductivity (dS m^{-1})	0.12	0.10
CEC (cmol(+) kg^{-1} soil)	5.20	4.80
Bulk density (kg m^{-3})	1.36	1.37
Particle density (kg m^{-3})	2.43	2.45
Porosity (%)	45.23	43.50
Water holding capacity (%)	41.30	39.80
P fixing capacity (%)	48	49
K fixing capacity (%)	30	31
Texture	Sandy clay loam	
Available nutrients		
Organic carbon (%)	0.68	0.52
Nitrogen (kg ha^{-1})	202.84	217.50
Phosphorus (kg ha^{-1})	13.20	15.50
Potassium (kg ha^{-1})	169.50	165.32
Calcium (cmol(+) kg^{-1} soil)	0.28	0.22
Magnesium (cmol(+) kg^{-1} soil)	0.20	0.18
Iron (ppm)	275.00	302.60
Manganese (ppm)	19.59	21.42
Zinc (ppm)	1.05	0.80
Copper (ppm)	0.94	1.00

Table 4. Physico-chemical characteristics of soils of Ottappalam

Soil characteristics	**Soil depth**	
	0-15 cm	15-30 cm
pH	4.90	4.65
Electrical conductivity (dS m^{-1})	0.155	0.148
CEC (cmol(+) kg^{-1} soil)	4.40	4.60
Bulk density (kg m^{-3})	1.32	1.32
Particle density (kg m^{-3})	2.48	2.49
Porosity (%)	46.80	42.50
Water holding capacity (%)	44.32	41.10
P fixing capacity (%)	44	42
K fixing capacity (%)	33.5	35.2
Texture	Sandy clay loam	
Available nutrients		
Organic carbon (%)	0.52	0.48
Nitrogen (kg ha^{-1})	265.30	221.20
Phosphorus (kg ha^{-1})	18.50	17.80
Potassium (kg ha^{-1})	128.00	134.50
Calcium (cmol(+) kg^{-1} soil)	0.35	0.30
Magnesium (cmol(+) kg^{-1} soil)	0.19	0.15
Iron (ppm)	263.40	206.60
Manganese (ppm)	22.76	23.66
Zinc (ppm)	1.47	1.33
Copper (ppm)	0.98	0.80

3.3.3 Chemical analysis

3.3.3.1 Soil analysis

Before starting the experiment soil samples were collected at two depths from the experimental site and analyzed for the basic physical and chemical properties like pH, EC, CEC, bulk density, particle density, water holding capacity, porosity, P fixing capacity, K fixing capacity, soil texture and available, macro and micro nutrients (Tables 3 and 4). Soil samples were collected from different treatments at critical stages and after harvest and analyzed for macro and micro nutrients. The methods used for soil analysis is given in table 5.

3.3.3.2 Plant analysis

Plant samples collected from different treatments at critical stages were oven dried, powdered and analyzed for N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and Si. The methods used for plant analysis is given in table 6.

3.3.4 Statistical analysis

The data were subjected to the analysis of variance technique (Panse and Sukhatme, 1978). Pooled analysis of the yield data was also done.

Table 5. Methods used for soil chemical analysis

Sl.No	Analysis	Method	Reference
1	Soil reaction (pH)	Soil water suspension 1:2.5 and read in pH meter - Elico	Hesse, 1971
2	Electrical conductivity (EC)	Soil water suspension 1:2.5 and read in digital conductivity bridge	Jackson,1958
3	Organic carbon	Walkely - Black method	,,
4	Available N	Alkaline permanganate method	Subbiah and Asija, 1956
5	Available P_2O_5	(Bray method) Ascorbic acid reduced molybdophosphoric blue colour method	Watnabe and Olsen, 1965
6	Available K_2O	Neutral Normal Ammonium acetate extract using flame photometer method	Jackson,1958
7	Exchangeable Ca	Neutral Normal Ammonium extract Using Atomic Absorption Spectrophotometer	,,
8	Exchangeable Mg	,,	,,
9	Available Fe	DTPA extract method using Atomic Absorption Spectrophotometer	Lindsey and Norvell, 1978
10	Available Mn	,,	,,
11	Available Zn	,,	,,
12	Available Cu	,,	,,

Table 6. Methods used for plant nutrient analysis

Sl. No.	Nutrient	Method	Reference
1	Nitrogen	Microkjeldhal digestion and distillation method	Jackson, 1958
2	Phosphorus	Vanadomolybdophosphoric yellow colour method using Spectronic 20	,,
3	Potassium	Diacid extract using flame photometer	
4	Calcium	Diacid extract using Atomic Absorption Spectrophotometer	
5	Magnesium	,,	Jackson, 1958
6	Iron	,,	,,
7	Manganese	,,	,,
8	Zinc	,,	,,
9	Copper	,,	,,
10	Silicon	Rapid Micro determination of silicon	Nayar *et al.*, 1975

Results

4. RESULTS

Field experiments were conducted at two locations of Palakkad district viz, Koyalmannam and Ottappalam to evaluate the pattern of influence of various levels of P, K and lime on the nutrient content of soil and plant and hence the yield. The results of the experiments are presented hereunder.

4.1 FIRST CROP OF RICE AT KOYALMANNAM AND OTTAPPALAM

4.1.1 Yield and growth attributes of rice

4.1.1.1 Effect of treatments on growth attributes of rice at Koyalmannam

Effect of P, K, lime and controls on plant height and number of tillers per hill are given in table 7.

Effect of P

Phosphorus application at two levels significantly influenced the plant height at flowering stage and tillers per hill at panicle initiation stage. Both increased significantly with increase in P level.

Effect of K

The plant height at maximum tillering, panicle initiation and at harvest stage increased significantly when the K dose increased from 70 kg ha^{-1} to 105 kg ha^{-1}. However application of K at 35 kg ha^{-1} and 70 kg ha^{-1} made no significant difference in the plant height at these stages.

The tillers per hill showed significant difference at various levels of K application at all stages except flowering stage. At panicle initiation stage significant increase was observed at K_3 compared to K_1. The number of tillers per hill increased significantly at K_2 level compared to K_1 and K_2 was on par with K_3 at the final stage of harvest.

Table 7 Effect of treatments on growth attributes of rice (Koyalmannam)

Treatments	Plant height (cm)				Tillers/hill (No.)		
	MT	PI	Flg	Harvest	PI	Flg	Harvest
Levels of Phosphorus							
P_1	31.67	50.43	73.36	72.78	4.36	4.50	4.94
P_2	32.83	53.87	75.56	70.92	4.80	4.84	5.35
CD (0.05)	NS	NS	1.89	NS	0.40	NS	NS
Levels of Potassium							
K_1	30.97	50.73	73.46	70.21	4.28	4.47	4.42
K_2	31.55	51.64	74.59	70.49	4.63	4.71	5.24
K_3	34.22	54.08	75.33	74.89	4.82	4.82	5.77
CD (0.05)	1.66	3.01	NS	2.53	0.50	NS	0.60
Levels of Lime							
L_1	32.14	50.58	72.38	70.10	4.70	4.30	4.77
L_2	32.36	53.17	76.54	73.60	4.45	5.04	5.52
CD (0.05)	NS	NS	1.89	2.06	NS	0.42	0.49
Controls							
C_1	27.80	54.52	74.60	71.30	4.08	4.40	4.13
C_2	31.73	50.09	72.00	75.50	4.95	5.66	5.10
C_3	30.00	49.79	77.00	74.06	3.53	3.68	3.58
CD (0.05)	3.32	NS	NS	NS	1.05	0.91	1.2

Effect of lime

Lime application at 600 kg ha^{-1} increased plant height and tillers per hill at flowering and harvest stage (Table 7).

Effect of controls

Between the control treatments C_2 (POP) showed the highest value for plant height at maximum tillering stage which was on par with C_3 and significantly higher than C_1.

All stages showed significant difference between the control treatments for the tillers per hill. In all the stages C_2 (POP) recorded the highest value for the tillers per hill and it was significantly superior to C_3.

4.1.1.2 Yield and yield attributes of rice at Koyalmannam

Effect of treatments on yield and yield attributes of rice is given in the table 8.

Effect of P

Yield and yield attributes were not significantly influenced by the two levels of P.

Effect of K

Graded levels of K application significantly influenced the yield and yield attributes in rice. Application of K at 70 kg ha^{-1} significantly increased the number of grains per panicle over K application at 35 kg ha^{-1} and K_2 was on par with K_3. The thousand grain weight showed a significant increase at K_3 to the tune of 9.8 per cent over K_1. K_2 was on par with both K_1 and K_3.

The grain yield and straw yield were significantly increased at K_2 level by 9.5 per cent and 20.45 per cent respectively over K_1 while K_2 was on par with K_3 for both grain and straw yield.

Table 8. Yield and yield attributes of rice (Koyalmannam)

Treatments	Grains/ Panicle (no.)	1000 grain wt (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{1})
Levels of Phosphorus				
P_1	84.06	26.07	3555	3315
P_2	80.06	26.75	3733	3115
CD (0.05)	NS	NS	NS	NS
Levels of Potassium				
K_1	75.25	25.08	3444	2919
K_2	89.92	27.55	3771	3516
K_3	81.00	26.61	3717	3164
CD (0.05)	6.50	1.71	207.50	457.20
Levels of Lime				
L_1	80.06	25.55	3296	3038
L_2	84.60	27.27	3592	3391
CD (0.05)	NS	1.39	169.42	313.40
Controls				
C_1	79.66	23.76	3410	2400
C_2	82.00	25.66	3680	2720
C_3	69.00	24.86	2996	2740
CD (0.05)	12.05	NS	348.90	NS

Table 9 Effect of P and K on yield and yield attributes of rice (Koyalmannam)

Treatment	Grains/panicle (no.)			1000 grain weight (g)			Grain yield (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	74.83	88.00	89.33	24.25	25.92	28.05	3180	3516	3968
P_2	75.67	91.83	72.67	25.90	29.17	28.17	3708	4026	3466
CD (0.05)	9.20			2.41			293.46		

Effect of lime

Lime application at two levels did not differ in their influence significantly on the number of grains per panicle. But the application of lime at higher level significantly increased the thousand grain weight and grain yield to the extent of 6.7 per cent and 8.4 per cent respectively over the lower level of lime application. The straw yield was increased by 11.6 per cent by lime application at 600 kg ha^{-1}.

Effect of controls

Among the control treatments, the C_2 (POP) recorded the maximum number of grains per panicle (82) and grain yield (3450 kg ha^{-1}). C_2 was significantly superior to C_3 for the number of grains per panicle and grain yield by 15.8 per cent and 11.3 per cent respectively. C_1 was on par with C_2 for yield and yield attributes of rice. The thousand grain weight and straw yield remained unaffected by the control treatments.

4.1.1.3 Interaction effects on yield and yield attributes of rice

Interaction effect of P and K on yield and yield attributes is given in the table 9.

Interaction between P and K

Phosphorus and K interacted significantly to influence the grains per panicle, 1000 grain weight and grain yield.

At P_1 when potassium was increased from 35 kg ha^{-1} to 70 kg ha^{-1}, grains per panicle increased significantly and no further change occurred on further increase in the dose of K. At P_2 also trend was same when K was increased from 35 kg ha^{-1} to 70 kg ha^{-1} where as when it was increased to 105 kg ha^{-1} the grains per panicle decreased.

At P_1, increased dose of K from 35 kg ha^{-1} to 105 kg ha^{-1} increased 1000 grain weight whereas at P_2 level 70 kg ha^{-1} of K increased 1000 grain weight over that of 35 kg ha^{-1}. Further increase in dose of K did not affect this character. Response to P in 1000 grain weight was observed only when K was applied at 70 kg ha^{-1}

At P_1, with increase in K dose the grain yield significantly increased. But at P_2 increasing the application of K from 70 kg ha^{-1} to 105 kg ha^{-1} decreased the grain yield. Similarly increased application of P resulted in increased grain yield at 35 kg ha^{-1} and 70 kg ha^{-1} of K.

Interaction between P and lime

Interaction between P and lime influenced the tillers per hill. An increase in the number of tillers per hill was observed at P_1L_2 and P_2L_1 to the tune of 18 per cent and 35 per cent respectively compared to P_1L_1. However P_2L_2 registered a decrease in the tillers per hill compared to P_2L_1.

4.1.1.4 Effect of treatments on growth attributes of rice at Ottappalam

Effect of P, K, lime and controls on plant height and number of tillers per hill is given in the table 10.

Effect of P

Among the growth characters studied, application of P at 35 kg ha^{-1} significantly increased the plant height at maximum tillering stage, panicle initiation and flowering stage compared to P application at 17.5 kg ha^{-1}. The two levels of P failed to differentiate significantly the productive tillers per hill.

Effect of K

Different levels of K application significantly influenced the plant height and tillers per hill. At maximum tillering stage, plant height increased from K_1 to K_2 and no significant difference was observed between K_2 and K_3.

At panicle initiation stage plant height decreased significantly from K_1 to K_2 and K_2 was on par with K_3. But at harvest stage, no significant difference was observed among the three levels of K.

Table 10. Effect of treatments on growth attributes of rice (Ottappalam)

Treatments	Plant height (cm)				Tillers/hill (no.)		
	MT	PI	Flg	Harvest	PI	Flg	Harvest
Levels of Phosphorus							
P_1	35.36	55.46	74.18	76.01	5.15	5.17	5.06
P_2	36.37	60.99	76.99	75.88	4.78	5.31	5.30
CD (0.05)	0.65	1.54	2.32	NS	NS	NS	NS
Levels of Potassium							
K_1	35.11	58.73	72.03	76.00	4.63	4.92	4.92
K_2	36.48	57.52	78.93	76.08	4.86	5.60	5.43
K_3	36.44	58.42	76.00	75.74	5.41	5.19	5.19
CD (0.05)	0.80	1.08	2.83	NS	0.53	0.47	0.43
Levels of Lime							
L_1	36.47	58.56	74.41	76.73	4.75	5.12	4.93
L_2	35.55	57.89	76.77	75.16	5.19	5.35	5.43
CD (0.05)	0.65	NS	NS	NS	0.40	0.39	0.35
Controls							
C_1	31.06	47.66	74.70	74.60	4.60	5.10	4.93
C_2	32.90	49.43	77.13	75.33	4.80	5.28	5.28
C_3	35.03	54.06	77.90	74.00	3.60	3.60	3.69
CD (0.05)	1.60	3.77	NS	NS	NS	0.95	0.87

Application of K significantly influenced the tillers per hill at panicle initiation, flowering and harvest stage. At flowering and harvest stage, number of tillers steadily increased from K_1 to K_2 and beyond K_2 it decreased.

Effect of lime

The two levels of lime application showed significant difference in plant height at maximum tillering stage only and it decreased with increasing level of lime. However the productive tillers per hill varied significantly at all stages with the two levels of lime application. There was a significant increase in the number of tillers at 600 kg ha^{-1} of lime application compared to lower level of lime application.

Effect of controls

There was significant difference in the plant height between the control treatments at maximum tillering stage and panicle initiation stage. Maximum plant height was observed in C_3 (farmer's practice) at these stages. C_3 was significantly different from C_2 and C_1 was on par with C_2 for the plant height at these stages.

There was significant difference between the control treatments for the productive tillers per hill at flowering and harvest stage and C_2 (POP) was significantly superior to C_3 (the farmer's practice) for the productive tillers per hill.

4.1.1.5 Yield and yield attributes of rice at Ottappalam

Effect of P, K, lime and controls on yield and yield attributes of rice is given in the table 11.

Effect of P

There was no response for the higher level of P application on yield and yield contributing parameters.

Effect of K

The different levels of K application significantly influenced the yield and yield attributes. There was higher number of grains per panicle at K_2 compared to K_1.

Table 11 Yield and yield attributes of rice (Ottappalam)

Treatments	Grains/panicle (no.)	1000 grain wt (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Levels of Phosphorus				
P_1	90.56	28.72	3758	3651
P_2	88.33	28.71	3552	3872
CD (0.05)	NS	NS	NS	NS
Levels of Potassium				
K_1	83.92	26.96	3383	3225
K_2	91.42	30.41	3725	4189
K_3	93.00	28.78	3858	3871
CD (0.05)	3.52	1.21	312	374
Levels of Lime				
L_1	87.44	28.08	3531	3899
L_2	91.40	29.36	3880	3624
CD (0.05)	2.87	0.99	255	NS
Controls				
C_1	83.33	25.11	3273	3046
C_2	84.00	25.86	3583	3216
C_3	69.66	23.00	2866	2206
CD (0.05)	NS	2.43	295	762

Table 12.Effect of P and lime with K on yield and yield attributes of rice

Treatment	1000 grain weight (g)		Straw yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	L_1	L_2	P_1	P_2	P_1	P_2
K_1	25.26	28.67	3200	3250	3275	3491
K_2	30.05	30.78	3820	4558	4010	3650
K_3	28.92	28.64	3883	3860	4000	3716
CD (0.05)	1.72		329.40		441.00	

Application of K at 70 kg ha^{-1} increased the thousand grain weight by 12 per cent compared to K application at 35 kg ha^{-1}.

The grain yield was increased significantly from K_1 to K_2 by 10 per cent and beyond K_2 the increase in grain yield was not significant. The straw yield increased significantly at K_2 to the extent of 29 per cent over K_1.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased thousand grain weight and grains per panicle to the extent of 4.5 per cent over application of lime at 300 kg ha^{-1}.

Similarly higher level of lime application significantly increased the grain yield by 13.0 per cent compared to lower level of lime application while the straw yield remained unaffected by higher level of lime application.

Effect of controls

Among the control treatments C_2 (POP) recorded the highest value for thousand grain weight and it was significantly superior to C_3 (the farmer's practice) and on par with C_1 (POP without lime).

Grain yield and straw yield were significantly higher in C_2 (POP) compared to C_3 (the farmer's practice). C_1 was on par with C_2 and significantly superior to C_3 for grain yield and straw yield.

4.1.1.6 Interaction effect on yield and yield attributes of rice

Interaction between P and K

The grain yield and straw yield were significantly influenced by the combined application of P and K (Table 12). Increasing the K dose to 70 kg ha^{-1} in the presence of 17.5 kg ha^{-1} of P increased the grain yield (4010 kg ha^{-1}).

Maximum straw yield (4558 kg ha^{-1}) was obtained by the combined application of 35 kg ha^{-1} of P and 70 kg ha^{-1} of K (P_2K_2) and the straw yield at this level was significantly superior to all other combinations of P and K. Highest yield obtained at P_2K_2 showed and 42 per cent increase over the lowest yield obtained at P_1K_1 .It was superior to POP and farmer's practice.

Interaction between K and lime

Lime application at 600 kg ha^{-1} in presence of 35 kg ha^{-1} of K significantly increased thousand grain weight by 21 per cent compared to K_1L_1 (Table 12).

4.1.2 Elemental composition of rice

4.1.2.1.1 Elemental composition of rice at MT stage at Koyalmannam

The effects of different levels of P, K, lime and controls on the elemental composition of rice are presented in table 13.

Effect of P

As seen in the table it was observed that application of P at 17.5 and 35 kg ha^{-1} produced no significant difference in the elemental composition of rice except Mn and Si. The content of Mn in rice was significantly increased at higher level of P application. On the other hand a decrease was observed in the silica content of rice.

Effect of K

Application of K at 105 kg ha^{-1} significantly increased the N, K and Zn content of the plant. But there was a decrease in the Mn content of the plant with increase in K levels applied. Highest content of N, K and Zn in the plant was recorded at K_3 which was significantly superior to the lower levels.

The Mn content at K_2 and K_3 level was significantly lower than the content of Mn at K_1 level. The highest content of Si was observed at K_2 level which was significantly superior to lower and higher levels of K application.

Table 13 Elemental composition of rice at MT stage (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	2.33	0.330	2.99	0.110	0.13	3580	516.00	37.42	12.52	2.27
P_2	2.33	0.330	2.91	0.110	0.13	3574	537.00	37.33	12.76	2.23
CD (0.05)	NS	NS	NS	NS	NS	NS	8.90	NS	NS	0.02
Levels of Potassium										
K_1	2.32	0.340	2.88	0.100	0.140	3508	539.00	35.75	12.57	2.23
K_2	2.30	0.330	2.94	0.110	0.130	3562	524.25	37.71	12.23	2.29
K_3	2.37	0.320	3.03	0.110	0.120	3662	518.73	38.68	13.13	2.23
CD (0.05)	0.04	NS	0.07	NS	NS	NS	10.90	0.57	NS	0.03
Levels of lime										
L_1	2.30	0.330	3.02	0.100	0.120	3682	528.71	36.63	12.59	2.26
L_2	2.36	0.320	2.88	0.120	0.140	3472	525.98	38.13	12.70	2.24
CD (0.05)	0.03	NS	NS	0.010	0.008	109	NS	NS	NS	NS
Controls										
C_1	2.30	0.290	3.12	0.094	0.163	3409	556.56	35.06	12.03	2.23
C_2	2.36	0.310	3.01	0.097	0.169	3320	554.06	36.13	12.66	2.23
C_3	2.19	0.320	2.87	0.082	0.103	3539	492.3	34.30	12.46	2.43
CD (0.05)	NS	NS	0.14	0.030	0.021	108	21.95	1.15	NS	NS

Effect of lime

Application of lime @ 600 kg ha^{-1} increased the plant content of N, Ca, Mg and Zn while the Fe content showed a decreasing trend with increase in lime rate and the decrease was to the tune of 6 per cent at higher level.

Effect of controls

Perusal of the data in the table 13 shows that there exists a significant difference between the controls for the K, Ca, Mg, Mn and Zn content at maximum tillering stage. The highest content of Ca, Mg and Zn was recorded by C_2 (POP) followed by C_1 (POP without lime). The C_3 (farmers practice) recorded the lowest content of Mg and Ca. The highest content of K was observed in C_1 followed by C_2. Manganese content of the plant was significantly higher in C_2 than C_3. The Zn content was highest in POP and lowest in the farmer's practice.

4.1.2.1.2 Interaction effect on elemental composition of rice

Interaction between P and K

A significant increase in the N content of the plant was observed at P_1 and P_2 level when the K dose was increased to 70 kg ha^{-1} (Table 14). Both were on par with 105 kg ha^{-1} of K. Maximum content of P was noted at the highest level of P and K application. There was an increase in Zn content at 105 kg ha^{-1} of K over 35 kg ha^{-1} at both levels of P application.

4.1.2.1.3 Elemental composition of rice at MT stage at Ottappalam

The effects of different levels of P, K, lime and controls on the elemental composition of rice at MT stage are presented in the table 15.

Effect of P

P application at the two levels significantly influenced the N, Mg, Cu and Si content of the plant. Application of 35 kg ha^{-1} of P increased the N, Mg and Cu content of the plant while it decreased the Si content compared to 17.5 kg ha^{-1} of P.

Table 15 Elemental composition of rice at MT stage (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	2.20	0.28	2.99	0.130	0.110	4305	453.65	22.82	10.98	2.44
P_2	2.30	0.28	3.01	0.140	0.120	4402	458.37	22.81	11.54	2.36
CD (0.05)	0.04	NS	NS	NS	0.007	NS	NS	NS	0.320	0.07
Levels of Potassium										
K_1	2.26	0.27	2.88	0.140	0.120	4239	463.18	22.25	10.86	2.47
K_2	2.15	0.28	3.03	0.140	0.110	4383	494.43	22.88	11.07	2.35
K_3	2.35	0.28	3.09	0.110	0.110	4438	455.42	23.32	11.86	2.37
CD (0.05)	0.04	NS	0.05	0.01	NS	92	NS	0.630	0.390	NS
Levels of Lime										
L_1	2.21	0.27	3.00	0.120	0.110	4330	452.90	22.74	10.89	2.43
L_2	2.29	0.29	2.98	0.140	0.120	4377	441.07	26.46	11.63	2.37
CD (0.05)	0.04	0.005	NS	0.01	0.007	NS	NS	NS	NS	NS
Controls										
C_1	2.42	0.261	3.17	0.141	0.123	4404	493.40	23.20	11.40	2.46
C_2	2.47	0.27	3.08	0.151	0.133	4371	485.20	22.70	11.90	2.40
C_3	2.14	0.26	2.94	0.060	0.099	4494	455.70	21.30	10.70	2.65
CD (0.05)	0.11	NS	0.10	0.020	0.018	NS	20.23	1.260	NS	NS

Table 14 Effect of P and K on elemental composition of rice at MT stage (Koyalmannam)

Treatment	N (%)			P (%)			Zn (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	2.22	2.38	2.38	0.33	0.32	0.33	36.13	38.97	40.17
P_2	2.25	2.38	2.37	0.32	0.33	0.34	35.37	36.45	37.18
CD(0.05)	0.06			0.013			0.81		

Table 16 Effect of P and K on elemental composition of rice at MT stage (Ottappalam)

Treatment	K (%)			Ca (%)			Fe (ppm)		
	K_1	K_2	K_2	K_1	K_2	K_2	K_1	K_2	K_2
P_1	2.89	3.05	3.04	0.14	0.13	0.12	4235	4352	4327
P_2	2.88	3.02	3.14	0.15	0.15	0.11	4243	4414	4550
CD(0.05)	0.07			0.01			130.95		

Effect of K

N and K content was highest at K_3 (105 kg ha^{-1}) and it was significantly superior to K_1 (35 kg ha^{-1}) and K_2 (70 kg ha^{-1}). Calcium content of the plant was lowest at K_3 levels and K_1 and K_2 were on par for the Ca content. Fe and Zn present at K_1 level was significantly lower compared to K_3 while K_1 and K_2 were on par. Maximum content of Cu was present at K_3. The other nutrients were not significantly influenced by various levels of K.

Effect of lime

Significant effect of lime in modifying the nutrient content of the plant at MT was confined only to N, P, Ca and Mg. The higher level of lime application at (600 kg ha^{-1}) significantly enhanced the N, P, Ca and Mg content of the plant.

Effect of controls

Maximum content of N, Ca and Mg was present in C_2 (POP) and it was significantly superior to C_3 (farmer's practice) Manganese content in C_1 and C_2 was significantly higher than C_3. C_1 recorded the highest content of K and it was significantly superior to C_3 and on par with C_2.

4.1.2.1.4 Interaction effects on elemental composition of rice

Interaction between P and K

Combined application of P and K significantly influenced the K, Ca and Fe content of rice plant (Table 16). K_3 was significantly superior to K_1 at both levels of P application for the K content. The highest value of K content (3.14%) was observed at P_2 when 105 kg ha^{-1} of K was applied. The Ca content of the plant registered the highest value at P_2K_1 and P_2K_2, the lowest value being at P_2K_3. The Fe content increased with higher level of K application at both levels of P application except that there was no effect when K was increased from K_2 to K_3 at P_1.

4.1.2.2.1 Elemental composition of rice at PI stage at Koyalmannam

The effect of different levels of P, K, lime and controls on nutrient content of rice at PI stage are presented in table 17.

Effect of P

Application of P significantly influenced the Fe, Mn Zn and Si content of rice plant at panicle initiation stage. The Mn content of the plant was significantly increased by 10 percent at higher levels of P application while the Fe and Si content of the plant decreased by 2.5 and 6.3 per cent respectively at higher level of P.

Effect of K

Nitrogen, K and Zn at K_3 level (105 kg ha^{-1}) was significantly superior to the lowest level of K (35 kg ha^{-1}). There was a significant increase in the K content of the plant at higher level of K application. K_2 and K_3 levels were on par for the K content.

Application of K at 70 kg ha^{-1} reduced the Ca content of the plant by 20 per cent over 35 kg ha^{-1}. The Fe and Mn content of the plant also decreased at higher levels of K. Plant Fe content was reduced by 2.2 and 3.4 per cent at K_2 and K_3 levels respectively. The Mn content of the plant was on par at K_2 and K_3 levels.

Effect of lime

The higher dose of lime at 600 kg ha^{-1} increased the N and Ca by 6 and 25 per cent respectively and decreased the K, Mg and Fe content by 4.6, 6.25 and 6.10 per cent respectively over the lower level.

Effect of controls

The N and Mg were significantly higher in the C_2 (POP treatment) compared to C_3 (the farmer's practice).There was no significant variation in the content of other nutrients.

Table17 Elemental composition of rice at PI stage (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	2.38	0.30	2.73	0.130	0.160	4606	487.00	42.38	13.42	2.71
P_2	2.38	0.30	2.72	0.140	0.150	4488	536.00	38.78	13.88	2.54
CD (0.05)	NS	NS	NS	NS	NS	85	17.50	2.15	NS	0.09
Levels of Potassium										
K_1	2.23	0.29	2.56	0.150	0.150	4596	536.90	37.22	13.23	2.81
K_2	2.42	0.30	2.81	0.120	0.160	4587	524.25	42.28	13.26	2.61
K_3	2.47	0.30	2.82	0.130	0.160	4459	518.73	42.16	14.46	2.45
CD (0.05)	0.05	NS	0.17	0.013	NS	104	10.97	1.68	NS	NS
Levels of lime										
L_1	2.30	0.30	2.79	0.120	0.160	4692	528.71	39.03	13.39	2.71
L_2	2.45	0.30	2.66	0.150	0.150	4402	525.91	42.07	13.91	2.54
CD (0.05)	0.04	NS	0.14	0.01	NS	85	NS	NS	NS	NS
Controls										
C_1	2.30	0.30	2.62	0.136	0.160	4694	516.96	37.66	12.60	2.78
C_2	2.36	0.29	2.54	0.130	0.173	4571	511.03	38.70	13.53	2.68
C_3	2.19	0.31	2.27	0.070	0.149	4771	512.93	35.00	13.10	3.04
CD (0.05)	0.112	NS	0.34	0.02	0.013	NS	NS	NS	NS	0.22

4.1.2.2..2 Interaction effect on elemental composition of rice

Interaction between P and K

When P was applied at higher level at K_1, the Ca content decreased while it increased at K_3 (Table 18a). The Fe content of the plant significantly decreased at K_2 and K_3 compared to K_1 at both levels of P application. The zinc content of plant significantly increased at P_1K_2 and decreased at P_1K_3. At P_2 level it decreased significantly at K_3 compared to K_2. K_1 was on par with K_2 and K_3.

Interaction between K and lime

With increase in lime dose there was an increase in N content at all levels of K (Table 18b).At higher level of lime application increasing the K dose to K_3 significantly increased the P content. At lower level of K increasing the lime dose, significantly decreased the K content of the plant. Similarly increasing the K dose in the presence of 600 kg ha^{-1} of lime significantly increased the K content at K_2 and K_3 compared to K_1. Magnesium content of the plant increased significantly with 600 kg ha^{-1} of lime at K_2 level but at K_1 and K_3 level it was decreased.

4.1.2.2.3 Second order interaction effect on elemental composition of rice at PI stage

Data on the combined effect of P, K and lime are presented in table 19.

Combined application of P at 17.5 kg ha^{-1}, K at 105 kg ha^{-1} and lime at 600 kg ha^{-1} recorded the highest value for K content of the plant (2.84%) and the lowest value was recorded by $P_1K_1L_1$ (2.57%).

Data on the Ca content revealed that increasing the lime dose to 600 kg ha^{-1} in the presence of 17.5 kg ha^{-1} of P at K_1 and K_2 decreased the Ca content but at K_3 no significant difference was observed.

Data on the Mg content revealed a significant decrease in the Mg content at $P_1K_3L_2$ compared $P_1K_3L_1$. Similarly $P_2K_2L_2$ showed a significant decrease in Mg content compared to $P_2K_2L_1$. But $P_2K_1L_2$ registered significant higher quantity of Mg

Table 18a . Effect of P and K on elemental composition of rice at PI stage (Koyalmannam)

Treatment	Ca (%)			Fe (ppm)			Zn (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.16	0.12	0.11	4780	4474	4563	38.00	43.53	36.43
P_2	0.14	0.13	0.14	4700	4411	4355	39.02	41.28	37.22
CD(0.05)	0.01			147			2.32		

Table 18b . Effect of K and lime on elemental composition of rice at PI stage (Koyalmannam)

Treatment	N (%)		P (%)		K (%)		Mg (%)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	2.19	2.27	0.30	0.29	2.73	2.39	0.16	0.14
K_2	2.33	2.51	0.29	0.30	2.80	2.82	0.15	0.17
K_3	2.37	2.58	0.30	0.31	2.85	2.78	0.18	0.13
CD(0.05)	0.07		0.01		0.24		0.009	

Table 19 Second order interaction effect on elemental composition of rice at PI stage (Koyalmannam)

Treatment	K(%)		Ca(%)		Mg(%)		Fe(ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	2.57	2.73	0.14	0.10	0.17	0.17	4356.00	4743.67
P_1K_2	2.64	2.81	0.16	0.12	0.16	0.16	4563.33	4483.33
P_1K_3	2.73	2.84	0.08	0.10	0.18	0.16	4922.00	4709.33
P_2K_1	2.78	2.78	0.16	0.14	0.16	0.18	4454.33	4748.67
P_2K_2	2.70	2.73	0.16	0.16	0.16	0.13	4611.67	4263.67
P_2K_3	2.70	2.69	0.13	0.15	0.14	0.14	4782.67	4433.33
CD(0.05)	0.24		0.02		0.01		208.87	

(0.18%) compared to $P_2K_1L_1$ (0.16%). Significant decrease in the Mg content was observed at K_3 in the presence of 35 kg ha^{-1} of P at both levels of lime application. Increasing the application of lime at P_1K_1 and P_2K_1 increased the Fe content. However a significant decrease in the Fe content was observed at K_3 at both P_1 and P_2 levels in the presence of 600 kg ha^{-1} of lime application. The treatment $P_2K_2L_2$ registered the lowest content of Fe (4263 ppm) and it was inferior to POP and farmer's practice.

4.1.2.2.4 Elemental composition of rice at PI stage at Ottappalam

Main effects of different levels of P, K and lime and that of controls on the elemental composition of rice at panicle initiation stage are presented in the table 20.

Effect of P

A perusal of the data in table 20 shows that the effects of the two levels of P application was confined only to P and Fe and the other nutrients remained unaffected. P application at 35 kg ha^{-1} significantly increased the P content and reduced the Fe content over P application at 17.5 kg ha^{-1}.

Effect of K

K application at the rate (70 kg ha^{-1}) significantly increased the N and K content of the plant and it was superior to K_1 (35 kg ha^{-1}).P content was highest at K_3 and it was significantly superior to K_1 and K_2 level. Calcium and Mg showed a decreasing trend from K_2 to K_3, the lowest content being recorded at K_3 levels. A steady and significant decline in the Fe content with increasing levels of K was observed at the panicle initiation stage while Mn decreased at K_2 level compared to K_1 and beyond K_2 there was no significant reduction noticed. The highest Si content was noted at K_2 level and it was significantly superior to K_1 and K_3.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased the N, P and Ca content by 6.4, 8 and 13 per cent respectively while it decreased the Fe content to the tune of 7.8 per cent.

Table 20. Elemental composition of rice at PI stage (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	1.90	0.250	2.84	0.160	0.120	4593	447.45	26.90	13.52	1.74
P_2	1.94	0.270	2.80	0.160	0.120	4068	440.55	26.60	13.55	1.70
CD (0.05)	NS	0.006	NS	NS	NS	130	NS	NS	NS	NS
Levels of Potassium										
K_1	1.89	0.260	2.73	0.170	0.130	4705	455.30	24.73	13.30	1.59
K_2	1.99	0.250	2.90	0.170	0.130	4316	436.94	27.46	13.32	1.89
K_3	1.87	0.270	2.83	0.130	0.100	3970	439.76	28.23	14.02	1.67
CD (0.05)	0.06	0.007	0.08	0.010	0.010	160	6.46	NS	0.21	0.12
Levels of Lime										
L_1	1.86	0.250	2.84	0.150	0.120	4508	442.92	27.15	13.51	1.82
L_2	1.98	0.270	2.80	0.170	0.120	4153	445.03	26.46	13.58	1.62
CD (0.05)	0.05	0.006	NS	0.008	NS	130	NS	NS	NS	NS
Controls										
C_1	2.00	0.258	2.87	0.146	0.134	4335	474.50	28.70	13.60	1.63
C_2	2.07	0.263	2.93	0.151	0.149	4178	470.50	29.10	14.20	1.53
C_3	2.12	0.221	2.57	0.112	0.090	4960	460.83	23.20	12.93	2.29
CD (0.05)	NS	0.010	0.17	0.020	0.020	320	NS	NS	NS	0.25

Effects of controls

It is evident from the table 20 that P, K, Ca, Mg, Fe and Si content of the plant was significantly influenced by various control treatments. The maximum content of P, K, Ca and Mg was recorded at C_2 (POP) and it was superior to C_3 (farmer's practice) and on par with C_1. Lowest quantity of Fe and Si was observed in the C_2 (POP) and it was significantly lower than C_3 and on par with C_1 (POP without lime).

4.1.2.2.5 Interaction effects on elemental composition of rice

Interaction between P and K

The maximum N content was observed at P_1K_2 (2.02%) and it was significantly superior to P_1K_1 and P_1K_3 (Table 21a).P content was significantly increased by the increased application of P as well as of K .The treatment combination P_2K_3 recorded the highest value for P (0.28%).

Manganese content of the plant recorded the lowest value at P_2K_2 (428.82 ppm) and the highest value at P_1K_1 (459.17 ppm) and both differed significantly by about 6 per cent. At P_1 level a significant decrease in Mn content was observed at K_3, but at P_2 level significant decrease was observed at K_2 over K_1 and K_3 showed an increase over K_2.

Interaction between K and lime

It is clear from the table (21b) there was a significant increase in the N content of the plant at K_2L_2 (2.16%) and this was significantly superior to all other combinations. At 600 kg ha^{-1} of lime application the N content increased significantly from K_1 to K_2 and beyond K_2 it decreased significantly.

The K content of the plant recorded the highest value at K_3L_2 level (105 kg ha^{-1} of K and 600 kg ha^{-1} of lime application). The K content of the plant showed a decrease at K_1 and K_2 level when the lime dose was increased from 300 kg ha^{-1} to

Table 21a Effect of P and K on elemental composition of rice at PI stage (Ottappalam)

Treatment	N (%)			P (%)			Mn (ppm)		
	K_1	K_2	K_2	K_1	K_2	K_2	K_1	K_2	K_2
P_1	1.86	2.02	1.81	0.24	0.24	0.26	459.17	451.07	432.12
P_2	1.92	1.96	1.92	0.26	0.27	0.28	451.43	428.82	441.40
CD(0.05)	0.09			0.01			9.14		

Table 21b Effect of K and lime on elemental composition of rice at PI stage (Ottappalam)

Treatment	N (%)		K (%)		Ca (%)		Mg (%)		Fe (ppm)		Mn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	1.87	1.91	2.81	2.64	0.17	0.18	0.13	0.14	4915	4495	461.88	448.72
K_2	1.82	2.16	2.89	2.76	0.16	0.18	0.12	0.13	4583	4050	433.95	445.93
K_3	1.88	1.86	2.82	2.97	0.11	0.14	0.11	0.10	4025	3914	433.07	440.45
CD(0.05)	0.09		0.12		0.01		0.01		226.80		9.14	

600 kg ha^{-1}. However at K_3 level the K content increased in spite of the increase in lime dose. The lowest content of K 2.64 per cent was observed at K_1L_2.

The Ca content of the plant increased with increase in level of lime at all levels of K. K_1L_2 recorded the highest value for Ca (0.18%) and the lowest value of 0.11 per cent was observed at K_3L_1. It can be seen from the table that at both levels of lime application. The lime content decreased significantly when the K application rate was increased from 70 kg ha^{-1} to 105 kg ha^{-1}. The Mg content of the plant registered the highest value at K_1L_1 and the lowest value at K_3L_2. The Mg content of the plant also showed a decrease with increase in K levels at both levels of lime application. The Fe content of the plant showed a decreasing trend with increasing levels of K and lime. The lowest content of Fe was observed at K_3L_2 (3914 ppm) and it was significantly lower than Fe content at K_1L_1 (4915 ppm) by 20 per cent. At K_2 and K_1 level when the lime dose was increased, the Fe content decreased by 11.6 per cent and 8.5 per cent respectively. At both levels of lime application there was a significant decrease in Fe content with increasing levels of K. The maximum Mn content was observed at K_1L_1 and the lowest content at K_3L_1 and these two different by about 6.2 per cent. At K_1 level with increase in lime there was a decrease in Mn content but at K_2 level a reverse trend was observed. At 300 kg ha^{-1} of lime application the Mn content decreased by 6 per cent when the K dose increased from 35 to 70 kg ha^{-1}.

4.1.2.2.6 Second order interaction effect on elemental composition of rice

Second order interaction effect on elemental composition of rice at panicle initiation stage is given in the table 22.

$P_2K_1L_1$ recorded the highest content of K (2.99 per cent) followed by $P_1K_2L_1$ (2.94 per cent). The K content of the plant decreased significantly at P_2K_1 when the lime dose increased to 600 kg ha^{-1}.

The lowest content of Fe (3971 ppm) was recorded by $P_2K_2L_1$ and it was on par with $P_1K_2L_1$. It was inferior to POP and farmer's practice. There was a significant decrease in Fe content at P_1K_3 and P_2K_3 when the lime dose increased to

Table 22 Second order interaction effect on elemental composition of rice at PI stage (Ottappalam)

Treatment	K (%)		Fe (ppm)		Mn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	2.87	2.77	4478.33	4647.33	445.30	466.10
P_1K_2	2.94	2.84	4016.67	4106.00	436.53	437.97
P_1K_3	2.71	2.63	4640.00	4043.33	463.03	423.97
P_2K_1	2.99	2.80	4391.67	4565.67	442.53	463.70
P_2K_2	2.82	2.78	3971.67	4526.00	432.70	454.83
P_2K_3	2.74	2.88	4691.67	4108.00	467.60	435.00
CD(0.05)	0.170		320.000		12.92	

600 kg ha^{-1}. Increasing the K dose to 70 kg ha^{-1} from 35 kg ha^{-1} in the presence of 17.5 kg ha^{-1} of P at both levels of lime application significantly decreased the Fe content. This trend was observed at P_2 level also. The Mn content registered its lowest value at $P_1K_3L_2$ (423.97 ppm). A significant decrease in Mn content was observed at P_1K_3 and P_2K_3 when the lime dose increased to 600 kg ha^{-1}. $P_2K_3L_2$ also showed a decrease in Mn content compared to $P_2K_3L_1$ and POP

4.1.2.3.1 Elemental composition rice at flowering stage at Koyalmannam

Data on the effect of P, K, lime and controls on the nutrient content of rice at the flowering stage are presented in the table 23.

Effect of P

Different levels of P application significantly influenced the Fe, Mn and Zn content of plant at flowering stage. Application of P at 35 kg ha^{-1} significantly decreased the Fe and Zn content of the plant to the tune of 16.5 and 6.7 per cent respectively. The P application at higher level had a significant effect in increasing the Mn content of the plant.

Effect of K

Potassium at K_2 level (70 kg ha^{-1}) significantly increased the N and K content of the plant. There was a significant increase in the Zn content of the plant at higher levels of K_3 (105 kg ha^{-1}) compared to K_1 (35 kg ha^{-1}).Along with increase in K levels, there was a significant decrease in the Mg, Fe and Mn content of the plant.

Effect of lime

As is evident in the table 23 the P, Ca and Si content of the plant significantly increased at higher level of lime application. Potassium, Fe and Mn content of the plant showed a decreasing trend with increase in the dose of lime, reduced by 6.2, 5.7 and 4.9 per cent respectively. The two levels of lime application did not affect the N, Mg and Zn content.

Table 23 Elemental composition of rice at flowering stage (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	1.76	0.220	1.39	0.140	0.130	1919	327.50	46.36	6.82	2.89
P_2	1.77	0.220	1.42	0.140	0.130	1601	342.00	43.25	7.37	2.88
CD (0.05)	NS	NS	NS	NS	NS	110	10.37	2.15	NS	NS
Levels of Potassium										
K_1	1.73	0.200	1.32	0.140	0.140	2176	350.40	43.46	7.06	3.14
K_2	1.78	0.220	1.49	0.140	0.130	1564	335.60	44.23	7.11	2.74
K_3	1.79	0.240	1.41	0.140	0.120	1541	319.16	46.73	7.13	2.78
CD (0.05)	0.04	NS	0.02	NS	0.006	135	12.70	2.64	NS	NS
Levels of Lime										
L_1	1.77	0.210	1.45	0.130	0.130	1813	343.00	45.63	7.33	2.79
L_2	1.76	0.230	1.36	0.140	0.130	1708	326.00	43.98	6.87	2.97
CD (0.05)	NS	0.007	0.02	0.003	NS	110	10.37	NS	NS	0.06
Controls										
C_1	1.80	0.230	1.42	0.139	0.140	1954	369.90	44.40	5.96	2.98
C_2	1.86	0.260	1.45	0.149	0.159	1821	365.30	44.10	6.23	2.78
C_3	1.92	0.170	1.24	0.109	0.119	2124	316.20	40.30	6.26	3.43
CD (0.05)	0.08	0.076	0.07	0.009	0.012	270	25.41	NS	NS	NS

Effect of controls

There was significant difference between the control treatments for all the nutrients except Zn, Cu and Si. The C_2 (POP practice) recorded the highest content of P, K, Ca and Mg and it was significantly superior to C_3 (farmer's practice). Significantly higher N and Fe content to the tune of 6 and 14 per cent respectively over C_2 was recorded by C_3 (the farmer's practice). C_1 recorded the maximum content of Mn.

4.1.2.3.2 Interaction effect on elemental composition of rice

Interaction between P and K

It is obvious from the table 24a that there was a significant increase in the N content of plant at P_1K_2 compared to P_1K_1. But at P_2 no significant difference was observed for the N content with changes in K levels. In the presence of 35 kg ha^{-1} of K increasing the P dose increased the N content of the plant. When K was increased to K_2 from K_1 the Fe content of the plant decreased significantly .Beyond K_2, K did not influence the Fe content while the same significantly increased the Fe content at P_2.

At P_1 level increase in the application of K from K_1 to K_2 decreased the Cu content and from K_2 to K_3 increased the cu content substantially.

Interaction between K and lime

Potassium and lime interacted significantly to influence the N, K, Mg, Fe and Cu content of the plant (Table 24b).

At lower level of lime application increase in K dose from K_1 to K_2 increased the N content of the plant and further increase in K dose did not affect the N content. At 300 and 600 kg ha^{-1} of lime application increasing the K levels significantly increased the K content plant. The Mg content of the plant significantly decreased with increase in lime dose at K_2 and K_3 level. Increasing the K to 70 kg ha^{-1} significantly decreased the Mg at both levels of lime application. Higher level of lime application decreased the Fe content of the plant when K was applied at K_1 or K_3.

Table 24 a Effect of P and K on elemental composition of rice at flowering stage (Koyalmannam)

Treatment	N (%)			Fe (ppm)			Cu (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	1.68	1.77	1.83	2274	1495	1587	6.87	6.42	7.18
P_2	1.78	1.78	1.78	2077	1232	1897	7.75	7.80	7.07
CD(0.05)	0.06			191			0.36		

Table 24 b Effect of K and lime on elemental composition of rice at flowering stage (Koyalmannam)

Treatment	N (%)		K (%)		Mg (%)		Fe (ppm)		Cu (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	1.68	1.78	1.34	1.30	0.14	0.14	2242	2109	6.55	7.57
K_2	1.80	1.75	1.46	1.35	0.13	0.12	1507	1622	7.50	6.72
K_3	1.83	1.77	1.50	1.42	0.13	0.12	1688	1393	7.93	6.32
CD(0.05)	0.06		0.04		0.008		191.2		0.36	

The Fe content of the plant significantly decreased at K_3 level in the presence of 600 kg ha^{-1} of lime application by 34 per cent compared to K_1L_1. At K_1 level increasing the lime dose increase the Cu content of the plant, but at K_2 and K_3 level a reverse trend was noted. In the presence of 300 kg ha^{-1} of lime, increasing the K levels increased the Cu content but at 600 kg ha^{-1} of lime a decrease in Cu content with increase in K was noted.

4.1.2.3.3 Elemental composition of rice at flowering stage at Ottappalam

Main effects of different levels of P, K, lime and that of controls on elemental composition of plant at flowering stage are presented in the table 25.

Effect of P

Higher levels of P application increased the P content while it decreased Fe, Zn and Si content of the plant.

Effect of K

Various levels of K application modified the nutrient content of rice at the flowering stage. Potassium application at 70 kg ha^{-1} registered the highest content of P and Mg. The P content at K_2 was on par with K_3 while the Mg content was on par with K_1. Calcium content at K_2 level (70 kg ha^{-1}) recorded the lowest value and was significantly inferior to K_1 and K_3. The Fe content of the plant showed a significant increase from K_1 to K_2 but showed a significant decrease from K_2 to K_3. The maximum Mn content was present at K_1 level and it was significantly higher than at K_2. K_2 and K_3 were on par for the Mn content. The Cu content of the plant significantly increased from K_2 to K_3 and K_1 and K_2 showed no significant difference for the Cu content.

Effect of lime

Lime application at two levels significantly influenced the N, P, Ca, Mg, Fe and Zn content of the plant. There was a significant increase in the N, P, Ca and

Table 25. Elemental composition of rice at flowering stage (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	1.50	0.170	1.74	0.160	0.100	2639	253.14	55.17	5.59	1.75
P_2	1.51	0.180	1.74	0.170	0.120	2048	258.96	46.76	5.76	1.61
CD (0.05)	NS	0.003	NS	NS	NS	98	NS	2.50	NS	0.11
Levels of Potassium										
K_1	1.56	0.160	1.61	0.180	0.110	2235	264.20	50.09	5.24	1.92
K_2	1.42	0.180	1.75	0.150	0.120	2841	250.73	53.13	5.50	1.56
K_3	1.53	0.180	1.85	0.160	0.090	1955	253.23	49.67	6.28	1.56
CD (0.05)	NS	0.004	0.08	0.005	0.010	120	11.00	NS	0.29	NS
Levels of Lime										
L_1	1.48	0.170	1.76	0.160	0.100	2544	255.63	52.64	5.38	1.79
L_2	1.52	0.180	1.72	0.170	0.120	2143	256.47	49.29	5.97	1.56
CD (0.05)	0.05	0.003	NS	0.004	NS	98	NS	2.50	NS	NS
Controls										
C_1	1.44	0.177	1.72	0.170	0.118	2315	297.43	51.93	5.46	1.63
C_2	1.49	0.182	1.77	0.183	0.118	2114	294.86	53.16	6.13	1.53
C_3	1.37	0.162	1.64	0.138	0.081	3023	282.13	48.10	5.50	2.29
CD (0.05)	0.07	0.008	0.06	0.01	NS	240	NS	NS	NS	0.27

Mg content of the plant at 600 kg ha^{-1} of lime application while a significant decrease was noted for Fe and Zn content.

Effect of controls

Maximum content of N, P, K and Ca was present in C_2 (POP) and these nutrients were higher than C_3 (the farmer's practice) by 8, 10, 7 and 24 per cent respectively. C_1 (POP without lime) and C_2 were on par for the N, K, Fe and Si content of the plant. C_3 recorded the highest content of Fe and Si and was significantly superior to C_2.

4.1.2.3.4 Interaction effects on elemental composition of rice

Interaction between P and K

Interaction between P and K significantly influenced the Ca, Fe, Mn and Zn content of rice at flowering stage (Table 26a). There was a decrease in the Ca content with increasing levels of K application at P_1 level. But at P_2 level the decrease was observed only at K_3. The maximum content of Ca was observed at P_1K_1 (0.18%) and the lowest content was observed at P_1K_3 (0.15%). The Fe content decreased drastically from K_1 to K_2 at P_1 while further increase in K did not have a profound effect on the Fe content of the plant. The lowest content of Fe was observed at P_2K_3 which was 47 per cent lesser than the highest content of Fe observed at P_1K_1. Similarly with increase in P also the decrease in Fe content was observed at all levels of K. Combined application of 35 kg ha^{-1} of P and 105 kg ha^{-1} of K registered the lowest content of Mn. At P_1 level increasing levels of K significantly decreased the Mn content upto K_2 level and beyond K_2 an increase was observed. But at P_2 level there was a significant decrease in Mn content when the dose was increased from 70 kg ha^{-1} to 105 kg ha^{-1}. Lowest Zn content (39.35 ppm) was observed at P_2K_3 level while the highest content (59.98 ppm) was observed at P_1K_3 level. At P_1 level when the K dose was increased from 75 kg ha^{-1} to 105 kg ha^{-1} a significant increase in zinc content was observed but at P_2 level. There was a decrease in Zn content with increase in K level from K_2 to K_3. At K_1 and K_3 levels increasing levels of P significantly decreased the zinc content.

Interaction between P and lime

Interaction between P and lime significantly influenced the N and Fe content of the plant at flowering stage (Table 26c). When lime was applied at higher level along with P_1, N content increased drastically while there was no such influence at P_2. The Fe content of the plant showed a progressive decrease with increasing levels of both P and lime. The highest content of Fe was observed at P_1L_1 (1906 ppm) and **the lowest content at P_2L_2 (1913 ppm).**

Interaction between K and lime

It can be observed from the table 26b that when the K was increased from K_1 to K_2 P content also increased but the P content was not affected by further increase in the dose of K. K_3L_2 recorded the highest content of K (1.87%) and it was on par with K_3L_1 (1.84%). At K_1 level there was a decrease in the K content with increase in lime dose. But at K_2 and K_3, changing the level of lime did not affect the K content. Maximum content of Mg was present at K_1L_2 (0.12%) and the lowest content was observed at K_3L_1 (0.07%). At K_1 and K_3 levels the Mg content increased with increasing levels of lime. The Cu content of the plant increased significantly at both levels of lime application when the K dose was increased from K_2 to K_3.

4.1.2.4.1 Elemental composition of straw at harvest at Koyalmannam

The effects of different levels of P, K and lime and controls on elemental composition of straw are presented in table 27.

Effect of P

At the harvest stage the P levels significantly influenced P, Mn and Zn content of the plant. There was an increase in the P and Mn content with an increase in the P dose while the zinc content of the plant showed a decreasing trend.

Effect of K

Application of K at 70 kg ha^{-1} significantly increased N and Zn content of the plant. The K content of the plant at K_3 levels (105 kg ha^{-1}) was significantly

Table 26a. Effect of P and K on elemental composition of rice at flowering stage (Ottappalam)

Treatment	Ca (%)			Fe (ppm)			Mn (ppm)			Zn (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.18	0.16	0.15	2977	2601	2538	279.97	246.90	273.97	51.47	54.07	59.98
P_2	0.17	0.17	0.16	2492	2081	1572	248.43	254.48	232.48	48.72	52.70	39.35
CD (0.05)	0.007			169			16.41			4.46		

Table 26b. Effect of K and lime on elemental composition of rice at flowering stage (Ottappalam)

Treatment	P (%)		K (%)		Mg (%)	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	0.16	0.17	1.65	1.57	0.11	0.12
K_2	0.17	0.19	1.77	1.73	0.11	0.11
K_3	0.17	0.19	1.84	1.87	0.07	0.11
CD (0.05)	0.005		0.04		0.01	

Table 26c Effect of P and lime on elemental composition of rice at flowering stage (Ottappalam))

Treatment	N(%)		Fe (ppm)	
	L_1	L_2	L_1	L_2
P_1	1.46	1.54	2906	2372
P_2	1.50	1.51	2183	1913
CD (0.05)	0.04		138.61	

Table 27 Elemental composition of straw at harvest stage (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	0.95	0.13	1.81	0.200	0.100	1474	285.90	64.84	7.13	2.99
P_2	0.92	0.17	1.83	0.200	0.110	1305	303.42	61.06	7.22	3.16
CD (0.05)	NS	0.016	NS	NS	NS	NS	5.60	2.20	NS	NS
Levels of Potassium										
K_1	0.92	0.15	1.75	0.220	0.100	1520	310.65	61.49	7.17	3.02
K_2	0.88	0.16	1.89	0.180	0.110	1290	290.51	63.36	7.38	2.88
K_3	1.00	0.15	1.82	0.190	0.110	1358	282.36	63.99	6.97	3.33
CD (0.05)	0.06	NS	0.019	0.010	NS	NS	8.50	NS	0.30	0.20
Levels of lime										
L_1	0.95	0.16	1.84	0.180	0.110	1419	298.78	62.23	6.82	2.99
L_2	0.92	0.14	1.80	0.210	0.100	1360	290.59	63.67	7.53	3.16
CD (0.05)	NS	NS	0.015	0.010	NS	62.77	5.62	NS	NS	NS
Controls										
C_1	1.00	0.08	1.80	0.197	0.106	1308	324.56	59.36	6.73	3.30
C_2	1.05	0.09	1.80	0.220	0.133	1154	318.56	59.93	7.36	3.03
C_3	0.86	0.11	1.73	0.170	0.135	1409	309.00	58.40	6.66	3.43
CD (0.05)	0.121	0.03	0.03	0.030	0.017	153.77	NS	NS	NS	NS

superior to K_1 level (35 kg ha^{-1}) and on par with K_2. Application of K at K_2 (70 kg ha^{-1}) recorded the highest content of K and Cu in the plant while it registered the lowest Ca and Mn content.

Effect of lime

It may be observed that there was significant influence of different levels of lime application on the P, K, Ca, Mg, Fe and Mn content of the plant. Application of lime at 600 kg ha^{-1} decreased the P, K, Mg, Fe and Mn content to the tune of 12.5, 2.1, 9 and 4.15 per cent respectively. While Ca content increased by 14.2 per cent.

Effect of controls

The N, P, K, Ca, Mg and Fe content of the plant was significantly influenced by the control treatments. POP (C_2) recorded the highest content of N and Ca. The maximum Fe content was observed in the farmer's practice (C_3) and the increase was to the tune o 18 per cent over POP.

4.1.2.4.2 Interaction effect on elemental composition of straw

Interaction between P and K

Data in the table 28 showed that phosphorus application at 17.5 kg ha^{-1} significantly decreased the Ca content at K_2 and K_3 compared to K_1. But in the presence of 35 kg ha^{-1} of P, significant decrease was observed only at K_3. Increasing the dose of P decreased Fe content of the straw at all levels of K .Increasing the dose of K from K_1 to K_2 decreased the Fe content at P_1 and P_2. Increase in the dose of K at the lower level of P resulted in decrease of Mn content of straw. But at P_2 increasing level of K from K_1 to K_2 resulted in a substantial increase in the Mn content of the straw and further increase in the dose of K resulted in decrease of Mn content.

4.1.2.4.3 Elemental composition of straw at Ottappalam

Main effects of P, K, lime and controls on elemental composition of straw at harvest are presented in the table 29.

Table 28 . Effect of P and K on elemental composition of straw at harvest (Koyalmannam)

Treatment	Ca (%)			Fe (ppm)			Mn (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.23	0.19	0.19	1544	1351	1518	307.18	281.38	269.32
P_2	0.22	0.20	0.17	1487	1062	1366	314.12	399.73	296.40
CD(0.05)	0.02			108.73			9.74		

Table 29 Elemental Composition of straw at harvest (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	0.69	0.130	2.00	0.210	0.070	1748	225.40	72.19	6.03	3.00
P_2	0.70	0.140	2.06	0.220	0.100	1542	221.40	65.91	6.53	2.93
CD (0.05)	NS	0.007	NS	NS	0.010	NS	NS	3.33	NS	NS
Levels of Potassium										
K_1	0.75	0.140	2.01	0.240	0.100	1900	209.85	63.32	5.76	3.20
K_2	0.77	0.120	2.02	0.230	0.110	1683	211.88	69.20	5.97	2.92
K_3	0.68	0.150	2.06	0.160	0.060	1352	233.69	74.63	7.12	2.78
CD (0.05)	0.05	NS	NS	NS	0.020	140	8.50	4.08	NS	NS
Levels of Lime										
L_1	0.70	0.130	2.08	0.200	0.080	1782	222.26	70.79	6.07	3.13
L_2	0.76	0.140	1.98	0.220	0.090	1508	214.68	67.31	6.49	2.80
CD (0.05)	0.04	0.007	0.10	0.016	NS	114.8	6.99	3.83	NS	NS
Controls										
C_1	0.68	0.126	2.11	0.241	0.116	1636	251.10	72.40	6.30	3.10
C_2	0.79	0.135	2.15	0.240	0.120	1653	245.20	72.60	7.20	3.11
C_3	0.75	0.120	1.93	0.200	0.060	2133	239.60	63.26	6.50	3.19
CD (0.05)	NS	NS	NS	0.040	0.04	281.2	NS	NS	0.50	NS

Effect of P

P applied at higher and lower levels significantly altered the P, Mg and Zn content of the straw at harvest. P and Mg content of the plant increased while the Zn content decreased at P_2 level (35 kg ha^{-1}) compared to P_1 levels.

Effect of K

Various levels of K application significantly influenced the N, Mg, Fe, Mn and Zn content of the plant. N and Zn content of the plant increased with increase in K levels. Maximum content of N was observed at K_2 level (70 kg ha^{-1}) while the maximum Zn content was observed at K_3 level (105 kg ha^{-1}). Mg content decreased from K_2 level to K_3 level and K_1 and K_2 were on par for the content of Mg.

There was a steady decline in the Fe content with increasing K levels and the lowest Fe content was observed at K_3 level. Highest content of Mn was observed at K_3 which was significantly higher than K_1 and K_2. Phosphorus, K, Ca, Cu and Si content of the plant remained unaffected by various levels of K application.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased N, P and Ca content of the plant compared to lime application at 300 kg ha^{-1}. Higher levels of lime application decreased the K content of the plant by 4.8 per cent over lower level. Lime application at 600 kg ha^{-1} decreased the Fe content by 15.3 per cent, the Mn content by 3 per cent and Zn by 4.9 per cent over lime application at 300 kg ha^{-1}. The different levels of lime application did not influence significantly the Mg, Cu and Si content of the straw.

Effect of controls

There was significant difference between various controls for Ca, Mg, Fe and Cu content of the straw.

C_3 (farmer's practice) recorded the lowest content of Ca and Mg. The Mg content at C_3 was significantly inferior to C_1 and C_2 and for Fe content C_3 was significantly superior to C_1 and C_2.

4.1.2.4.4 Interaction effects on elemental composition of straw

Interaction between K and lime

Effect of K and lime on the N,K and Cu content of straw is given in the table 30a.

Increase in the dosage of lime resulted in increased N content of the straw when K was applied at K_2 .At other levels of K the two lime doses could not make a difference in the N content of the straw. At 300 kg ha^{-1} of lime, 105 kg ha^{-1} of K was required to increase the N content of the straw, while at 600 kg ha^{-1} of lime 70 kg ha^{-1} of K brought about an increase in the N content of the straw. Further increase in the application of K decreased the N content.

Application of K at 105 kg ha^{-1} combined with 300 kg ha^{-1} (K_3L_1) of lime registered the highest value for K (2.17%) and the lowest value was observed at K_2L_2 (1.92%) and these two differed significantly by about 11 per cent. Higher level of lime application at K_2 and K_3 levels decreased the K content by 9.8 per cent and 9.6 per cent respectively. An increase in Cu content at K_2 and K_3 level was observed when the lime dose was increased from 300 to 600 kg ha^{-1}.

Interaction between P and lime

Effect of P and lime on the P, Fe and Cu content of the straw is given in table 30b.

There was a significant increase in P content at P_1 level when the lime dose was increased from 300 kg ha^{-1} to 600 kg ha^{-1}. However maximum P content was observed at both P_1L_2 and P_2L_2 as seen from the table 30b. Increasing the dose of lime resulted in decreased Fe content of the straw at both levels of P application. The Fe

Table 30a Effect of K and lime on elemental composition of straw at harvest (Ottappalam)

Treatment	N (%)		K (%)		Cu (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	0.64	0.71	1.95	2.06	5.78	5.73
K_2	0.70	0.84	2.13	1.92	5.73	6.20
K_3	0.76	0.73	2.17	1.96	6.70	7.53
CD (0.05)	0.08		0.18		0.35	

Table 30b Effect of P and lime on elemental composition of straw at harvest (Ottappalam)

Treatment	P (%)		Fe (ppm)		Cu (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	0.12	0.14	1944	1553	5.71	6.34
P_2	0.13	0.14	1620	1463	6.43	6.63
CD (0.05)	0.01		162.3		0.290	

content of the straw decreased by 20 per cent when the lime application rate increased from 300 kg ha^{-1} to 600 kg ha^{-1} at P_1 but at P_2 level the decrease was to the tune of only 9 per cent. Copper content of the straw was increased by increasing the dosage of lime at P_1 or by increasing the dosage of P at 300 kg ha^{-1} of lime.

4.1.2.5.1 Elemental composition of grain at Koyalmannam

The effects of different levels of P K, lime, and the controls on the elemental composition of grain are presented in the table 31.

Effect of P

The effect of P in influencing the grain nutrient content was mainly confined to the N, Mg, Fe, Mn and Zn. Between the two levels of application of P, that at 35 kg ha^{-1} significantly increased the N, Mg and Mn content of the plant to the tune of 11.4, 9 and 6.5 percent respectively while it decreased the Fe and Zn to the tune of 15.5 and 8.6 per cent respectively.

Effect of K

The P content of grain at K_3 level was significantly superior to P content at K_1 and K_2 levels. As for the K content, K_1 (35 kg ha^{-1}) was on par with K_2 (70 kg ha^{-1}), while K_3 (105 kg ha^{-1}) recorded the highest content and was significantly superior to K_1 and K_2. K_1 was on par with K_2 for the Ca content of the grain, while the lime content showed a significant decrease at K_3 levels. The Mg, Fe and Zn content of the grain was significantly decreased at K_2 level compared to K_1 where as K_2 was on par with K_3 for these nutrients. Highest content of Mn was observed at K_1 level and it showed a significant decrease at K_2 level and beyond K_2 level there was a significant increase in the Mn content. K_2 was significantly inferior to both K_1 and K_3

Effect of lime

A perusal of the data shows that the significant effect of the two levels of lime on the nutrient content of the grain was confined only to N Mg and Fe content.

Plate 1. Experimental site (Ottappalam)

Plate 2. Experimental site (Koyalmannam)

Table 31.Elemental composition of grain (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	1.05	0.160	0.430	0.030	0.110	238.44	32.41	23.09	6.520	2.15
P_2	1.17	0.180	0.450	0.020	0.120	201.50	34.54	21.70	6.450	2.22
CD (0.05)	0.04	NS	NS	NS	0.003	22.46	1.20	0.88	NS	NS
Levels of Potassium										
K_1	1.00	0.170	0.410	0.030	0.120	306.25	36.91	24.05	6.100	2.24
K_2	1.20	0.160	0.430	0.030	0.110	156.00	30.23	21.93	6.280	2.18
K_3	1.14	0.180	0.470	0.010	0.110	196.00	33.28	21.61	7.060	2.14
CD (0.05)	NS	0.003	0.020	0.005	0.004	57.51	1.47	1.08	0.189	NS
Levels of lime										
L_1	1.08	0.160	0.440	0.020	0.110	252.22	33.55	22.41	6.410	2.21
L_2	1.14	0.170	0.440	0.030	0.120	187.20	33.40	22.65	6.560	2.17
CD (0.05)	0.04	NS	NS	NS	0.003	22.46	NS	NS	NS	NS
Controls										
C_1	1.16	0.170	0.471	0.028	0.125	229.67	40.56	23.26	6.330	2.28
C_2	1.19	0.176	0.458	0.035	0.131	175.33	39.20	24.30	6.860	2.22
C_3	0.95	0.163	0.425	0.016	0.090	342.00	33.73	23.00	6.930	2.35
CD (0.05)	0.09	0.006	NS	0.010	0.009	55.03	2.95	NS	NS	NS

Between the two levels of application, lime at 600 kg ha^{-1} increased the N and Mg content by 9 and 5.2 per cent respectively while it decreased the Fe content by 25 per cent.

Effect of controls

It may be observed from the table that the POP (C_2) recorded the highest content of N, P, Ca and Mg and it was significantly superior to the farmer's practice (C_3).The POP (C_2) was on par with C_1 for the N, P, Ca, Mg and Fe content of the grain. It may be seen from the table that a significantly higher quantity of Fe is present in the grain in farmers practice compared to C_2 while the Mn content present was significantly lower.

4.1.2.5.2 Interaction effect on elemental composition of grain

Interaction effect of P and K on elemental composition of grain is given in the table 32.

Interaction between P and K

Effect of P and K on the N, P, Mg and Fe content of the grain is given in the table 32.

Higher level of P application did not affect the N content of the grain in the presence of 105 kg ha^{-1} of K, while at lower levels of K the N content of the grain was increased by higher level of application of P. An increase in the level of application of K increased the N content of then grain when P was at the lower level. At higher level of P the same trend was observed from K_1 to K_2 and not beyond K_2. The P content of the grain showed significant increase with increase in K dose at both levels of P. Increasing the P dose at various levels of K also significantly increased the P content of the grain. The Mg content of the grain showed significant decrease with increase in K dose at 17.5 kg ha^{-1} of P application. But at P_2 level a significant decrease at K_2 was noted and beyond K_2 an increase in Mg content was observed. Increasing the P dose at K_1 and K_3 significantly increased the Mg content of the grain. The Fe content of the

Table 32 Effect of P and K on elemental composition of grain (Koyalmannam)

Treatment	N (%)			P (%)			Mg (%)			Fe (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.95	1.04	1.17	0.15	0.16	0.17	0.12	0.11	0.10	331.00	237.00	147.00
P_2	1.05	1.23	1.22	0.16	0.18	0.19	0.13	0.11	0.12	281.50	158.30	164.60
CD (0.05)	0.07			0.004			0.006			38.90		

grain decreased with increase in the level of K application at 17.5 kg ha^{-1} of P. But at higher level of P the trend was noticed only up to K_2 beyond which Fe content did not change. Application of P at higher level decreased the Fe content at lower levels of K application .At K_3 Fe was not affected by increase in the P level.

4.1.2.5.3 Second order interaction effect on elemental composition of the grain

Elemental composition of the grain is given in the table 33

At 600 kg ha^{-1} of lime application, an increase in the dose of K from K_1 to K_2 increased the N content of the grain. This change did not sustain beyond K_2.When increased lime application was done at P_1K_3, the P content of the grain increased. P content was not affected by changes in lime application at other PK combinations or P and K levels. Increased lime application resulted in decrease of Fe content of grain at P_1K_3 and the Fe content of grain was not affected by changes in levels of lime application at other PK combinations or by changing the levels of P and K.

4.1.2.5.4 Elemental composition of the grain at Ottappalam

The effects of different levels of P, K and lime and controls on the elemental composition of grain at harvest are given in the table 34.

Effect of P

The application of P at two levels of P_1 and P_2 (17.5 kg ha^{-1} and 35 kg ha^{-1}) had significant effects on P, K, Mg and Fe content of the grain. Phosphorus at P_2 level increased the P and K content of the grain by 18 and 23 per cent respectively. There was a significant reduction in the Fe content of the grain at P_2 levels which was to the tune of 21 per cent. The P levels could not significantly influence the N, Ca, Mg, Mn, Zn, Cu and Si content of the grain.

Effect of K

It may be observed from the table that the various levels of K had a significant effect in modifying the nutrient content of N, K, Ca, Mg, Fe, Mn and Si of

Table 33 Second order interaction effect on elemental composition of grain (Koyalmannam)

Treatments	N (%)		P (%)		Fe (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	1.19	1.07	0.167	0.168	237.67	212.67
P_1K_2	1.17	1.19	0.172	0.167	228.33	178.00
P_1K_3	1.08	1.15	0.167	0.175	221.33	160.33
P_2K_1	1.24	0.99	0.167	0.170	249.00	234.33
P_2K_2	1.13	1.17	0.173	0.168	306.33	196.67
P_2K_3	1.01	1.03	0.173	0.168	254.67	208.00
CD (0.05)	0.090		0.006		55.02	

Table 34 Elemental composition of grain (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	0.99	0.110	0.380	0.030	0.091	250.89	30.80	22.37	4.67	2.25
P_2	1.00	0.130	0.470	0.020	0.094	195.72	33.82	20.01	4.87	2.23
CD (0.05)	NS	0.003	0.014	NS	0.002	22.89	NS	NS	NS	NS
Levels of Potassium										
K_1	0.89	0.110	0.430	0.030	0.100	325.08	36.01	22.24	4.54	2.20
K_2	1.06	0.130	0.390	0.030	0.080	123.33	30.12	20.73	4.83	2.24
K_3	1.03	0.120	0.450	0.010	0.090	221.50	29.90	20.60	4.93	2.27
CD (0.05)	0.04	NS	0.017	0.007	0.005	28.00	1.72	NS	NS	0.04
Levels of Lime										
L_1	0.97	0.110	0.430	0.020	0.090	269.00	34.11	22.10	4.55	2.28
L_2	1.02	0.120	0.420	0.030	0.090	177.61	30.51	20.28	4.99	2.20
CD (0.05)	NS	0.003	NS	NS	NS	22.80	NS	NS	0.23	NS
Controls										
C_1	0.930	0.125	0.464	0.022	0.096	254.00	46.56	22.60	4.33	2.27
C_2	0.956	0.130	0.447	0.030	0.105	205.60	30.20	23.60	5.00	2.23
C_3	0.933	0.116	0.379	0.020	0.083	360.60	48.73	20.00	3.70	2.38
CD (0.05)	0.09	0.008	0.030	NS	0.011	56.07	NS	1.77	0.585	0.07

the grain. The maximum content of N and P was observed at the K_2 level (70 kg ha^{-1}) and it was significantly superior to K_1 (35 kg ha^{-1}).

The K content of the grain showed a decrease at K_2 level compared to K_1, however the maximum content of K was present at K_3 level (105 kg ha^{-1}) and it was significantly superior to K_1 and K_2. The minimum content of Ca was present at K_3 level while lowest Mg content was present at K_2 level. Lowest content of Fe was present at K_2 level. The Mn content of the grain showed significant reduction with increasing levels of K.

Effect of lime

The two levels of lime application significantly influenced the P, Fe and Cu content of the grain. Lime application at (600 kg ha^{-1}) significantly increased the P and Cu content while the Fe content of the grain showed a decrease.

Effect of controls

C_2 (POP) recorded the highest content of N, P, K, Mg, Zn and Cu while C_3 (farmer's practice) recorded the highest content of Fe and Si. Fe and Si content in C_3 was significantly superior to C_2. Calcium and Mn content of the grain was not significantly influenced by the control treatments.

4.1.2.5.5 Interaction effects on elemental composition of grain

Interaction between P and K

It can be seen from the table 35a that higher level of P and K (P_2K_3) recorded the highest content of K (0.49%). Increasing the P application from 17.5 to 35 kg ha^{-1} significantly increased the K content at all levels of K application. At 17.5 kg ha^{-1} of P application increasing the K level from K_2 to K_3 increased the K content by 12 per cent while at 35 kg ha^{-1} of P application increase in K content from K_1 to K_3 was 14 per cent. There was a decreasing trend for the Ca content of the grain with increase in K dose from K_1 to K_3 at both levels P. For the Mg content of the grain

Table 35 a Effect of P and K on elemental composition of grain (Ottappalam)

Treatment	K (%)			Ca (ppm)			Mg (ppm)			Zn (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.36	0.36	0.41	0.04	0.04	0.01	0.09	0.08	0.07	22.97	23.17	20.98
P_2	0.42	0.48	0.49	0.03	0.02	0.01	0.10	0.10	0.09	21.52	18.30	20.22
CD(0.05)	0.02			0.01			0.007			1.25		

Table 35 b Effect of K and lime on elemental composition of grain (Ottappalam)

Treatment	P (%)		Fe (%)		Mn (%)	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	0.11	0.11	381.67	268.50	37.92	35.90
K_2	0.11	0.14	141.67	105.00	34.13	26.10
K_3	0.12	0.13	283.67	159.33	30.27	29.53
CD(0.05)	0.005		39.64		2.44	

there was a decrease with increasing levels of K at P_1. At P_2 the decrease was seen only at K_3 level.

Increase in level of P decreased the Zn content of the grain at K_1 and K_2. Combined application of 17.5 kg ha^{-1} of P and 70 kg ha^{-1} of K recorded the highest content of zinc (23.17 ppm) in the grain and the lowest content (18.30 ppm) was observed at P_2K_2 and these two differed significantly by 20.3 per cent.

Interaction between K and lime

Effect of K and lime on P, Fe and Mn content of the grain is given in table 35b.

Increasing level of K from K_2 to K_3 at 300 kg ha^{-1} of lime increased the P content of the grain. At 600 kg ha^{-1} of lime, increasing K from K_1 to K_2 increased the P content though this change was ineffective at lower dose of lime. Increase in K application from K_1 to K_2 resulted in substantial reduction in Fe content of the grain .Fe content of the grain was decreased to the lowest level of 105 ppm by the combined application of 70 kg ha^{-1} of K and 600 kg ha^{-1} of lime. The extent of reduction compared to the highest content (381.67 ppm) at K_1L_1 was by 72 per cent.

Lime application at higher level resulted in decrease of Mn content of grain at K_2 and at other levels of K change in lime dose did not affect the Mn content. Increase in K dose resulted in decrease in Mn content of the grain at 300 kg ha^{-1} of lime application while at 600 kg ha^{-1} of lime application the Mn content of the grain showed an increase beyond K_2. The maximum value for Mn content was observed at K_1L_1 and the minimum value recorded at K_2L_2 and the Mn content at both these levels differed by 30 per cent.

4.1.3 Nutrient uptake by rice crop

4.1.3.1 Nutrient uptake of straw at Koyalmannam

Effect of different levels of P, K, lime and the controls on nutrient uptake of straw is given in the table 36.

Table 36. Nutrient uptake in straw (kg ha^{-1}) (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	29.33	4.24	59.28	6.65	3.41	4.85	0.94	0.22	0.02	100.19
P_2	33.02	5.37	57.97	6.11	3.34	4.09	0.95	0.19	0.02	97.83
CD (0.05)	NS	0.74	NS	NS	NS	0.50	NS	0.02	NS	NS
Levels of Potassium										
K_1	26.92	4.38	51.00	6.52	2.89	4.43	0.91	0.18	0.02	88.07
K_2	33.97	5.47	67.35	6.95	3.88	4.83	1.03	0.23	0.03	102.61
K_3	32.63	4.56	37.52	5.67	3.34	4.16	0.89	0.20	0.02	106.34
CD (0.05)	5.09	NS	8.44	0.86	0.53	NS	NS	0.03	NS	NS
Levels of Lime										
L_1	28.50	4.82	56.03	5.63	3.36	4.31	0.90	0.19	0.02	90.78
L_2	33.85	4.79	61.22	7.13	3.38	4.63	0.98	0.22	0.03	107.23
CD (0.05)	4.16	NS	NS	0.70	NS	NS	NS	0.02	0.002	NS
Controls										
C_1	24.08	1.93	47.14	4.75	2.55	3.11	0.76	0.14	0.016	79.33
C_2	28.57	2.56	51.58	5.94	3.63	3.10	0.85	0.16	0.020	82.50
C_3	23.67	2.97	47.40	4.01	3.69	3.86	0.84	0.15	0.018	93.98
CD (0.05)	NS	NS	3.80	1.70	1.06	0.65	NS	NS	NS	NS

Effect of P

It is clear from the table that the two levels of P application significantly influenced the uptake of mainly P, Fe and Zn. The uptake of P increased by 21 per cent, while the Fe and Zn uptake was decreased by 15.6 and 13.6 per cent respectively with an increase in P level from 17.5 kg ha^{-1} to 35 kg ha^{-1}.

Effect of K

Different levels of K application significantly influenced the N, K, Ca, Mg and Zn uptake. K_2 (70 kg ha^{-1}) recorded the highest value for N, K, Ca, Mg and Zn uptake. K_2 was significantly superior to K_1 for the uptake of the above elements except Ca for which it was on par with K_1. A significant decrease in K and Ca uptake was noticed with the application of 105 kg ha^{-1} of potassium.

Effect of lime

Lime application at higher level significantly modified the N, Ca, Zn and Cu uptake.

There was a significant increase in the uptake of N, Ca, Zn and Cu to the tune of 18.7, 26.6, 15.7 and 33 per cent respectively. When the lime dose was increased from 300 kg ha^{-1} to 600 kg ha^{-1}. The other elements remained unaffected by the two levels of lime application.

Effect of controls

The significant effect of different control treatments on modifying the nutrient uptake was confined only to Ca and Mg. The Ca uptake in C_2 (POP) increased by 32 per cent over C_3 (farmer's practice). Magnesium uptake in C_1 decreased by 30 per cent over farmer's practice.

4.1.3.2 Interaction effect on nutrient uptake in straw

Interaction of P and K on nutrient uptake by straw is given in the table 37.

Table 37 Effect of P and K on nutrient uptake by straw (Koyalmannam)

Treatment	Ca (kg ha^{-1})			Fe (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	6.42	6.89	6.64	4.37	4.88	5.31	0.17	0.24	0.23
P_2	6.62	7.02	4.69	4.50	4.78	3.01	0.19	0.21	0.18
CD (0.05)		1.21			0.88			0.01	

Interaction between P and K

Increasing K application did not affect the Ca uptake in straw when P was applied at 17.5 kg ha^{-1}. The uptake of Ca showed a significant decrease at P_2K_3 compared to all other treatment combinations .From the data on the Fe uptake it can be seen that a substantial decrease in Fe uptake in straw was observed by increasing the level of P when K was applied at 105 kg ha^{-1}. The uptake of Zn by straw showed a significant increase with increase in the K dose at P_1 level and K_2 was on par with K_3 for the uptake. But at P_2 level there was a significant increase in the Zn uptake at K_2 and beyond K_2 a decrease was observed. Increasing the P dose to 35 kg ha^{-1} in the presence of 35 kg ha^{-1} of K increased the uptake by 11 per cent, but in the presence of 70 and 105 kg ha^{-1} of K the Zn uptake was decreased significantly by 12.5 and 21 per cent respectively.

4.1.3.3 Nutrient uptake of straw at Ottappalam

Effect of P, K, lime and controls on the nutrient uptake of straw is given in the table 38.

Effect of P

It may be seen from the table 38 that P application at two levels 17.5 kg ha^{-1} and 35 kg ha^{-1} significantly influenced the uptake of N, P, Mg and Cu by increasing the uptake of these nutrients at a higher level of P. On the other hand the different levels of application of P failed to significantly influence the K, Ca, Fe, Mn, Zn and Si uptake by straw.

Effect of K

The uptake of N, P, K, Mn, Zn and Cu was maximum at K_2 levels (70 kg ha^{-1}) which was significantly superior to K_1 (35 kg ha^{-1}) and on par with K_3 level (105 kg ha^{-1}).Calcium and Mg and Fe uptake at K_3 level registered the lowest value and it was significantly inferior to both K_1 and K_2. Maximum Silicon uptake was at K_2 level and it was significantly superior to both K_1 and K_3.

Table 38. Nutrient uptake in straw (kg ha^{-1}) (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	25.31	4.85	73.15	7.69	2.57	6.34	1.04	0.26	0.02	106.42
P_2	29.88	5.31	79.85	8.42	3.86	5.95	1.18	0.25	0.03	111.18
CD (0.05)	3.00	0.42	NS	NS	0.744	NS	NS	NS	0.002	NS
Levels of Potassium										
K_1	21.79	3.77	64.59	7.90	3.47	6.43	1.01	0.20	0.02	103.94
K_2	32.22	5.77	85.03	9.82	4.01	7.07	1.22	0.29	0.03	118.72
K_3	28.77	5.70	79.89	6.45	2.16	5.24	1.11	0.28	0.03	103.74
CD (0.05)	4.00	0.52	9.09	1.26	0.911	0.807	0.119	0.027	0.002	11.18
Levels of Lime										
L_1	27.65	5.05	81.63	7.97	3.09	6.85	1.17	0.26	0.02	118.36
L_2	27.54	5.11	71.37	8.14	3.34	5.44	1.04	0.25	0.02	99.24
CD (0.05)	NS	NS	7.42	NS	NS	0.659	0.097	NS	NS	9.12
Controls										
C_1	23.90	4.08	68.05	7.76	3.72	5.24	1.04	0.23	0.02	106.35
C_2	24.12	4.11	65.50	7.63	3.59	5.02	0.96	0.22	0.02	94.89
C_3	2026	3.60	58.22	6.01	1.98	6.39	0.93	0.19	0.01	95.89
CD (0.05)	NS	NS	8.00	NS	1.02	1.01	NS	NS	NS	NS

Effect of lime

As is evident from the table 39, the application of lime at 600 kg ha^{-1} significantly decreased the uptake of K, Fe and Mn by 15, 20 and 11 per cent respectively.

Effect of controls

The various control treatments could significantly influence the straw uptake of only K, Mg and Fe. C_3 (farmer's practice) recorded the minimum uptake of K and maximum uptake of Fe. However maximum Mg uptake was in C_1 and it was significantly superior to C_3.

4.1.3.4 Interaction effect on nutrient uptake of straw

Interaction between P and lime

Increasing the level of application of P increased the P uptake by straw at lower and higher levels of lime (Table 39a). Either by increasing the level of application of lime at lower level of P or by increasing the level of P at lower level of lime resulted in increased Ca uptake by straw.

Interaction between K and lime

It can be seen from the table 39b that K_2L_1 recorded the highest value for K uptake (96.12 kg ha^{-1}) which is significantly superior to the lowest K uptake (62.31 kg ha^{-1}) obtained at K_1L_1 by 35 per cent. At 300 kg ha^{-1} of lime application there was a significant increase in the K uptake with increasing levels of K dose from K_1 to K_2 and further increase in K level was ineffective. At higher level of lime, increasing the dose of K did not result in a change in K uptake. With increasing levels of K and lime, Fe uptake decreased. The Fe uptake showed its maximum value at K_1L_1 (8.17 kg ha^{-1}) and the minimum value (4.45 kg ha^{-1}) at K_3L_2. At all levels of K Fe uptake decreased, when the lime dose increased from 300 kg ha^{-1} to 600 kg ha^{-1}. When application of K was increased from 35 to 70 kg ha^{-1} at 300 kg ha^{-1} of lime, Fe uptake decreased and there was no further change for increase in K .But at 600 kg ha^{-1} of lime application

Table 39 a Effect of P and lime on nutrient uptake by straw (Ottappalam)

Treatment	P (kg ha^{-1})		Ca (kg ha^{-1})	
	L_1	L_2	L_1	L_2
P_1	4.43	5.27	7.11	8.28
P_2	5.67	4.95	8.83	8.00
CD (0.05)	0.60		1.06	

Table 39 b Effect of K and lime on nutrient uptake by straw (Ottappalam)

Treatment	K (kg ha^{-1})		Fe (kg ha^{-1})		Zn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	62.31	66.86	8.17	6.35	0.19	0.21
K_2	96.12	73.94	5.99	5.90	0.31	0.27
K_3	86.47	75.31	6.04	4.95	0.30	0.27
CD (0.05)	12.85		1.02		0.02	

the decrease in Fe uptake occurred only when K dose was increased from 35 to 105 kg ha^{-1}. The Zn uptake increased when K dose increased from 35 kg ha^{-1} to 70 kg ha^{-1} and further increase in K application was ineffective at higher and lower levels of lime.

4.1.3.5 Nutrient uptake of grain at Koyalmannam

Effects of P, K, lime and controls on nutrient uptake of grain is given in table 40.

Effect of P

The P application significantly enhanced the grain uptake of N, P, K, Mg, Mn and Si as is evident from the table. The P application at 35 kg ha^{-1} increased the N, P and K uptake by 15.9, 13.7 and 8 per cent respectively over P_1. Uptake of other elements remained unaffected with changes in P application.

Effect of K

Application of K at three different levels i.e., 35 kg ha^{-1}, 70 kg ha^{-1} and 105 kg ha^{-1} was found to modify the uptake of N, P, K, Ca, Mg, Fe, Mn, Cu and Si. A significant increase in the N, P and K uptake to the extent of 24.1,15.45 and 15 percent respectively was observed at K_2 (70 kg ha^{-1}) compared to K_1 (35 kg ha^{-1}). K_2 and K_3 were on par for the N, P and K uptake. While K_1 and K_2 were on par for Ca, Mn and Cu uptake. There was a decrease in the uptake of Ca and Mn and an increase in the uptake of Cu, when the K dose was increased from K_2 (70 kg ha^{-1}) to K_3 (105 kg ha^{-1}). Maximum Mg uptake was obtained at K_1 level and it was significantly different from the K_3 level. There was a steady decline in the uptake of Fe with increasing levels of K. The uptake of Fe decreased by 29 and 22 per cent as K dose was increased from K_1 to K_2 and K_2 to K_3 respectively.

Effect of lime

The two levels of lime application significantly influenced the uptake of N, P, K, Ca, Mg, Fe and Zn. Lime application at 600 kg ha^{-1} significantly, increased the

Table 40 Nutrient uptake in grain (kg ha^{-1}) (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	37.70	5.76	15.34	0.95	3.81	0.82	0.16	0.080	0.020	76.44
P_2	43.71	6.55	16.71	0.81	4.44	0.75	0.18	0.080	0.020	83.08
CD (0.05)	1.88	0.29	0.95	NS	0.22	NS	0.01	NS	NS	3.80
Levels of Potassium										
K_1	34.73	5.50	14.17	1.07	4.28	1.05	0.18	0.080	0.020	77.45
K_2	43.11	6.35	16.36	1.06	4.15	0.74	0.18	0.080	0.020	82.26
K_3	44.28	6.60	17.54	0.53	3.96	0.57	0.16	0.080	0.030	79.57
CD (0.05)	2.31	0.36	1.61	0.20	0.27	0.12	0.01	NS	0.001	4.10
Levels of Lime										
L_1	38.00	5.77	15.31	0.79	3.74	0.87	0.17	0.080	0.020	77.41
L_2	43.41	6.54	16.74	0.97	4.52	0.70	0.17	0.090	0.020	82.12
CD (0.05)	1.88	0.29	0.95	0.17	0.22	0.09	NS	0.005	NS	NS
Controls										
C_1	41.79	6.08	16.87	1.02	4.48	0.82	0.19	0.083	0.022	81.75
C_2	43.06	6.40	16.63	1.27	4.77	0.63	0.18	0.080	0.024	80.76
C_3	33.78	5.76	15.03	0.57	3.41	1.20	0.16	0.081	0.024	82.94
CD (0.05)	4.62	NS	NS	0.41	0.55	0.24	NS	NS	NS	NS

uptake of N, P, K, Ca, Mg, Fe and Zn to the tune of 14.2, 13.3, 9.3, 22, 20, 9.5 and 12.5 per cent respectively over lime application at 300 kg ha^{-1}.

Effect of controls

It is obvious from the table 40 that various control treatments significantly modified the uptake of N, Ca, Mg and Fe. N uptake in C_2 (POP) was significantly higher than C_3 (the farmer's practice). C_1 (POP without lime) was on par with C_2 for N uptake. The Ca and Mg uptake in C_2 was higher than C_3 by 55 and 28 per cent respectively and C_2 was on par with C_1. C_3 recorded the highest Fe uptake and it was significantly superior to C_2 i.e., by about 47 per cent.

4.1.3.6 Interaction effect on nutrient uptake by grain

Interaction effect of P and K on nutrient uptake by grain is given in the table 41.

Interaction between P and K

It can be seen from the table 41 that P uptake increased with increase in K dose at both levels of P application. At K_1 and K_2 level increase in P dose increased the uptake of P by 24 per cent. But at K_3 no significant difference was observed between P_1 and P_2. P_2K_2 and P_1K_1 respectively registered the highest and lowest uptake of P by grain. Significant increase in K uptake with increase in K level was observed at P_1. P_1K_2 and P_1K_3 showed significant increase in K uptake over P_1K_1 to tune of 25 and 50 per cent respectively. At P2 increase in K uptake occurred upto 70 kg ha^{-1} beyond which there was no change in K uptake.

Increasing the level of K affected the Mn uptake only when K was increased from K_2 to K_3 in presence of P_2. This change was to decrease the Mn uptake drastically. The Mn uptake registered the highest value at P_2K_1 and P_2K_2 and it was significantly superior to all other treatments. Data on the Zn uptake showed that the application of K at 105 kg ha^{-1} significantly increased the uptake in the presence of 17.5 kg ha^{-1} of P application. But with 35 kg ha^{-1} of P application a significant

Table 41 Effect of P and K on nutrient uptake by grain (Koyalmannam)

Treatment	P (kg ha^{-1})			K (kg ha^{-1})			Mn (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	4.91	5.66	6.72	12.78	15.16	18.09	0.16	0.16	0.17	0.08	0.08	0.09
P_2	6.09	7.05	6.50	15.56	17.56	17.00	0.19	0.19	0.15	0.08	0.09	0.07
CD (0.05)	0.50			1.65			0.01			0.009		

decrease was observed at K_3. Increasing the P to 35 kg ha^{-1} at K_2 or by increasing the level of K from K_1 to K_2 at P_2 significantly increased the Zn uptake.

4.1.3.7 Nutrient uptake by grain at Ottappalam

Effect of P, K, lime and controls on nutrient uptake of grain is given in the table 42.

Effect of P

As is given in the table, P application at higher level increased the uptake of K while it decreased the uptake of Ca, Fe and Zn. The two levels of P failed to influence significantly the uptake of N, P, Mg, Mn, Cu and Si.

Effect of K

The uptake of K was significantly increased at higher levels of K while the Fe and Mn uptake decreased with increasing levels of K. The Ca uptake was minimum at K_3 level and it was significantly inferior to K_1 and K_2. The uptake of Si increased with increasing levels of K and it was maximum at K_3 level.

Effect of Lime

Lime application at higher level significantly increased the uptake of N, P, K, Ca and Mg.

Effect of controls

Maximum K uptake was observed in C_1 and it was significantly superior to C_3 and on par with C_2. However, the C_2 recorded the highest value for Mg uptake and it was significantly superior to C_3. Maximum Fe uptake was in C_3 followed by C_1. C_3 and C_1 were significantly superior to C_2 for Fe uptake. C_1 and C_2 were on par for Zn uptake and significantly superior to C_3.

Table 42 Nutrient uptake in grain (kg ha^{-1}) (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	37.44	4.24	14.28	0.99	3.14	0.78	0.11	0.08	0.020	84.64
P_2	35.40	4.53	16.56	0.69	3.38	0.64	0.12	0.07	0.020	80.69
CD (0.05)	NS	NS	1.13	0.22	NS	0.08	NS	0.006	NS	NS
Levels of Potassium										
K_1	29.98	3.68	13.25	1.03	3.22	1.09	0.13	0.08	0.020	76.00
K_2	38.30	5.00	15.73	1.05	3.36	0.60	0.11	0.08	0.010	83.88
K_3	40.99	4.48	17.28	0.45	3.20	0.44	0.11	0.08	0.020	88.10
CD (0.05)	NS	NS	1.38	0.27	NS	0.10	0.01	NS	NS	NS
Levels of Lime										
L_1	33.29	3.94	14.61	0.72	2.95	0.79	0.12	0.08	0.020	76.44
L_2	39.56	4.83	16.23	0.96	3.57	0.62	0.12	0.08	0.020	88.89
CD (0.05)	2.89	0.33	1.13	0.22	0.28	NS	NS	NS	NS	5.73
Controls										
C_1	30.59	4.08	15.13	0.92	3.17	0.82	0.13	0.07	0.014	75.25
C_2	32.34	4.36	14.94	1.10	3.58	0.67	0.13	0.07	0.016	75.64
C_3	27.69	3.98	11.24	0.48	2.80	1.22	0.11	0.05	0.012	77.65
CD (0.05)	NS	NS	2.00	NS	0.70	0.20	NS	0.01	NS	NS

4.1.3.8 *Interaction effect on nutrient uptake by grain*

Interaction between P and K

Effect of P and K on N, Ca and Zn uptake is given in the table 43a.

Increasing the dose of K from 35 to 70 kg ha^{-1} at P_1 increased the N uptake by grain and straw and further increase in K dose was ineffective for N uptake. However at P_2 level significant increase was observed only at K_3. Significant effect of P at higher level on N uptake was only when K was applied at 70 kg ha^{-1} and at other levels of K increase in P was ineffective. Similarly when dose of P was increased at 70 kg ha^{-1} of K, Ca uptake decreased and the change in dose of P was ineffective for the Ca uptake also at other levels of K as in the case of N uptake. The grain uptake of Zn showed a significant decrease at higher level of P in the presence of 70 kg ha^{-1} of P application, a similar pattern as that of N and Ca.

Interaction between K and lime

Application of 105 kg ha^{-1} K along with 600 kg ha^{-1} of lime registered the highest value for the uptake of P and the lowest value was recorded at K_1L_1 (Table 43b). Increasing the lime application rate at K_2 and K_3 level significantly increased the P uptake by 29 per cent and 27 per cent respectively. At 300 kg ha^{-1} of lime application, a significant increase in P uptake at K_3 compared to K_1 was observed and at 600 kg ha^{-1} of lime application a significant increase at K_2 and K_3 compared to K_1 was seen.

There was a significant reduction in the uptake of Fe when the dose of K was increased at 300 kg ha^{-1} of lime dose. But at 600 kg ha^{-1} of lime dose the decrease in Fe uptake occurred only up to 70 kg ha^{-1} of K. Maximum Fe uptake was recorded by K_1L_1 and the minimum uptake registered by K_3L_1 and the extent of reduction between the two levels was 65 per cent. K_3L_1 recorded the lowest Mn uptake while K_1L_2 registered the highest Mn uptake and both differed significantly by 15 per cent. In the presence of 600 kg ha^{-1} of lime application K_2 recorded significantly lower Mn uptake compared to K_1. Similarly lime application at higher level when K was applied at 70 kg ha^{-1} decreased the Mn uptake of grain.

Table 43a Effect of P and K on nutrient uptake by grain (Ottappalam)

Treatment	N ($kg\ ha^{-1}$)			Ca ($kg\ ha^{-1}$)			Zn ($kg\ ha^{-1}$)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	28.69	41.69	42.04	1.15	1.43	0.39	0.08	0.09	0.08
P_2	31.27	34.99	39.95	0.90	0.66	0.51	0.08	0.06	0.07
CD (0.05)	5.00			0.38			0.01		

Table 43b Effect of K and lime on nutrient uptake by grain (Ottappalam)

Treatment	P ($kg\ ha^{-1}$)		Fe ($kg\ ha^{-1}$)		Mn ($kg\ ha^{-1}$)	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	3.52	3.84	1.25	0.93	0.12	0.13
K_2	3.91	5.05	0.70	0.50	0.12	0.10
K_3	4.39	5.61	0.43	0.44	0.11	0.12
CD (0.05)	0.58		0.14		0.01	

Table 44 Second order interaction effect on nutrient uptake by grain (Ottappalam)

Treatment	P (kg ha^{-1})		Fe (kg ha^{-1})		Mn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	3.90	4.78	0.60	0.59	0.12	0.10
P_1K_2	4.53	3.90	0.65	0.65	0.11	0.12
P_1K_3	4.70	4.46	0.62	0.84	0.10	0.11
P_2K_1	4.04	5.08	0.73	0.67	0.13	0.10
P_2K_2	4.62	4.40	0.70	1.03	0.12	0.15
P_2K_3	4.22	4.23	0.77	0.86	0.10	0.12
CD (0.05)	0.82		0.21		0.02	

Second order interaction effect on nutrient uptake of grain

The uptake of P, Fe and Mn were significantly influenced by the interaction of P, K and lime (Table 44).

Increased lime application resulted in an increase in P uptake when K was applied at 70 kg ha^{-1} The P and Fe registered the maximum uptake at $P_2K_1L_2$ and $P_2K_2L_2$ respectively. When lime dose was increased there was an increase in Fe uptake of grain at P_1K_3 and P_2K_2. Also when K was increased from 35 to 70 kg ha^{-1} at P_2L_2 there was an increase in the Fe uptake of grain. The Mn uptake was significantly increased at $P_2K_2L_2$. The lowest value for Mn uptake was registered by $P_1K_3L_1$ that was lower than POP and farmer's practice.

4.1.4 Nutrient content of soil

The nutrient content of soil at critical stages were analysed which are presented hereunder

4.1.4.1.1 Nutrient content of soil at MT stage at Koyalmannam

The Effect of different levels of P, K, lime and controls on the available nutrient content of soil are presented in the table 2.1.

Effect of P

It is evident from the table table 2.1 that application of P at higher levels significantly increased the P, Mg and Cu content of the soil by 11, 10 and 17 per cent respectively compared to lower level whereas that of Ca and Zn decreased to the extent of 10 per cent while Fe and Mn decreased by 5.2 and 2 per cent respectively.

Effect of K

Increasing the dose of K from 35 to 105 kg ha^{-1} increased the N and K content of the soil by 1.4 and 5.6 per cent respectively. The Ca and Fe content of the

Table 2.1 Nutrient content of soil at MT stage (Koyalmannam)

Treatment	Available nutrients ($kg\ ha^{-1}$)			Exchangeable nutrients $cmol\ kg^{-1}$		Available nutrients ($kg\ ha^{-1}$)			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	215.76	23.29	218.09	0.560	0.350	645.81	44.72	2.57	0.86
P_2	216.30	25.86	220.35	0.500	0.360	611.51	43.80	2.29	1.04
CD(0.05)	NS	1.42	NS	0.040	0.006	24.69	0.67	0.16	0.14
Levels of Potassium									
K_1	214.55	24.13	213.67	0.570	0.360	679.38	44.84	2.34	1.03
K_2	216.01	24.77	218.68	0.520	0.350	566.76	44.54	2.48	0.87
K_3	217.53	24.82	225.01	0.500	0.350	639.83	43.00	2.47	0.95
CD(0.05)	1.40	NS	4.35	0.050	NS	30.24	NS	NS	NS
Levels of Lime									
L_1	215.56	23.65	221.52	0.440	0.350	663.14	44.14	2.53	0.93
L_2	216.50	25.50	216.92	0.620	0.360	594.17	42.00	2.33	0.97
CD(0.05)	NS	1.42	3.50	0.040	0.006	24.69	NS	0.16	NS
Controls									
C_1	219.86	24.05	218.17	0.315	0.361	644.91	44.84	2.03	1.23
C_2	219.66	24.48	219.40	0.586	0.362	641.92	45.18	1.90	1.236
C_3	214.35	16.42	190.16	0.310	0.352	685.67	43.80	1.63	1.20
CD(0.05)	2.90	4.22	8.70	0.110	0.001	30.49	NS	NS	NS

soil decreased significantly to the tune of 1.2 per cent and 16.6 per cent respectively at K_2 compared to K_1 and at K_3 an increase in the content of both Ca and Fe compared to K_2 was observed.

Effect of lime

Application of lime at 600 kg ha^{-1} increased the P, Ca and Mg content and decreased the K, Fe and Zn content of the soil.

Effect of controls

Among the control treatments C_2 (POP) recorded the highest content of N, P, K, Ca and Mg while the C_3 (the farmers practice) recorded the highest content of Fe. Significant difference between C_1 and C_2 was observed only for Ca content and C_2 was superior to C_1 for the content of Ca.

4.1.4.1.2 Interaction effect on nutrient content of soil

Interaction between P and K

Combined application of P and K significantly influenced the Mg, Fe, Mn and Zn content of the soil (2.2a). Application of K at 105 kg ha^{-1} in the presence of 17.5 kg ha^{-1} of P significantly decreased the Mg content of the soil by 5 per cent compared to 35 kg ha^{-1} of K application. The Mg content at P_2K_3 was also significantly lower than P_2K_2 by 5 per cent. At K_2 and K_3 higher dose of P gave higher content of Mg.

As the dose of K increased to 70 kg ha^{-1}, Fe content of the soil decreased and further increase in K dose did not make a significant decrease. The content of Mn was significantly reduced at higher level P and K. Mn content of soil decreased either by increasing the level of P at K_3 or by increasing the level of K from 70 kg ha^{-1} to 105 kg ha^{-1} at P_2.P_2K_3 registered the lowest quantity of Mn compared to all other treatment combinations.

There was a significant decrease in the Zn content at higher level of P application in the presence of 35 kg ha^{-1} of K. P_2K_3 registered significantly higher quantity of Zn compared to P_2K_1.

Interaction between K and lime

The interaction between K and lime significantly influenced the Mg, Fe and Zn content of the soil (2.2b). At K_1 level increase in lime dose significantly increased the Mg content of the soil. In the presence of 600 kg ha^{-1} of lime application increase in K dose to 105 kg ha^{-1} significantly decreased the Mg content compared to 35 kg ha^{-1} of K. 600 kg ha^{-1} of lime application significantly decreased the Fe content by 8.1 and 18 per cent respectively at K_1 and K_2 level compared to 300 kg ha^{-1} of lime. With 300 kg ha^{-1} and 600 kg ha^{-1} of lime the Fe content decreased at higher level of K application. There was a significant decrease in the Fe content at K_2L_1 and K_2L_2 respectively by 12.1 and 21 per cent compared to K_1L_1 and K_1L_2. There was a significant decrease in the Zn content with increase in lime application at K_3 level. The Zn content of soil was significantly decreased by 12 per cent when the K dose increased to 105 kg ha^{-1} from 70 kg ha^{-1} in the presence of 600 kg ha^{-1} of lime.

4.1.4.1.3 Nutrient content of soil at MT stage at Ottappalam

Effect of P, K, lime and controls on nutrient content of soil at maximum tillering stage is given in the table 2.3.

Effect of P

Application of P at 35 kg ha^{-1} significantly increased the N and P content of the soil while it decreased the Fe and Zn content.

Effect of K

Graded levels of K application significantly increased the N and K content of soil. But the N content at K_3 level decreased compared to K_2. Magnesium and Mn content of the soil decreased with increasing levels of K application. K_1 was on par with K_2 for the Mn content.

Table 2.2a. Effect of P and K on nutrient content of soil at MT stage (Koyalmannam)

Treatment	Mg (cmol (+) kg^{-1})			Fe (kg ha^{-1})			Mn (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.36	0.35	0.34	682.02	604.00	651.41	44.89	44.64	44.64	2.49	2.50	2.41
P_2	0.36	0.37	0.35	676.74	529.52	628.26	44.80	44.44	42.24	2.20	2.45	2.53
CD(0.05)	0.01			42.77			1.16			0.28		

Table 2.2b. Effect of K and Lime on nutrient content of soil at MT stage (Koyalmannam)

Treatment	Mg (cmol (+) kg^{-1})		Fe (kg ha^{-1})		Zn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	0.35	0.37	708.75	650.00	2.40	2.29
K_2	0.35	0.36	622.76	510.77	2.55	2.50
K_3	0.35	0.35	657.92	621.75	2.65	2.20
CD(0.05)	0.01		42.77		0.28	

Table 2.4. Effect of P and K on nutrient content of soil at MT stage (Ottappalam)

Treatment	N (kg ha^{-1})			Fe (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	247.44	257.46	247.74	673.24	633.75	631.83
P_2	254.91	272.00	269.21	599.40	584.61	643.51
CD(0.05)	6.4			28.5		

Table 2.3 . Nutrient content of soil at MT stage (Ottappalam)

Treatment	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	250.88	15.93	168.38	0.380	0.138	646.27	29.27	3.47	1.20
P_2	265.37	25.19	173.39	0.390	0.137	609.17	29.05	3.10	1.25
CD(0.05)	3.74	0.86	NS	NS	NS	15.64	NS	0.125	NS
Levels of Potassium									
K_1	251.17	20.38	162.69	0.380	0.138	616.32	30.41	3.16	1.12
K_2	264.90	20.35	169.32	0.370	0.132	629.18	30.13	3.26	1.29
K_3	258.48	20.94	180.64	0.390	0.131	637.67	26.94	3.43	1.28
CD(0.05)	4.50	NS	3.50	NS	0.004	NS	1.84	NS	NS
Levels of Lime									
L_1	255.01	20.46	170.95	0.330	0.131	624.58	29.08	3.30	1.24
L_2	261.24	20.65	170.81	0.430	0.136	630.86	29.24	3.26	1.21
CD(0.05)	3.74	NS	NS	0.050	0.003	NS	NS	NS	NS
Controls									
C_1	252.40	23.36	169.65	0.330	0.130	590.34	28.70	3.07	1.13
C_2	257.74	23.25	168.30	0.400	0.125	602.84	27.33	3.10	1.23
C_3	239.50	11.84	160.13	0.350	0.127	589.84	30.71	2.95	1.30
CD(0.05)	9.16	2.11	7.01	NS	NS	NS	NS	NS	NS

Effect of lime

Lime application at 600 kg ha^{-1} increased the N, Ca and Mg content of the soil.

Effect of controls

The C_2 (POP) recorded the highest content of N and for the P and K content C_2 was on par with C_1. But for the N, P and K C_2 was significantly superior to C_3.

4.1.4.1.4 Interaction effect on nutrient content of soil

Interaction between P and K

Effect of P and K on available N and Fe content of soil is given in the table 2.4. With increase in level of K the available N content of soil increased up to 70 kg ha^{-1} of K and beyond which it decreased when P was applied at 17.5 kg ha^{-1}. At 35 kg ha^{-1} of P application the same trend was observed up to 70 kg ha^{-1} of K application beyond which there was no change in the N content of the soil. Increased application of P resulted in an increase in the available N content of soil at all levels of K and this effect was more pronounced at K_2. There was a significant decrease in the Fe content of soil at higher level of P and K. P_2K_2 registered the lowest value for the available Fe content of soil.

4.1.4.2.1 Nutrient content of soil at PI stage at Koyalmannam

Effect of different levels of P, K, lime and controls on the nutrient content of soil at MT are presented in the table 2.5.

Effect of P

It can be seen from the table that application of P at higher levels significantly increased the soil P content by 28 per cent, while the Fe and Mn content was decreased to by 2 and 9 per cent respectively. The other nutrients remained unaffected at higher level of P application.

Table 2.5. Nutrient content of soil at PI stage (Koyalmannam)

Treatment	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	188.00	20.26	196.37	0.40	0.23	571.37	43.24	2.51	1.10
P_2	193.07	26.11	199.02	0.40	0.24	517.32	42.39	2.26	1.30
CD(0.05)	NS	0.92	NS	NS	NS	13.87	0.68	NS	NS
Levels of Potassium									
K_1	187.12	22.50	199.24	0.38	0.24	557.00	43.36	2.40	1.19
K_2	191.44	22.99	193.23	0.39	0.23	536.70	43.04	2.37	1.17
K_3	193.72	23.90	200.61	0.43	0.23	538.40	42.04	2.38	1.27
CD(0.05)	1.51	1.12	3.42	NS	NS	NS	0.84	NS	NS
Levels of Lime									
L_1	190.07	22.75	199.10	0.32	0.23	550.72	42.75	2.43	1.23
L_2	191.44	23.62	196.29	0.48	0.23	537.97	42.88	2.33	1.18
CD(0.05)	NS	0.91	2.78	0.03	NS	NS	NS	NS	NS
Controls									
C_1	193.60	24.25	195.77	0.32	0.23	581.07	44.98	2.30	0.716
C_2	195.40	27.50	197.66	0.40	0.24	576.43	45.16	2.36	0.88
C_3	189.72	15.35	183.30	0.31	0.23	583.41	43.87	2.13	0.91
CD(0.05)	NS	2.25	6.83	0.07	NS	NS	NS	NS	NS

Effect of K

Application of K at increasing levels increased the N content of the soil while the K content of the soil decreased at K_2 but at K_3 it significantly increased by 6.8 per cent. The Mn content of the soil decreased with increase in K levels. However significant decrease was observed only at K_3.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the P and Ca content of the soil by 3.8 and 50 per cent respectively while the K content of the soil decreased by 1.4 per cent.

Effect of controls

The control treatments could significantly influence only P, K and Ca content of soil. Maximum content of P, K and Ca was present in C_2 (POP) followed by C_1 (POP without lime).

4.1.4.2.2 Interaction effect on nutrient content of soil

Interaction between P and K

Phosphorus and K interacted significantly to influence the N, Ca, Fe, Mn and Zn content of the soil (Table 2.6a).

Maximum content of N was observed at P_2K_3 and the minimum content was at P_1K_1 and both differed significantly by 6.2 per cent. A significant increase in the N content of soil at P_1 was observed with increase in K dose but not with P_2. A significant decrease in the Ca content at K_2 and K_3 to the tune of 15.2 and 23.9 per cent respectively in the presence of 17.5 kg ha^{-1} of P was observed. P_2K_2 registered significantly lower quantity of Ca to the extent of 4.8 per cent compared to P_2K_1.

The Fe content at P_2K_2 and P_2K_3 was significantly decreased by 8.7 and 7.6 percent respectively compared to P_2K_1. At P_1 level no significant difference was observed with increasing dose of K. At K_2 and K_3 levels increasing the P dose

Table 2.6a . Effect of P and K on nutrient content of soil at PI stage (Koyalmannam)

Treatment	N (kg ha^{-1})			Ca (cmol (+) kg^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	181.90	189.77	193.67	0.46	0.39	0.35
P_2	192.34	193.10	193.77	0.41	0.39	0.40
CD(0.05)	2.14			0.05		

Treatment	Fe (kg ha^{-1})			Mn (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	568.68	574.00	571.41	43.37	43.09	43.27	2.48	2.25	2.58
P_2	547.13	499.39	505.45	43.35	42.99	40.82	2.32	2.48	1.97
CD(0.05)	24.02			1.19			0.40		

Table 2.6 b Effect of K and lime on nutrient content of soil at PI stage (Koyalmannam)

Treatment	Ca (cmol (+) kg^{-1})		Zn (kg ha^{-1})		Cu (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	0.32	0.54	2.58	2.22	1.18	1.19
K_2	0.33	0.46	2.47	2.27	1.34	0.99
K_3	0.32	0.43	2.23	2.52	1.18	1.35
CD(0.05)	0.05		0.30		0.23	

significantly decreased the Fe content by 12.9 and 11.5 per cent respectively. The lowest quantity of the Mn content was recorded at P_2K_3. At P_2 level increasing the K dose to 105 kg ha^{-1} from 70 kg ha^{-1} significantly decreased the Mn content by 4.9 per cent. Similarly P_2K_3 registered 5.6 per cent lower Mn content than P_1K_3. However with 17.5 kg ha^{-1} of P no significant difference was observed.

Highest level of application of both P and K registered the lowest quantity of Zn in the soil. At P_2 level increasing the K dose to 105 kg ha^{-1} significantly decreased the Zn content by 20 per cent compared to 70 kg ha^{-1} of K.

Interaction between K and lime

Effect of K and lime on the Ca, Zn and Cu content of the soil is given in the table 2.6b

The increase in Ca content at K_1, K_2 and K_3 were respectively by 68, 39 and 34 per cent. The Ca content of the soil decreased significantly with increase in K dose in the presence of 600 kg ha^{-1} of lime application. With 300 kg ha^{-1} lime, no regular pattern with varying levels of K was observed.

Lime application at 600 kg ha^{-1} significantly decreased the Zn content of the soil in the presence of 35 kg ha^{-1} of K. With 300 kg ha^{-1} of lime, there was a significant decrease in the Zn content at K_3 level compared to K_1. At K_2 level a significant decrease in the Cu content was observed with increase in lime application rate. A significant increase in the Cu content at K_3 compared to K_2 was observed with 600 kg ha^{-1} of lime application.

4.1.4.2.3 Nutrient content of soil at PI stage at Ottappalam

Effect of P, K, lime and controls on nutrient content of soil at panicle initiation stage is given in the table 2.7

Effect of P

Application of P at 35 kg ha^{-1} significantly increased the P, K, Mg and Cu by 26.9, 2.0, 4.3 and 5.8 per cent respectively compared to P at 17.5 kg ha^{-1}. The Fe

Table 2.7 . Nutrient content of soil at PI stage (Ottappalam)

Treatment	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	264.50	23.78	193.39	0.46	0.230	562.59	22.99	3.80	1.28
P_2	269.70	30.19	197.42	0.49	0.240	522.08	24.10	3.63	1.36
CD(0.05)	NS	0.42	2.31	NS	0.004	25.91	1.04	0.157	0.11
Levels of Potassium									
K_1	265.19	26.29	187.64	0.52	0.240	650.28	27.75	3.64	1.17
K_2	271.28	26.84	194.83	0.50	0.240	524.25	23.96	3.67	1.38
K_3	264.95	27.82	203.70	0.42	0.230	446.70	19.69	3.84	1.39
CD(0.05)	4.30	0.52	2.77	0.06	NS	31.80	1.28	NS	0.113
Levels of Lime									
L_1	263.17	26.63	198.00	0.38	0.230	569.92	25.08	3.76	1.33
L_2	271.11	27.34	192.20	0.58	0.240	514.74	22.02	3.67	1.31
CD(0.05)	3.56	0.42	2.30	0.04	0.004	25.91	1.04	NS	NS
Controls									
C_1	264.08	30.21	193.03	0.39	0.238	614.00	24.70	3.41	1.14
C_2	256.78	30.40	190.60	0.45	0.240	576.00	23.30	3.44	1.29
C_3	263.74	18.89	172.97	0.33	0.223	676.20	28.71	3.29	1.32
CD(0.05)	8.70	8.70	5.55	0.11	0.011	63.61	2.5	NS	NS

and Zn content of the soil showed a decreasing trend while the Mn content showed an increasing trend.

Effect of K

The maximum content of N was observed at K_2 and it was significantly superior to K_1 and K_3. Application of K at 105 kg ha^{-1} recorded the maximum content of P, K and Cu. The K content of the soil increased by 3.7 and 8.5 per cent respectively at K_2 and K_3 compared to K_1. There was a significant decrease in the Ca, Fe and Mn content of the soil with increasing levels of K. Application of K at 105 kg ha^{-1} recorded the lowest content of Fe and Mn 446.70 kg ha^{-1}, 19.69 kg ha^{-1} respectively.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased the N, P, Ca and Mg content of the soil by 2.3, 2.6, 52 and 4.3 per cent respectively, while the content of K, Fe and Mn decreased by 3, 9.6 and 12.2 per cent respectively.

Effect of controls

The maximum content of soil N was recorded by C_1 followed by C_3. The C_2 (POP) recorded the highest value for P, Ca and Mg while C_1 recorded the maximum content of K. The maximum content of Fe and Mn was present in C_3 and the minimum content was present in C_2.

4.1.4.2.4 Interaction effect on nutrient content of soil

Interaction between P and K

Phosphorus content of the soil increased significantly with increasing levels of K at P_1 level (Table 2.8). No significant difference was observed at P_2 level. With increasing dose of P at various K levels an increase in P content was observed. The Mg content of the soil decreased with increase in K dose at P_1 level. However with P_2 level it increased at K_2 and beyond K_2 no change was observed. The Mn content of the soil decreased significantly with increase in the dose of K at P_1 and P_2 level.

4.1.4.3.1 *Nutrient content of soil at flowering stage at Koyalmannam*

Effect of P, K, lime and controls on the nutrient content of soil at flowering stage are presented in the table 2.9

Effect of P

The two levels of P application significantly influenced the P, K, Mn and Zn content of the soil at flowering. Application of P at 35 kg ha^{-1} significantly increased the P and K content of the soil while it decreased the Mn and Zn content of the soil.

Effect of K

Application of K at 105 kg ha^{-1} significantly increased the P content of the soil compared to 35 kg ha^{-1} of P application. A steady increase in the soil K content with increase in level of K application was noted. The Mg content of the soil increased at K_2 and beyond K_2 it decreased. K_1 was on par with K_2 for the Mg content. The Ca content of the soil at K_3 significantly decreased compared to K_1 and K_2. The Fe content of the soil at K_2 and K_3 significantly decreased compared to K_1 to the extent of 13.8 and 12.8 per cent respectively. K_2 was on par with K_3 for the Fe content. N, Mn, Zn and Cu content of the soil remained unaffected by the various levels of K.

Effect of lime

Lime application at two levels significantly influenced the P, Ca, Mg, Fe content of the soil. Increased application of lime increased. P, Ca and Mg content by 14.8, 48 and 6.25 per cent respectively and decreased the Fe content by 20.3 per cent.

Effect of controls

C_3 (the farmers practice) recorded the highest content of soil nitrogen followed by C_2 (POP). C_2 (POP) registered the highest content of soil P, K, Ca and Mg. However, C_3 recorded the highest content of Fe and Zn.

Table 2.9. Nutrient content of soil at flowering stage (Koyalmannam)

Treatment	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	214.03	17.69	217.40	0.630	0.160	549.39	36.94	2.42	1.05
P_2	216.68	19.91	220.63	0.600	0.160	530.94	34.63	2.01	1.19
CD(0.05)	NS	1.24	1.80	NS	NS	NS	1.70	0.07	NS
Levels of Potassium									
K_1	214.85	18.36	209.23	0.630	0.150	592.83	36.86	2.14	1.09
K_2	216.55	17.35	217.44	0.630	0.160	510.67	34.78	2.22	1.13
K_3	215.04	20.68	230.38	0.590	0.150	517.00	35.71	2.29	1.13
CD(0.05)	NS	1.24	2.20	0.050	0.001	36.70	NS	NS	NS
Levels of Lime									
L_1	215.77	17.16	219.88.	0.500	0.150	600.94	36.22	2.29	1.13
L_2	214.93	19.71	218.44	0.740	0.160	479.39	35.55	2.14	1.10
CD(0.05)	NS	1.24	NS	0.040	0.009	29.90	NS	NS	NS
Controls									
C_1	210.08	15.88	207.57	0.315	0.155	645.66	38.81	1.67	0.763
C_2	212.20	16.90	209.06	0.660	0.161	540.00	35.73	1.87	0.89
C_3	215.72	12.52	203.84	0.310	0.150	654.66	38.68	1.88	0.97
CD(0.05)	2.73	3.09	3.88	0.111	0.002	73.40	NS	0.17	NS

Table 2.8 . *Effect of P and K on nutrient content of soil at PI stage* **(Ottappalam)**

Treatment	P (kg ha^{-1})			Mg (cmol (+) kg^{-1})			Mn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	22.58	23.68	25.07	0.24	0.23	0.22	27.14	24.66	17.17
P_2	30.00	30.00	30.58	0.23	0.24	0.24	26.86	23.26	22.20
CD(0.05)	0.73			0.008			1.8		

Table 2.10 Effect of P and K on nutrient content of soil at flowering stage (Koyalmannam)

Treatment	N (kg ha^{-1})			K (kg ha^{-1})			Ca (cmol (+) kg^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	214.56	214.50	212.99	203.71	217.24	231.27	0.61	0.66	0.64
P_2	215.20	217.74	217.10	214.74	217.65	220.40	0.66	0.61	0.53
CD(0.05)	1.93			3.16			0.07		

Treatment	Fe (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	604.33	491.17	552.67	2.32	2.53	2.40
P_2	581.33	530.17	481.33	1.96	1.94	2.03
CD(0.05)	51.91			0.12		

4.1.4.3.2 Interaction effect on nutrient content of soil

Interaction between P and K

Interaction effect on the nutrient content of soil is given in the table 2.10

The nitrogen content of the soil increased significantly at K_2 and K_3 with increase in P dose from 17.5 kg ha^{-1} to 35 kg ha^{-1}. The K content of the soil showed a significant increase with increase in K dose of K_1 to K_3 with 17.5 kg ha^{-1} P application. But with 35 kg ha^{-1} of P application significant increase was observed at K_3 level only. Increase in P dose at K_1 level increased the K content of soil. However K_3 level showed a reverse trend.

The treatment P_2K_3 recorded significantly lower quantity of Ca compared to all other treatment combinations. There was a significant decrease in Ca content with increase in P dose at K_3 level.

The Fe content of the soil decreased significantly at K_2 in the presence of 17.5 kg ha^{-1} of P. But with 35 kg ha^{-1} of the P significant decrease was observed at K_3 level. No significant difference was observed between P_1 and P_2 levels at various levels of K application. There was a significant decrease in the Zn content of the soil with increase in P dose at all levels of K application. The Zn content of the soil increased at K_2 and beyond K_2 it was significantly decreased in the presence of 17.5 kg ha^{-1} of P. But with 35 kg ha^{-1} of P a significant increase was observed at 105 kg ha^{-1} of K application.

4.1.4.3.3 Nutrient content of soil at flowering stage at Ottappalam

Effect of P, K, lime and controls on nutrient content of soil at flowering is given in the table 2.11

Effect of P

It can be seen from the table 2.11 that P application at 35 kg ha^{-1} significantly increased the P and decreased the Zn content by 5 and 8.4 per cent respectively.

Table 2.11 . Nutrient content of soil at flowering stage (Ottappalam)

Treatments	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	257.82	27.92	181.91	0.430	0.130	543.26	25.05	3.68	1.15
P_2	263.59	29.57	182.87	0.440	0.130	496.45	24.80	3.37	1.10
CD(0.05)	NS	0.802	NS	NS	NS	NS	NS	0.157	NS
Levels of Potassium									
K_1	258.45	27.94	178.94	0.450	0.130	526.69	25.69	3.38	1.00
K_2	264.90	28.95	182.51	0.430	0.120	530.98	23.39	3.55	1.19
K_3	258.77	29.34	185.71	0.420	0.130	501.90	24.49	3.65	1.18
CD(0.05)	2.61	NS	2.77	0.020	0.003	22.14	1.50	0.192	NS
Levels of Lime									
L_1	261.51	28.04	183.05	0.370	0.120	538.69	24.56	3.46	1.09
L_2	259.90	29.45	181.92	0.500	0.130	511.02	24.48	3.59	1.16
CD(0.05)	NS	0.802	NS	0.030	0.001	18.08	NS	NS	NS
Controls									
C_1	254.12	28.56	188.05	0.340	0.136	580.50	24.91	3.17	1.13
C_2	257.28	29.65	184.10	0.460	0.130	575.67	23.55	3.24	1.09
C_3	259.70	19.90	170.40	0.360	0.120	588.36	28.65	3.18	1.08
CD(0.05)	NS	1.06	6.23	0.080	0.002	NS	3.00	NS	NS

Effect of K

Increasing levels of K increased the N, K and Zn content of the soil. The Mg content of the soil showed a significant decrease at K_2 compared to K_1 while Ca content decreased significantly at K_3. Similarly Fe content showed a significant decrease at K_3 by 4.7 per cent while Mn content decreased significantly at K_2 by 8.9 per cent.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the P, Ca and Mg content of the soil and decreased the Fe content of the soil.

Effect of controls

The C_2 (POP) registered the highest content of P and Ca while C_1 recorded maximum content of K and Mg. Maximum content of Mn was observed in C_3 (the farmers practice).

4.1.4.3.4 Interaction effect on nutrient content of soil

Interaction between P and K

Effect of P and K on nutrient content of soil is given in table 2.12a.

Maximum content of N was observed at P_2K_2 (262.03 kg ha^{-1}). There was a significant increase in the N content at P_2 level in the presence of 70 kg ha^{-1} of K compared to all other treatment combinations except P_2K_3. At higher level of P application, increasing the K dose increased the K content of the soil. But K_2 was on par with K_3 at P_1 level. The Cu content of the plant showed a significant increase at K_2 from K_1 in the presence of 17.5 kg ha^{-1} of P. Increasing the level of P at K_3 decreased the Cu content of soil.

Interaction between K and lime

Effect of K and lime on nutrient content of soil is given in table 2.12b.

Table 2.12 a . Effect of P and K on nutrient content of soil at flowering stage (Ottappalam)

Treatment	N (kg ha^{-1})			K (kg ha^{-1})			Cu (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	258.50	257.77	257.20	180.70	180.74	184.21	0.94	1.23	1.28
P_2	258.40	262.03	260.35	177.10	184.28	187.21	1.06	1.15	1.08
CD(0.05)	4.0			3.6			0.15		

Table 2.12 b Effect of K and lime on nutrient content of soil at flowering stage (Ottappalam)

Treatment	K (kg ha^{-1})		Mg (cmol (+) kg^{-1})		Fe (kg ha^{-1})		Mn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	183.12	174.77	0.13	0.12	532.18	521.19	25.54	25.84
K_2	184.08	180.95	0.12	0.13	528.54	533.42	23.08	23.71
K_3	184.11	187.32	0.13	0.12	525.35	478.46	25.07	23.91
CD(0.05)	3.60		0.001		3.130		1.10	

At K_1 levels increasing the lime dose decreased the K content of soil. The K content of the soil showed a significant increase with increase in K levels in the presence of 600 kg ha^{-1} of lime. The Mg content of the soil significantly increased at K_2 level with increase in lime dose. But at K_1 and K_3 level it was decreased.

The lowest value for Fe was recorded at K_3L_2 and the highest value at K_2L_2 and both differed significantly by 10.3 per cent. With an increase in K level to 70 kg ha^{-1} the Mn content showed a decrease at both L_1 and L_2 by 9.6 and 5.2 per cent respectively. The Mn content showed a significant decrease at K_2L_2. Increasing lime application at K_3 resulted in a decrease of Mn content of soil.

4.1.4.4.1 Nutrient content of soil at harvest at Koyalmannam

Effect of P, K, lime and controls on nutrient content of soil at harvest is given in the table 2.13.

Effect of P

Application of P at 35 kg ha^{-1} significantly increased the P content of soil while it decreased Fe and Zn content of soil.

Effect of K

It can be seen from the table 2.13 that K and Zn content were significantly influenced by the application of K at various levels. There was a steady increase in the K content of the soil with increase in levels of K application. The Zn content of soil significantly increased at K_2 and beyond K_2 it decreased. K_1, K_3 were on par for the soil Zn content.

Effect of lime

Lime application at higher level significantly increased the P and Ca content of soil and decreased the Fe and Zn content of the soil.

Table 2.13 . Nutrient content of soil at harvest (Koyalmannam)

Treatment	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	209.07	20.45	212.67	0.590	0.140	567.07	32.63	1.75	0.99
P_2	208.70	23.65	212.03	0.550	0.130	527.19	31.78	1.65	1.00
CD(0.05)	NS	0.34	NS	NS	NS	34.70	NS	0.08	NS
Levels of Potassium									
K_1	206.93	21.78	201.63	0.580	0.130	570.16	32.41	1.63	1.03
K_2	208.93	21.23	209.45	0.580	0.140	546.20	33.15	1.78	1.02
K_3	210.83	23.10	225.97	0.560	0.130	525.04	31.04	1.63	1.08
CD(0.05)	NS	NS	4.20	NS	NS	42.57	NS	0.10	NS
Levels of Lime									
L_1	207.37	20.77	213.67	0.470	0.140	574.04	32.64	1.76	1.04
L_2	210.40	23.32	211.03	0.670	0.130	520.22	31.76	1.63	1.04
CD(0.05)	NS	0.35	NS	0.040	NS	34.70	NS	0.88	NS
Controls									
C_1	209.00	20.20	191.84	0.315	0.135	612.47	34.93	1.88	0.746
C_2	210.80	20.24	192.63	0.653	0.115	527.00	32.36	1.87	0.886
C_3	206.30	15.28	201.56	0.310	0.107	621.82	35.32	1.67	0.976
CD(0.05)	2.28	NS	0.10	0.010	85.18	NS	0.172	NS	NS

Effect of controls

The three control treatments significantly influenced the P, Ca, Mg, Fe and Zn content of the soil. The C_2 (POP) recorded the highest content of Ca and P while C_1 (POP without lime) recorded the highest content of Mg and Zn. The highest content of Fe was present in C_3 (the farmer's practice).

4.1.4.4.2 Interaction effect on nutrient content of soil

Interaction between P and K

It can be seen from the table 2.14a that P and K interacted significantly to influence the N, K and Ca content of soil. Application of 17.5 kg ha^{-1} of P with increasing levels of K significantly increased the N content of the soil. A decrease in the N content was observed at P_2K_3 compared to P_1K_3. Significant increase in the K content was observed with increasing levels of K in the presence of both P_1 and P_2. Increasing the dose of P at K_3 or increasing the dose of K at P_2 decreased the Ca content of soil. Combined application of 35 kg ha^{-1} of P with 105 kg ha^{-1} of K significantly decreased the Ca content of the soil compared to all other treatments except P_2K_2.

Interaction between K and lime

Combined application of K and lime significantly influenced the K and Mg content of soil (Table 2.14b). Increasing the K dose in the presence of 300 kg ha^{-1} of lime application significantly increased the K content of soil. But with 600 kg ha^{-1} of lime application significant increase was observed only from K_2 to K_3. A significant decrease in the Mg content was observed at K_3 when the lime dose increased to 600 kg ha^{-1} from 300 kg ha^{-1}.

An increase in P content at K_2 level was observed when the lime dose was increased to 600 kg ha^{-1}. Similarly with 300 kg ha^{-1} of lime a decrease in P content was observed at K_2 compared to K_1 but with 600 kg ha^{-1} an increase in P content was noted.

Table 2.14a Effect of P and K on nutrient content of soil at harvest (Koyalmannam)

Treatment	N (kg ha^{-1})			K (kg ha^{-1})			Ca (cmol (+) kg^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	205.34	208.75	213.12	198.54	205.47	225.99	0.57	0.59	0.62
P_2	208.52	209.04	208.53	204.72	213.44	225.95	0.60	0.56	0.49
CD(0.05)	2.75			5.95			0.07		

Table 2.14 b Effect of K and lime on nutrient content of soil at harvest stage (Koyalmannam)

Treatment	K (kg ha^{-1})		Mg (cmol (+) kg^{-1})		P (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	199.10	204.16	0.14	0.13	21.51	22.04
K_2	210.29	208.61	0.13	0.14	18.06	24.39
K_3	231.63	220.31	0.14	0.12	22.73	23.53
CD(0.05)	5.95		0.01		1.61	

4.1.4.4.3 Nutrient content of soil at harvest at Ottappalam

Effect of P, K, lime and controls on nutrient content of soil at harvest stage is given in the table 2.15

Effect of P

Phosphorus application at 35 kg ha^{-1} significantly increased the P content of soil and decreased the Zn content of the soil by 7.6 and 4.2 per cent respectively. Other elements remained unaffected by higher level of P application.

Effect of K

Potassium application at higher levels significantly increased the N and Mg content of the soil. The maximum content of N was observed at K_2 level. The Ca content of the soil showed a decreasing trend with in K levels.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the N, P and Ca content of the soil by 1.7, 5.7 and 30 per cent respectively. However, there was a significant decrease in the Fe and Mn. Zn content of the soil at higher level of lime application.

Effect of controls

Among the control treatments significant difference was observed only in the P and K content of soil. Maximum content of P and K was observed in the C_2 (POP) and it was significantly superior to C_1.

4.1.4.4.4 Interaction effect on nutrient content of soil

Interaction between P and K

Nitrogen content of the soil significantly increased at P_2K_2 and P_2K_3 (Table 2.16a). Compared to all other treatment combinations. At K_2 and K_3 levels

Table 2.15 . Nutrient content of soil at harvest (Ottappalam)

Treatments	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	237.46	25.05	169.09	0.420	0.120	513.00	20.91	3.03	0.91
P_2	244.84	26.97	168.21	0.400	0.120	490.79	20.82	2.90	1.03
CD(0.05)	NS	0.97	NS	NS	NS	NS	NS	0.107	NS
Levels of Potassium									
K_1	237.29	26.07	165.76	0.460	0.120	516.97	21.22	3.03	0.94
K_2	244.79	25.78	170.44	0.420	0.120	509.48	20.84	2.96	0.97
K_3	241.39	26.16	169.74	0.370	0.130	479.24	20.54	2.92	0.99
CD(0.05)	2.73	NS	NS	0.02	0.001	NS	NS	NS	NS
Levels of Lime									
L_1	239.04	25.41	171.91	0.360	0.120	517.11	20.89	2.99	0.94
L_2	243.26	26.88	165.38	0.470	0.120	486.69	20.84	2.94	0.99
CD(0.05)	2.23	0.97	NS	0.02	NS	20.86	NS	0.109	NS
Controls									
C_1	238.33	25.00	162.93	0.357	0.113	547.83	20.90	2.60	0.916
C_2	238.00	25.43	165.24	0.430	0.120	541.67	20.50	2.70	0.980
C_3	231.33	14.68	144.02	0.350	0.113	563.36	22.20	2.61	0.916
CD(0.05)	NS	2.38	9.40	0.05	NS	NS	NS	NS	NS

Table 2.16 a Effect of P and K on nutrient content of soil at harvest stage (Ottappalam)

Treatment	N (kg ha^{-1})			K (kg ha^{-1})			Mn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	237.55	237.02	237.80	164.03	169.74	173.49	21.90	21.37	19.45
P_2	237.02	252.55	244.95	167.49	171.15	168.00	20.53	20.31	21.62
CD(0.05)	3.80			5.9			1.55		

Table 2.16 b Effect of P and lime on nutrient content of soil at harvest stage (Ottappalam)

Treatment	N (kg ha^{-1})		Ca (cmol (+) kg^{-1})		Fe (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	237.28	237.63	0.36	0.49	512.84	513.17
P_2	240.00	248.90	0.36	0.45	521.37	460.20
CD(0.05)	3.15		0.03		29.50	

increasing the P dose increased the N content significantly by 5.9 and 2.8 per cent respectively. At P_1K_3 level and P_2K_2 there was significant increase in the K content of soil compared to P_1K_1 level. P_2K_3 showed significant increase in the Mn content compared to P_1K_3.

Interaction between P and lime

There was significant increase in the N content of the soil at P_2L_1 and P_2L_2 compared to P_1L_1 and P_1L_2 (Table 2.16b). Significant increase in the Ca content of the soil was observed when the lime dose increased to 600 kg ha^{-1} at P_1 and P_2 level. The Fe content of the soil showed a significant decrease at P_2L_2 compared to all other treatment combinations.

4.1.5 Correlation studies

4.1.5.1 Correlation coefficient of nutrient ratios with yield

The various nutrient ratios in soil and plant at MT and PI stage were calculated for evaluating the correlation pattern of these ratios with yield. The results of the study are described hereunder.

The correlation studies showed that total yield was correlated with various nutrient ratios of the soil and the plant. A review of the N based nutrient ratios at Koyalmannam area showed that total yield was positively correlated with plant N/Fe, N/Mn and negatively correlated with N/P, N/K, N/Ca and N/Mg ratios at MT stage (Table 3.1). Nutrient ratios in soil revealed a significant positive correlation of N/Fe and N/Mg ratio with yield. Yield was positively and significantly correlated with N/Fe and N/Mn ratios of the plant at panicle initiation stage (Table 3.2). Soil N/Fe and N/Mg ratio also showed a significant positive correlation with yield.

The correlation studies between various nutrient ratios have shown that the N/K ratio of the plant was negatively and significantly correlated with N/Ca and N/Mn ratios of the plant as well as with the N/Ca ratio of the soil at MT stage (Table 3.1). Similarly N/Ca ratio of the plant showed significant negative correlation with N/Mn of

Table 3.1 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield at Koyalmannam

	plant								soil						
	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	-0.293	-0.294	-0.111	-0.027	0.027	0.359(*)	-0.333(*)	0.054	0.101	-0.238	0.358(*)	0.434(**)	0.044	0.044
N/P	-0.293	1.000	0.047	-0.104	0.152	0.143	0.074	0.267	0.322(*)	-0.057	0.119	-0.286	-0.569(**)	-0.472(**)	-0.328(*)
N/K	-0.294	0.047	1.000	-0.495(**)	-0.213	0.376(*)	0.583(**)	0.214	-0.121	-0.108	-0.440(**)	0.088	0.285	-0.115	-0.044
N/Ca	-0.111	-0.104	-0.495(**)	1.000	0.148	-0.161	-0.549(**)	0.108	0.077	0.174	0.311(*)	-0.093	0.262	0.113	0.076
N/Mg	0.027	0.152	-0.213	0.148	1.000	0.305(*)	-0.043	-0.013	0.239	0.121	0.373(*)	0.092	-0.016	0.116	-0.020
N/Fe	0.027	0.143	0.376(*)	-0.161	0.305(*)	1.000	0.093	0.284	0.152	0.401(**)	-0.204	-0.030	0.078	0.136	-0.354(*)
N/Mn	0.359(*)	0.074	0.583(**)	-0.549(**)	-0.043	0.093	1.000	-0.055	-0.143	-0.212	-0.059	0.168	0.018	-0.211	-0.084
N/Zn	-0.333	0.267	0.214	0.108	-0.013	0.284	-0.055	1.000	-0.223	0.084	0.166	-0.167	0.186	0.127	-0.051
N/P	0.054	0.322(*)	-0.121	0.077	0.239	0.152	-0.143	-0.223	1.000	0.080	0.235	-0.023	-0.126	0.060	0.014
N/K	0.101	-0.057	-0.108	0.174	0.121	0.401(**)	-0.212	0.084	0.080	1.000	0.143	0.085	0.106	0.303(*)	-0.082
N/Ca	-0.238	0.119	-0.440(**)	0.311(*)	0.373(*)	-0.204	-0.059	0.166	0.235	0.143	1.000	0.160	-0.104	0.145	-0.008
N/Mg	0.358(*)	-0.286	0.088	-0.093	0.092	-0.030	0.168	-0.167	-0.023	0.085	0.160	1.000	0.148	0.142	-0.097
N/Fe	0.434(**)	-0.569(**)	0.285	0.262	-0.016	0.078	0.018	0.186	-0.126	0.106	-0.104	0.148	1.000	0.526(**)	0.303(*)
N/Mn	0.044	-0.472(**)	-0.115	0.413(**)	0.136	0.136	-0.211	0.127	0.060	0.303(*)	0.145	0.142	0.526(**)	1.000	0.308(*)

Table 3.2 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield at Koyalmannam

	plant								soil						
	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	-0.364(*)	-0.014	-0.079	0.031	0.571(**)	0.506(**)	-0.329(*)	-0.245	-0.255	-0.403(**)	0.311(*)	0.463(**)	-0.176	-0.161
N/P	-0.364(*)	1.000	0.185	-0.145	0.106	0.169	0.370(*)	0.116	0.412(**)	0.453(**)	-0.254	-0.100	0.199	0.320(*)	-0.364(*)
N/K	-0.014	0.185	1.000	-0.048	0.117	-0.176	-0.057	0.051	-0.141	0.172	0.014	-0.247	0.160	0.079	0.241
N/Ca	-0.079	-0.145	-0.048	1.000	-0.265	-0.272	-0.066	0.017	0.181	0.163	0.289	-0.211	-0.311(*)	-0.069	-0.090
N/Mg	0.031	0.106	0.117	-0.265	1.000	0.170	0.001	-0.178	-0.189	-0.039	-0.161	-0.037	0.272	0.155	-0.082
N/Fe	0.571(**)	0.169	-0.176	-0.272	0.170	1.000	0.661(**)	-0.202	-0.286	-0.381(**)	-0.381(**)	0.152	0.485(**)	0.336(*)	-0.117
N/Mn	0.506(**)	0.370(*)	-0.057	-0.066	0.001	0.661(**)	1.000	-0.316(*)	0.016	-0.371(*)	-0.270	0.183	0.184	0.028	-0.054
N/Zn	-0.329(*)	0.116	0.051	0.017	-0.178	-0.202	-0.316(*)	1.000	0.083	0.158	0.246	-0.304(*)	-0.057	0.028	0.394(**)
N/P	-0.245	0.412(**)	-0.141	0.181	-0.189	0.183	0.016	0.083	1.000	0.541(**)	0.385(**)	0.246	-0.324(*)	-0.085	-0.403(**)
N/K	-0.255	0.453(**)	0.172	0.163	-0.039	-0.286	-0.371(*)	0.158	0.541(**)	1.000	0.284	-0.192	-0.071	-0.220	0.588(**)
N/Ca	-0.403(**)	-0.254	0.014	0.289	-0.161	-0.381(**)	-0.270	0.246	0.385(**)	0.284	1.000	-0.005	-0.225	0.159	0.242
N/Mg	0.311(*)	-0.100	-0.247	-0.211	-0.037	-0.381(**)	0.183	-0.304(*)	0.246	-0.192	-0.005	1.000	0.079	-0.190	0.025
N/Fe	0.463(**)	0.199	0.160	-0.311(*)	0.272	0.485(**)	0.184	-0.057	-0.324(*)	-0.071	-0.225	0.079	1.000	0.183	-0.129
N/Mn	-0.176	0.320(*)	0.079	-0.069	0.155	0.336(*)	0.028	0.028	-0.085	-0.220	0.159	-0.190	0.183	1.000	-0.107
N/Zn	-0.161	-0.364(*)	0.241	-0.090	-0.082	-0.117	-0.054	0.394(**)	-0.403(**)	0.588(**)	0.242	0.025	-0.129	-0.107	1.000

the plant. N/Fe ratio of the plant showed positive correlation with N/K ratio of the plant and soil at MT stage but at PI stage negative correlation was observed. N/Mn and N/Fe ratios of the soil showed significant negative correlation with N/P ratios of the plant at MT stage.

A perusal of the data on P based ratios proved that total yield was positively correlated with P/Fe and P/Mn ratios of the plant at MT and PI stage (Table 3.3 and 3.4). P/Ca ratio of plant was positively correlated with K/Ca + Mg of the plant while P/Ca of the soil was positively correlated K/Ca + Mg of the soil.

It is clear from the K based ratios that the yield was significantly and negatively correlated with K/Zn of the plant and K/Mg of soil at MT stage (Table 3.5). K/Ca ratio of the plant was positively and significantly correlated with K/Zn ratio of the plant at MT stage. But at PI stage yield was positively and significantly correlated with K/Fe and K/Mn ratios of the plant and K/Fe of soil.

It can be seen from the table 3.7 that at Ottappalam total yield was positively correlated with N/Fe, N/Mn and N/Zn ratios of the plant at MT stage. Similarly the N/Fe and N/Mn ratios of the soil were positively correlated with yield and the correlation with N/Mn was significant. Significant positive correlation was observed for the N/K ratio of the plant with N/Fe, N/Mn and N/Zn ratios soil at MT stage. N/K was negatively correlated with N/Ca and N/Mg ratio of both plant and soil. N/Ca of the plant showed significant positive correlation with N/Mg of the plant.

At panicle initiation stage significant positive correlation of yield with N/Fe and N/Mn ratio of the soil was observed (Table 3.8). Similarly significant negative correlation of yield was observed for the N/P and N/K ratios of both plant and soil. The plant ratios of N/K and N/Ca were significantly and positively correlated with N/P ratio of the plant. The same N/P ratio showed significant negative correlation with N/Fe and N/Mn ratios and positive correlation with N/P and N/K ratios of the soil.

Table 3.3 *Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield at Koyalmannam*

	plant							soil							
	Total yield	**P/K**	**P/Ca**	**P/Mg**	**P/Fe**	**P/Mn**	**P/Zn**	**K/Ca+Mg**	**P/K**	**P/Ca**	**P/Mg**	**P/Fe**	**P/Mn**	**P/Zn**	**K/Ca+Mg**
Total yield	1.000	-0.203	-0.142	-0.166	0.326(*)	0.354	-0.508(**)	-0.178	0.206	-0.243	0.380(*)	0.424(**)	0.193	0.097	-0.154
P/K	-0.203	1.000	0.135	0.202	0.150	-0.024	0.266	0.102	0.078	0.131	-0.132	-0.112	-0.060	0.321(*)	-0.170
P/Ca	-0.142	0.135	1.000	-0.079	-0.110	0.106	0.267	0.521(**)	-0.220	0.138	-0.166	-0.394(**)	-0.287	-0.253	0.115
P/Mg	-0.166	0.202	-0.079	1.000	0.127	0.069	0.175	-0.121	0.059	-0.037	0.007	-0.029	0.079	0.081	-0.083
P/Fe	0.326(*)	0.150	-0.110	0.127	1.000	0.599(**)	0.021	-0.324(*)	-0.067	-0.228	0.031	-0.066	-0.044	0.121	-0.037
P/MN	0.254	-0.024	0.106	0.069	0.599(**)	1.000	0.013	-0.228	-0.454(**)	-0.296(*)	-0.199	-0.410(**)	-0.430(**)	-0.160	0.104
P/ZN	-0.508(**)	0.266	0.267	0.175	0.021	0.013	1.000	-0.039	-0.264	0.206	-0.416(**)	0.107	-0.388(**)	0.126	0.127
K/Ca+Mg	-0.178	0.102	0.521(**)	-0.121	-0.324(*)	-0.228	-0.039	1.000	-0.052	0.347(*)	-0.205	-0.151	0.010	-0.166	0.214
P/K	0.206	0.078	-0.220	0.059	-0.067	-0.454(**)	-0.264	-0.052	1.000	0.303(*)	0.157	0.804(**)	0.931(**)	0.715(**)	-0.260
P/Ca	-0.243	0.131	0.138	-0.037	-0.228	-0.296(*)	0.206	0.347(*)	0.303(*)	1.000	0.247	0.151	0.322(*)	0.272	0.374(*)
P/Mg	0.380(*)	-0.132	-0.166	0.007	0.031	-0.199	-0.416(**)	-0.205	0.157	0.247	1.000	0.189	0.191	0.104	0.020
P/Fe	0.424(**)	-0.112	-0.394(**)	-0.029	-0.066	-0.410(**)	0.107	-0.151	0.804(**)	0.151	0.189	1.000	0.805(**)	0.509(**)	-0.186
P/MN	0.193	-0.060	-0.287	0.079	-0.044	-0.430(**)	-0.388(**)	0.010	0.931(**)	0.322(*)	0.191	0.805(**)	1.000	0.634(**)	-0.079
P/ZN	0.097	0.321(*)	-0.253	0.081	0.121	-0.160	0.126	-0.166	0.715(**)	0.272	0.104	0.509(**)	0.634(**)	1.000	-0.247
K/Ca+Mg	-0.154	-0.170	0.115	-0.083	-0.037	0.104	0.127	0.214	-0.260	0.374(*)	0.020	-0.186	-0.079	-0.247	1.000

Table 3.4 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield at Koyalmannam

	plant							soil							
	Total yield	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn	K/Ca+Mg	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn	K/Ca+Mg
Total yield	1.000	0.115	-0.085	0.050	0.740(**)	0.472(**)	-0.040	0.112	0.013	-0.266	-0.389(**)	0.236	-0.013	0.031	-0.163
P/K	0.115	1.000	-0.284	-0.102	0.427(**)	0.697(**)	0.491(**)	0.091	0.249	-0.344(*)	-0.382(**)	0.625(**)	0.387(**)	0.241	-0.250
P/Ca	-0.085	-0.284	1.000	0.171	-0.116	-0.395(**)	0.215	-0.124	0.050	0.276	-0.196	0.168	0.227	0.091	0.200
P/Mg	0.050	-0.102	0.171	1.000	0.308(*)	0.008	0.013	0.348(*)	0.134	0.292	-0.303(*)	-0.019	0.201	0.034	0.050
P/Fe	0.740(**)	0.427(**)	-0.116	0.308(*)	1.000	0.182	0.315(*)	0.316(*)	0.197	-0.274	-0.267	0.180	0.157	-0.238	-0.273
P/MN	0.472(**)	0.697(**)	-0.395(**)	0.008	0.182	1.000	0.227	0.208	0.170	-0.026	-0.227	0.424(**)	0.298(*)	0.171	0.063
P/ZN	-0.040	0.491(**)	0.215	0.013	0.315(*)	0.227	1.000	-0.027	0.463(**)	0.177	-0.336(*)	0.721(**)	0.684(**)	0.344(*)	0.236
K/Ca+Mg	0.112	0.091	-0.124	0.348(*)	0.316(*)	0.208	-0.027	1.000	-0.049	0.228	-0.246	-0.003	0.008	-0.302(*)	0.188
P/K	0.013	0.249	0.050	0.134	0.197	0.170	0.463(**)	-0.049	1.000	0.125	0.264	0.625(**)	0.740(**)	0.135	-0.103
P/Ca	-0.266	-0.344(*)	0.276	0.292	-0.274	-0.026	0.177	0.228	0.125	1.000	-0.033	-0.029	0.146	0.015	0.679(**)
P/Mg	-0.389(**)	-0.382(**)	-0.196	-0.303(*)	-0.267	-0.227	-0.336(*)	-0.246	0.264	-0.033	1.000	-0.284	-0.098	0.011	-0.061
P/Fe	0.236	0.625(**)	0.168	-0.019	0.180	0.424(**)	0.721(**)	-0.003	0.625(**)	-0.029	-0.284	1.000	0.786(**)	0.378(*)	0.018
P/MN	-0.013	0.387(**)	0.227	0.201	0.157	0.298(*)	0.684(**)	0.008	0.740(**)	0.146	-0.098	0.786(**)	1.000	0.368(*)	0.022
P/ZN	0.031	0.241	0.091	0.034	-0.238	0.171	0.344(*)	-0.302(*)	0.135	0.015	0.011	0.378(*)	0.368(*)	1.000	0.073
K/Ca+Mg	-0.163	-0.250	0.200	0.050	-0.273	0.063	0.236	0.188	-0.103	0.679(**)	-0.061	0.018	0.022	0.073	1.000

Table 3.5 Correlation coefficient of nutrient ratios of soil and plant at MTstage with yield at Koyalmannam

	plant						soil				
	Total yield	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn
Total yield	1.000	-0.119	-0.091	-0.169	0.176	-0.502(**)	-0.257	-0.382(**)	0.272	-0.046	0.032
K/Ca	-0.119	1.000	0.269	0.035	-0.187	0.551(**)	0.290	-0.167	0.125	0.228	0.050
K/Mg	-0.091	0.269	1.000	0.386(**)	0.192	0.305(*)	0.346(*)	-0.145	-0.333(*)	0.001	-0.073
K/Fe	-0.169	0.035	0.386(**)	1.000	-0.131	0.170	-0.114	-0.082	-0.301(*)	-0.198	-0.417(**)
K/Mn	0.176	-0.187	0.192	-0.131	1.000	-0.025	0.366(*)	0.162	-0.137	-0.011	-0.043
K/Zn	-0.502(**)	0.551(**)	0.305(*)	0.170	-0.025	1.000	0.477(**)	0.091	-0.191	0.055	-0.020
K/Ca	-0.257	0.290	0.346(*)	-0.114	0.366(*)	0.477(**)	1.000	-0.067	-0.069	0.152	0.016
K/Mg	-0.382(**)	-0.167	-0.145	-0.082	0.162	0.091	-0.067	1.000	-0.571(**)	-0.413(**)	-0.005
K/Fe	0.272	0.125	-0.333(*)	-0.301(*)	-0.137	-0.191	-0.069	-0.571(**)	1.000	0.618(**)	0.382(**)
K/Mn	-0.046	0.228	0.001	-0.198	-0.011	0.055	0.152	-0.413(**)	0.618(**)	1.000	0.414(**)
K/Zn	0.032	0.050	-0.073	-0.417(**)	-0.043	-0.020	0.016	-0.005	0.382(**)	0.414(**)	1.000

Table 3.6 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield at Koyalmannam

	plant						soil				
	Total yield	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn
Total yield	1.000	-0.063	0.012	0.435(**)	0.366(*)	-0.179	-0.366(*)	0.364(*)	0.504(**)	0.072	-0.093
K/Ca	-0.063	1.000	-0.047	0.028	0.171	0.254	0.238	-0.114	-0.359(*)	-0.096	-0.239
K/Mg	0.012	-0.047	1.000	0.579(**)	0.348(*)	0.363(*)	-0.123	0.193	0.133	0.290	-0.192
K/Fe	0.435(**)	0.028	0.579(**)	1.000	0.805(**)	0.471(**)	-0.221	0.503(**)	0.302(*)	0.400(**)	-0.191
K/Mn	0.366(*)	0.171	0.348(*)	0.805(**)	1.000	0.431(**)	-0.124	0.661(**)	0.102	0.272	-0.103
K/Zn	-0.179	0.254	0.363(*)	0.471(**)	0.431(**)	1.000	0.204	0.101	-0.180	0.021	0.023
K/Ca	-0.366(*)	0.238	-0.123	-0.221	-0.124	0.204	1.000	-0.015	-0.213	0.076	0.101
K/Mg	0.364(*)	-0.114	0.193	0.503(**)	0.661(**)	0.101	-0.015	1.000	0.284	0.485(**)	-0.110
K/Fe	0.504(**)	-0.359(*)	0.133	0.302(*)	0.102	-0.180	-0.213	0.284	1.000	0.375(*)	-0.197
K/Mn	0.072	-0.096	0.290	0.400(**)	0.272	0.021	0.076	0.485(**)	0.375(*)	1.000	-0.252
K/Zn	-0.093	-0.239	-0.192	-0.191	-0.103	0.023	0.101	-0.110	-0.197	-0.252	1.000

Table 3.7 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield at Ottappalam

	plant								soil						
	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	-0.173	0.043	-0.243	-0.022	0.122	0.278	0.115	-0.201	-0.008	-0.105	0.168	0.034	0.355(*)	-0.115
N/P	-0.173	1.000	0.323(*)	0.062	-0.089	0.286	0.317(*)	0.170	-0.357(*)	-0.164	0.059	-0.138	0.291	0.274	0.132
N/K	0.043	0.323(*)	1.000	-0.205	-0.164	0.127	0.218	0.262	-0.364(*)	-0.009	-0.305(*)	-0.102	0.329(*)	0.298(*)	0.305(*)
N/Ca	-0.243	0.062	-0.205	1.000	0.521(**)	-0.047	0.039	-0.083	0.389(**)	-0.125	0.156	0.046	-0.107	-0.099	-0.081
N/Mg	-0.022	-0.089	-0.164	0.521(**)	1.000	0.208	-0.043	-0.341(*)	0.066	0.240	0.096	0.541(**)	0.073	-0.003	0.130
N/Fe	0.122	0.286	0.127	-0.047	0.208	1.000	0.269	0.203	-0.430(**)	-0.105	-0.069	-0.016	0.239	0.414(**)	0.210
N/Mn	0.278	0.317(*)	0.218	0.039	-0.043	0.269	1.000	0.348(*)	-0.186	-0.262	0.120	-0.071	0.188	0.366(*)	0.069
N/Zn	0.115	0.170	0.562(**)	-0.083	-0.341(*)	0.203	0.348(*)	1.000	-0.251	-0.085	-0.254	-0.158	0.228	0.358(*)	0.191
N/P	-0.201	-0.357(*)	-0.364(*)	0.389(**)	0.066	-0.430(**)	-0.186	-0.251	1.000	-0.131	-0.019	-0.274	-0.571(**)	-0.327(*)	-0.514(**)
N/K	-0.008	-0.164	-0.009	-0.125	0.240	-0.105	-0.262	-0.085	-0.131	1.000	0.092	0.631(**)	0.413(**)	-0.322(*)	0.438(**)
N/Ca	-0.105	0.059	-0.305(*)	0.156	0.096	-0.069	0.120	-0.254	-0.019	0.092	1.000	0.037	0.078	-0.158	-0.161
N/Mg	0.168	-0.138	-0.102	0.046	0.541(**)	-0.016	-0.071	-0.158	-0.274	0.631(**)	0.037	1.000	0.321(*)	-0.065	0.367(*)
N/Fe	0.034	0.291	0.329(*)	-0.107	0.073	0.239	0.188	0.228	-0.571(**)	0.413(**)	0.078	0.321(*)	1.000	0.165	0.681(**)
N/Mn	0.355(*)	0.274	0.298(*)	-0.099	-0.003	0.414(**)	0.366(*)	0.358(*)	-0.327(*)	-0.322(*)	-0.158	-0.065	0.165	1.000	0.103
N/Zn	-0.115	0.132	0.305(*)	-0.081	0.130	0.210	0.069	0.191	-0.514(**)	0.438(**)	-0.161	0.367(*)	0.681(**)	0.103	1.000

Table 3.8 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield at Ottappalam

	plant								soil						
	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	-0.414(**)	-0.315(*)	-0.204	-0.058	0.140	0.033	-0.314(*)	-0.297(*)	-0.298(*)	-0.154	0.129	0.624(**)	0.515(**)	-0.151
N/P	-0.414(**)	1.000	0.728(**)	0.307(*)	0.181	-0.121	0.159	0.402(**)	0.463(**)	0.305(*)	0.176	0.031	-0.539(**)	-0.505(**)	0.002
N/K	-0.315(*)	0.728(**)	1.000	0.288	0.194	0.268	0.177	0.104	0.178	0.422(**)	-0.191	-0.032	-0.268	-0.342(*)	0.154
N/Ca	-0.204	0.307(*)	0.288	1.000	0.676(**)	0.164	0.354(*)	0.091	0.173	-0.089	0.340(*)	0.372(*)	0.059	-0.049	-0.324(*)
N/Mg	-0.058	0.181	0.194	0.676(**)	1.000	0.122	0.386(**)	0.049	0.130	0.025	0.142	0.496(**)	0.246	0.030	-0.647(**)
N/Fe	0.140	-0.121	0.268	0.164	0.122	1.000	0.670(**)	-0.014	-0.432(**)	-0.056	-0.261	-0.103	0.480(**)	0.192	0.219
N/Mn	0.033	0.159	0.177	0.354(*)	0.386(**)	0.670(**)	1.000	0.302(*)	-0.058	0.155	-0.229	0.091	0.186	-0.045	-0.033
N/Zn	-0.314(*)	0.402(**)	0.104	0.091	0.049	-0.014	0.302(*)	1.000	0.153	0.299(*)	-0.271	-0.156	-0.287	-0.136	0.237
N/P	-0.297(*)	0.463(**)	0.178	0.173	0.130	-0.432(**)	-0.058	0.153	1.000	0.380(*)	0.166	0.172	-0.377(*)	-0.190	-0.097
N/K	-0.298(*)	0.305(*)	0.422(**)	-0.089	0.025	-0.056	0.155	0.299(*)	0.380(*)	1.000	-0.306(*)	0.374(*)	-0.313(*)	-0.328(*)	-0.007
N/Ca	-0.154	0.176	-0.191	0.340(*)	0.142	-0.261	-0.229	-0.271	0.166	-0.306(*)	1.000	-0.044	-0.220	-0.238	-0.126
N/Mg	0.129	0.031	-0.032	0.372(*)	0.496(**)	-0.103	0.091	-0.156	0.172	0.374(*)	-0.044	1.000	0.135	-0.073	-0.651(**)
N/Fe	0.624(**)	-0.539(**)	-0.268	0.059	0.246	0.480(**)	0.186	-0.287	-0.377(*)	-0.313(*)	-0.220	0.135	1.000	0.610(**)	-0.115
N/Mn	0.515(**)	-0.505(**)	-0.342(*)	-0.049	0.030	0.192	-0.045	-0.136	-0.190	-0.328(*)	-0.238	-0.073	0.610(**)	1.000	-0.084
N/Zn	-0.151	0.002	0.154	-0.324(*)	-0.647(**)	0.219	-0.033	0.237	-0.097	-0.007	-0.126	-0.651(**)	-0.115	-0.084	1.000

Table3.9 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield at Ottappalam

	plant							soil					
	Total Yield	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn
Total Yield	1.000	0.186	-0.200	0.021	0.385(**)	0.252	0.348(*)	0.128	0.039	0.165	0.107	0.234	0.074
P/K	0.186	1.000	-0.101	0.084	0.119	0.136	0.587(**)	-0.041	-0.260	-0.053	-0.068	-0.105	-0.025
P/Ca	-0.200	-0.101	1.000	0.547(**)	0.036	0.063	-0.111	-0.388(**)	-0.159	-0.287	-0.370(*)	-0.339(*)	-0.341(*)
P/Mg	0.021	0.084	0.547(**)	1.000	0.350(*)	0.100	-0.230	-0.088	-0.070	0.072	-0.135	-0.161	-0.091
P/Fe	0.385(**)	0.119	0.036	0.350(*)	1.000	0.412(**)	0.275	-0.021	-0.082	0.003	-0.045	-0.028	-0.007
P/Mn	0.252	0.136	0.063	0.100	0.412(**)	1.000	0.300(*)	-0.143	-0.044	-0.089	-0.093	-0.031	-0.093
P/Zn	0.348(*)	0.587(**)	-0.111	-0.230	0.275	0.300(*)	1.000	-0.107	-0.355(*)	-0.128	-0.129	-0.075	-0.088
P/K	0.128	-0.041	-0.388(**)	-0.088	-0.021	-0.143	-0.107	1.000	0.704(**)	0.955(**)	0.172	0.862(**)	0.966(**)
P/Ca	0.039	-0.260	-0.159	-0.070	-0.082	-0.044	-0.355(*)	0.704(**)	1.000	0.667(**)	0.708(**)	0.644(**)	0.656(**)
P/Mg	0.165	-0.053	-0.287	0.072	0.003	-0.089	-0.128	0.955(**)	0.667(**)	1.000	0.925(**)	0.831(**)	0.929(**)
P/Fe	0.107	-0.068	-0.370(*)	-0.135	-0.045	-0.093	-0.129	0.172	0.708(**)	0.925(**)	1.000	0.893(**)	0.968(**)
P/Mn	0.234	-0.105	-0.339(*)	-0.161	-0.028	-0.031	-0.075	0.862(**)	0.644(**)	0.831(**)	0.893(**)	1.000	0.881(**)
P/Zn	0.074	-0.025	-0.341(*)	-0.091	-0.007	-0.093	-0.088	0.966(**)	0.656(**)	0.929(**)	0.968(**)	0.881(**)	1.000

Table 3.10 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield at Ottappalam

	plant							soil					
	Total Yield	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn
Total Yield	1.000	0.195	0.059	0.156	0.320(*)	0.461(**)	0.018	0.120	0.017	0.275	0.530(**)	0.510(**)	0.063
P/K	0.195	1.000	0.189	0.201	0.676(**)	0.724(**)	0.636(**)	0.492(**)	-0.239	0.336(*)	0.532(**)	0.432(**)	0.399(**)
P/Ca	0.059	0.189	1.000	0.680(**)	0.324(*)	0.355(*)	0.025	-0.026	0.280	0.304(*)	0.354(*)	0.269	-0.170
P/Mg	0.156	0.201	0.680(**)	1.000	0.308(*)	0.435(**)	0.068	0.038	0.075	0.370(*)	0.442(**)	0.284	-0.411(**)
P/Fe	0.320(*)	0.676(**)	0.324(*)	0.308(*)	1.000	0.898(**)	0.283	0.494(**)	0.033	0.424(**)	0.765(**)	0.612(**)	0.490(**)
P/Mn	0.461(**)	0.724(**)	0.355(*)	0.435(**)	0.898(**)	1.000	0.418(**)	0.432(**)	-0.057	0.445(**)	0.773(**)	0.673(**)	0.326(*)
P/Zn	0.018	0.636(**)	0.025	0.068	0.283	0.418(**)	1.000	0.244	-0.318(*)	0.082	0.192	0.327(*)	0.261
P/K	0.120	0.492(**)	-0.026	0.038	0.494(**)	0.432(**)	0.244	1.000	0.276	0.828(**)	0.612(**)	0.411(**)	0.676(**)
P/Ca	0.017	-0.239	0.280	0.075	0.033	-0.057	-0.318(*)	0.276	1.000	0.346(*)	0.226	0.093	0.252
P/Mg	0.275	0.336(*)	0.304(*)	0.370(*)	0.424(**)	0.445(**)	0.082	0.828(**)	0.346(*)	1.000	0.669(**)	0.414(**)	0.339(*)
P/Fe	0.530(**)	0.532(**)	0.354(*)	0.442(**)	0.765(**)	0.773(**)	0.192	0.612(**)	0.226	0.669(**)	1.000	0.730(**)	0.456(**)
P/Mn	0.510(**)	0.432(**)	0.269	0.284	0.612(**)	0.673(**)	0.327(*)	0.411(**)	0.093	0.414(**)	0.730(**)	1.000	0.349(*)
P/Zn	0.063	0.399(**)	-0.170	-0.411(**)	0.490(**)	0.326(*)	0.261	0.676(**)	0.252	0.339(*)	0.456(**)	0.349(*)	1.000

Table 3.11 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield at Ottappalam

	plant							soil					
	Total yield	**K/Ca**	**K/Mg**	**K/Fe**	**K/Mn**	**K/Zn**	**K/Ca +Mg**	**K/Ca**	**K/Mg**	**K/Fe**	**K/Mn**	**K/Zn**	**K/Ca +Mg**
Total yield	1.000	-0.248	-0.020	0.097	0.239	0.089	-0.045	-0.103	0.229	-0.034	0.287	-0.130	0.039
K/Ca	-0.248	1.000	0.562(**)	0.202	0.212	0.132	0.790(**)	0.213	0.165	-0.071	-0.081	-0.072	0.188
K/Mg	-0.020	0.562(**)	1.000	0.441(**)	0.140	-0.182	0.925(**)	0.088	0.504(**)	-0.158	-0.126	-0.078	0.074
K/Fe	0.097	0.202	0.441(**)	1.000	0.252	-0.002	0.491(**)	0.233	0.205	0.019	0.141	-0.018	0.299(*)
K/Mn	0.239	0.212	0.140	0.252	1.000	0.271	0.284	0.386(**)	0.206	0.153	0.210	0.010	0.503(**)
K/Zn	0.089	0.132	-0.182	-0.002	0.271	1.000	0.014	0.005	-0.038	0.014	0.121	-0.005	0.031
K/Ca +Mg	-0.045	0.790(**)	0.925(**)	0.491(**)	0.284	0.014	1.000	0.204	0.461(**)	-0.089	-0.051	-0.095	0.213
K/Ca	-0.103	0.213	0.088	0.233	0.386(**)	0.005	0.204	1.000	-0.046	0.082	-0.035	-0.189	0.930(**)
K/Mg	0.229	0.165	0.504(**)	0.205	0.206	-0.038	0.461(**)	-0.046	1.000	0.075	0.130	0.118	0.135
K/Fe	-0.034	-0.071	-0.158	0.019	0.153	0.014	-0.089	0.082	0.075	1.000	0.483(**)	0.610(**)	0.278
K/Mn	0.287	-0.081	-0.126	0.141	0.210	0.121	-0.051	-0.035	0.130	0.483(**)	1.000	0.309(*)	0.231
K/Zn	-0.130	-0.072	-0.078	-0.018	0.010	-0.005	-0.095	-0.189	0.118	0.610(**)	0.309(*)	1.000	0.011
K/Ca +Mg	0.039	0.188	0.074	0.299(*)	0.503(**)	0.031	0.213	0.930(**)	0.135	0.278	0.231	0.011	1.000

Table 3.12 Correlation coefficient of nutrient ratios of soil and plant at PIstage with yield at Ottappalam

	plant							soil					
	Total yield	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg
Total yield	1.000	-0.027	0.100	0.314(*)	0.446(**)	-0.113	0.113	-0.068	0.319(*)	0.623(**)	0.512(**)	-0.027	0.132
K/Ca	-0.027	1.000	0.678(**)	0.181	0.322(*)	-0.121	0.831(**)	0.454(**)	0.641(**)	0.304(*)	0.198	-0.273	0.543(**)
K/Mg	0.100	0.678(**)	1.000	0.175	0.434(**)	-0.100	0.945(**)	0.212	0.637(**)	0.391(**)	0.200	-0.621(**)	0.323(*)
K/Fe	0.314(*)	0.181	0.175	1.000	0.709(**)	-0.196	0.277	-0.017	0.118	0.650(**)	0.422(**)	0.226	0.128
K/Mn	0.446(**)	0.322(*)	0.434(**)	0.709(**)	1.000	-0.081	0.547(**)	0.159	0.408(**)	0.599(**)	0.464(**)	-0.069	0.332(*)
K/Zn	-0.113	-0.121	-0.100	-0.196	-0.081	1.000	-0.129	-0.140	-0.196	-0.105	0.163	0.170	-0.179
K/Ca +Mg	0.113	0.831(**)	0.945(**)	0.277	0.547(**)	-0.129	1.000	0.339(*)	0.703(**)	0.430(**)	0.266	-0.534(**)	0.462(**)
K/Ca	-0.068	0.454(**)	0.212	-0.017	0.159	-0.140	0.339(*)	1.000	0.184	0.025	-0.031	0.104	0.938(**)
K/Mg	0.319(*)	0.641(**)	0.637(**)	0.118	0.408(**)	-0.196	0.703(**)	0.184	1.000	0.387(**)	0.170	-0.524(**)	0.411(**)
K/Fe	0.623(**)	0.304(*)	0.391(**)	0.650(**)	0.599(**)	-0.105	0.430(**)	0.025	0.387(**)	1.000	0.676(**)	0.094	0.285
K/Mn	0.512(**)	0.198	0.200	0.422(**)	0.464(**)	0.163	0.266	-0.031	0.170	0.676(**)	1.000	0.110	0.143
K/Zn	-0.027	-0.273	-0.621(**)	0.226	-0.069	0.170	-0.534(**)	0.104	-0.524(**)	0.094	0.110	1.000	0.089
K/Ca +Mg	0.132	0.543(**)	0.323(*)	0.128	0.332(*)	-0.179	0.462(**)	0.938(**)	0.411(**)	0.285	0.143	0.089	1.000

The relation between yield and P based ratios at Ottappalam as seen from the table 3.9 revealed significant positive correlation of yield with P/Fe and P/Zn ratios of the plant at MT stage.

A perusal of the K based ratios at Ottappalam showed that the total yield was positively correlated with K/Fe, K/Mn and K/Zn ratios of the plant at MT stage (Table 3.11). The K/Ca of the plant showed significant positive correlation with K/Mg and K/Ca + Mg ratio of the plant. Similarly K/Mg ratio of the plant showed significant positive correlation with K/Fe and K/Ca + Mg of the plant. The K/Ca + Mg ratio of the soil and plant was positively and significantly correlated with K/Fe ratio of the plant at MT stage. The K/Mn ratio of the plant showed positive correlation with K/Ca + Mg of the plant and significant positive correlation with K/Ca + Mg of the soil. Significant positive correlation was observed between the K/Mg ratios of the plant and soil.

From the table 3.12, it is clear that at PI stage total yield was significantly and positively correlated with K/Fe and K/Mn ratios of plant and soil. The K/Ca + Mg ratio of the plant was significantly and positively correlated with K/Ca, K/Mg and K/Mn ratios of plant. The K/Fe and K/Mn ratios of the plant were significantly and positively correlated with the corresponding ratios in the soil. The plant K/Mn ratio showed significant positive correlation with K/Ca, K/Mg, K/Fe ratios of the plant. The K/Mg ratio of soil was significantly and positively correlated with K/Fe and K/Ca + Mg and negatively correlated with K/Zn ratio of the soil.

4.1.5.2 Correlation studies of K based nutrient ratios with grain and straw yield

The correlation studies of K based ratios of the plant at panicle initiation stage at Koyalmannam showed that grain and straw yield were significantly and positively correlated with K/Fe ratio (Table 3.13). At PI stage the K/Fe ratio of soil showed significant positive correlation with grain and straw yield (Table 3.14).

The correlation pattern of plant K based nutrient ratios with yield at Ottappalam revealed a significant positive correlation of K/Fe ratio with grain and straw yield at PI stage (Table3.15). But the K/Mn ratio was significantly and

Table 3.13 Correlation coefficient of nutrient ratios of rice with yield(Koyalmannam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	-0.100	-0.105	K/Ca	0.072	0.048
K/Mg	-0.162	-0.023	K/Mg	0.099	0.099
K/Fe	-0.047	-0.213	K/Fe	0.364(*)	0.349(*)
K/Mn	0.056	0.218	K/Mn	0.271	0.271
K/Zn	0.219	0.247	K/Zn	-0.067	0.074
K/Ca+Mg	-0.197	-0.126	K/Ca+Mg	0.132	0.134

Table 3.14 Correlation coefficient of nutrient ratios of soil with yield(Koyalmannam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	-0.248	-0.207	K/Ca	0.264	0.271
K/Mg	-0.356(*)	-0.167	K/Mg	0.210	0.352
K/Fe	0.579(**)	0.156	K/Fe	0.478(**)	0.410(**)
K/Mn	0.055	-0.104	K/Mn	0.136	0.014
K/Zn	-0.123	0.128	K/Zn	-0.061	-0.094
K/Ca+Mg	-0.124	-0.140	K/Ca+Mg	-0.175	-0.120

Table 3.15 Correlation coefficient of nutrient ratios of rice with yield(Ottappalam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	-0.165	-0.214	K/Ca	-0.056	0.003
K/Mg	-0.021	-0.012	K/Mg	0.106	0.061
K/Fe	0.011	0.120	K/Fe	0.297(*)	0.294(*)
K/Mn	0.104	0.244	K/Mn	0.204	0.450(**)
K/Zn	0.060	0.076	K/Zn	-0.005	-0.146
K/Ca+Mg	-0.041	-0.031	K/Ca+Mg	0.093	0.086

Table 3.16 Correlation coefficient of nutrient ratios of soil with yield(Ottappalam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	-0.150	-0.033	K/Ca	-0.324(*)	0.134
K/Mg	0.280	0.112	K/Mg	0.198	0.286
K/Fe	-0.225	0.108	K/Fe	0.484(**)	0.491(**)
K/Mn	0.284	0.184	K/Mn	0.570(**)	0.297(*)
K/Zn	-0.275	0.016	K/Zn	-0.173	0.081
K/Ca+Mg	-0.041	0.079	K/Ca+Mg	-0.175	0.292(*)

Table 3.17 Rainfall and sunshine hours during different phenophases and grain yield

Location	Vegetative phase		Reproductive phase		Ripening Phase		45 days prior to harvest	Average Grain Yield
	RF (mm)	SH (hrs)	RF (mm)	SH (hrs)	RF (mm)	SH (hrs)	SH (hrs)	t/ha
Koyalmannnam	747	263	421	78	185	150	176	1.7
Ottappalam	224	256	122	92	48	198	228	2.25

Table 3.18 Rainfall, sunshine hours and grain yield from 1999 to 2001 at Koyalmannam

Year	Vegetative phase		Reproductive phase		Ripening Phase		45 days prior to harvest	Average Grain Yield
	RF (mm)	SH (hrs)	RF (mm)	SH (hrs)	RF (mm)	SH (hrs)	SH (hrs)	t/ha
1999	960	220	157	173	24	198	279	2.2
2000	747	263	421	78	185	150	199	1.7
2001	829	127	214	176	88	148	236	2.0

positively correlated only with straw yield. The K/Fe and K/Mn ratios of soil at panicle initiation stage were significantly and positively correlated with grain and straw yield (Table 3.16).

4.1.6 Effect of weather parameters on grain yield

A review of the influence of weather parameters at two locations showed that a difference was noticed in the number of bright sunshine hours during the reproductive and ripening phase (Table 3.17). The number of sunshine hours 45 days prior to harvest was high (198 hours) at Ottappalam when compared to that of Koyalmannam (150 hours). It might be one of the reasons for, why the grain yield was more at Ottappalam in addition to other environmental factors.

A perusal of the data on weather parameters and grain yield of the three consecutive years at Koyalmannam showed that a higher grain yield was obtained in the year 1999 when the sunshine hours in the ripening phase and 45 days prior to harvest was higher compared to the succeeding years (Table 3.18).

4.2 SECOND CROP OF RICE AT KOYALMANNAM AND OTTAPPALAM

The second crop of rice was taken during the mundakan season with the same treatments and variety at Koyalmannam and Ottappalam. The results of the experiment are reviewed hereunder.

4.2.1 Yield and growth attributes of rice

4.2.1.1 Effect of treatments on growth attributes of rice

Effect of P, K, lime and controls on growth characters is given in the table 4.1.

Effect of P

Phosphorus application at two levels significantly increased the plant height and tillers per hill. Application of P at 35 kg ha^{-1} increased the plant height at all stages except panicle initiation. There was a significant increase in the number of tillers per hill at the highest level of P at all stages of growth.

Table 4.1. Effect of treatments on growth attributes of rice (Koyalmannam)

Treatments	Plant height (cm)				Tillers/hill (No.)		
	MT	PI	Flg	Harvest	PI	Flg	Harvest
Levels of Phosphorus							
P_1	32.37	53.24	75.93	75.14	4.36	4.40	4.40
P_2	34.05	56.06	78.96	78.03	4.91	5.09	4.98
CD (0.05)	1.45	NS	1.47	1.55	0.16	0.15	0.15
Levels of Potassium							
K_1	31.98	50.88	76.51	77.09	4.53	4.54	4.54
K_2	33.04	56.64	75.97	75.32	4.74	4.91	4.83
K_3	34.62	56.42	79.84	77.35	4.63	4.78	4.70
CD (0.05)	1.78	3.10	1.80	NS	NS	0.19	0.18
Levels of Lime							
L_1	33.12	53.48	77.21	75.67	4.69	4.64	4.54
L_2	33.00	55.82	77.68	77.50	4.58	4.84	4.84
CD (0.05)	NS	NS	NS	1.50	NS	0.16	0.15
Controls							
C_1	28.14	54.83	78.13	78.33	4.51	4.51	4.51
C_2	32.08	54.78	78.35	77.75	4.70	4.78	4.78
C_3	29.06	50.10	76.60	74.33	4.00	4.00	4.00
CD (0.05)	NS	NS	NS	NS	0.41	0.38	0.38

Effect of K

The plant height showed a significant increase at K_2 level at the panicle initiation stage. At maximum tillering stage and flowering stage the significant increase was observed at K_3 level and at harvest stage no significant difference was observed with varying levels of K application.

The productive tillers per hill showed a significant increase at 70 kg ha^{-1} of K application compared to 35 kg ha^{-1} of K throughout the growth period except at panicle initiation stage. No significant difference was observed between K_2 and K_3 level for the productive tillers per hill.

Effect of lime

The plant height showed significant increase at harvest stage with higher level of lime application while the number of tillers per hill showed a significant increase at flowering and harvest stage.

Effect of controls

Between the control treatments no significant variation was observed for the plant height. But the treatment C_2 (POP) significantly increased the tillers per hill at all stages of crop growth compared to C_3. The productive tillers per hill showed no significant variation between C_1 and C_2 at any stage of crop growth.

4.2.1.2 Yield and yield attributes of rice at Koyalmannam

Effect of P, K, lime and controls on yield and yield attributes of rice is given in the table 4.2

Effect of P

Phosphorus application at 17.5 kg ha^{-1} was on par with P application at 35 kg ha^{-1} for the number of grains per panicle and thousand grain weight. Grain yield and straw yield was increased by 10.5 and 21 per cent at 35 kg ha^{-1} of P application over P application at 17.5 kg ha^{-1}.

Table 4.2 Yield and yield attributes of rice (Koyalmannam)

Treatments	Grains/ Panicle (no.)	1000 grain wt (g)	Grain yield ($kgha^{-1}$)	Straw yield ($kgha^{-1}$)
Levels of Phosphorus				
P_1	82.23	26.05	3363	2897
P_2	83.78	26.77	3715	3508
CD (0.05)	NS	NS	222.80	147.20
Levels of Potassium				
K_1	77.92	24.41	3185	3045
K_2	82.25	29.40	3589	3323
K_3	89.00	25.23	3894	3240
CD (0.05)	5.45	1.01	272.86	180.38
Levels of Lime				
L_1	83.33	25.65	3472	3068
L_2	82.70	27.17	3507	3237
CD (0.05)	NS	0.83	NS	147.00
Controls				
C_1	74.00	28.90	3333	2780
C_2	76.33	29.06	3466	3558
C_3	69.00	24.01	2000	2806
CD (0.05)	NS	2.03	445.73	360.77

Effect of K

Application of K significantly influenced the yield and yield attributes. There was a steady increase in the number of grains per panicle with increasing levels of K application from K_1 to K_3 to the tune of 14.21 per cent. Thousand grain weight showed a significant increase from K_1 to K_2 and beyond K_2 it showed a significant decline.

Graded levels of K application significantly increased the grain yield. The grain yield was increased by 12.6 per cent when the K dose was increased from 35 kg ha^{-1} to 70 kg ha^{-1} and it showed an increase to the tune of 8.4 per cent when the K dose increased from 70 kg ha^{-1} to 105 kg ha^{-1}.The overall increase in grain yield between K_1 and K_3 level was to the extent of 22 per cent. Unlike in grain yield, the straw yield showed an increase to the tune of 9 per cent up to K_2 level and no significant difference was observed beyond K_2.

Effect of lime

Among the yield attributes studied the 1000 grain weight was significantly increased by the application of lime at higher level. The number of grains per panicle and the grain yield remained unaffected by the lime application at two levels. The straw yield increased by 5.5 per cent at higher level of lime application.

Effect of controls

The treatment C_2 (POP) recorded the highest grain yield and straw yield and it was significantly superior to C_3 (the farmer's practice). The increase in grain and straw yield in C_2 was to the tune of 73 per cent and 26.7 per cent respectively over C_3.

4.2.1.3 Interaction effect on yield and yield attributes of rice

Interaction between P and K

It can be seen from the table 4.3a that maximum number of grains per panicle was registered by the P_2K_3 and the minimum number of grains per panicle was

Table 4.3a Effect of P and K on yield and yield attributes of rice (Koyalmannam)

Treatment	Grains/panicle			1000 grain weight (g)			Grain yield (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	74.83	83.33	88.83	22.38	29.52	26.25	2816	3253	4021
P_2	81.00	81.17	89.17	26.43	29.29	24.60	3055	3825	3766
CD(0.05)	7.71			1.40			385.88		

Table 4.3 b Effect of K and lime on yield and yield attributes of rice (Koyalmannam)

Treatment	1000 grain weight		Grain yield		Straw yield	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	23.45	25.37	3335	3036	2896	3195
K_2	25.42	29.39	3253	3825	3298	3348
K_3	24.08	26.77	3828	3960	3310	3170
CD(0.05)	1.40		385.80		255	

observed at P_1K_1 and these two treatments differed significantly by 19.16 per cent. Increasing the level of K to 105 kg ha^{-1} with 17.5 kg ha^{-1} of P increased the number of grains per panicle by 18.7 per cent and 6.6 per cent respectively over K_1 and K_2, while the increase with 35 kg ha^{-1} of P at K_3 was to the extent of 10 per cent over K_1 and K_2.

P_1K_2 registered the highest value for 1000 grain weight (29.52 g) which was significantly superior to the lowest value of 1000 grain weight at P_1K_1 (22.38 g) by 31 per cent. Increasing the level of K with 17.5 kg ha^{-1} of P increased the 1000 grain weight significantly compared to the lowest level of K. This pattern of was observed at P_2 level also. Grain yield registered the highest value at P_1K_3 (4021 kg ha^{-1}). It was significantly higher than the lowest grain yield obtained at P_1K_1 (2816 kg ha^{-1}) by 42 per cent. Increasing levels of K application with 17.5 kg ha^{-1} of P significantly increased the grain yield at K_2 and K_3 compared to K_1. With 35 kg ha^{-1} of P application also the increasing pattern was observed at K_2 and K_3 compared to K_1. It is to be noted that with increase in P level from P_1 to P_2 there was a significant increase in grain yield at K_1 and K_2 level but at K_3 it was ineffective.

Interaction between K and lime

It can be seen from the table 4.3b that there was a significant increase in the 1000 grain weight at K_2 over K_1 to the extent of 25 per cent and 15.8 per cent at L_1 and L_2 respectively. Increasing the lime dose was found to increase the 1000 grain weight at K_1 and K_3 level. K_3L_2 showed 19 per cent increase in grain yield over K_1L_1. However the lowest grain yield was obtained at K_2L_1. K_1 and K_2 were on par at 300 kg ha^{-1} of lime, but at 600 kg ha^{-1} of lime application K_2 showed significant increase to the tune of 25 per cent over K_1. On comparing K_2 and K_3 at the two levels of lime application a significant increase at K_3 over K_2 to the tune of 17.6 per cent was observed in the presence of 300 kg ha^{-1} of lime application while in the presence of 600 kg ha^{-1} of lime application K_2 and K_3 were on par.

Increasing the K to 70 kg ha^{-1} and lime to 600 kg ha^{-1} (K_2L_2) significantly increased the straw yield by 15.6 per cent over the lowest level of K and lime (K_1L_1). Increasing the K dose from 35 kg ha^{-1} to 70 kg ha^{-1} at L_1 and L_2 increased the straw yield by 13.8 per cent and 4 per cent respectively.

4.2.1.4 Effect of treatments on growth attributes of rice at Ottappalam

Effect of P, K, lime and controls on growth attributes of rice is given in the table 4.4.

Effect of P

None of the growth attributes were significantly influenced by the two levels of P application.

Effect of K

Plant height alone was influenced by the application of K at different levels and the significant effect was confined to flowering stage and harvest. At flowering and harvest stage there was significant increase in plant height, up to K_2 level. Beyond K_2 level the plant height decreased at flowering stage, but at harvest no significant difference was noticed.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased the tillers per hill at all critical stages and the plant height was not influenced by lime application.

Effect of controls

The control treatments did not significantly affect the growth characters except for plant height at maximum tillering stage.

4.2.1.5 Yield and yield attributes of rice at Ottappalam

Effect of P, K, lime and controls on yield and yield attributes of rice is given in the table 4.5

Effect of P

Higher level of P application significantly increased thousand grain weight but it failed to influence significantly the grains per panicle, grain yield and straw yield.

Table 4.4 Effect of treatments on growth attributes of rice (Ottappalam)

Treatments	Plant height (cm)				Tillers/hill (No.)			
	MT	PI	Flg	Harvest	MT	PI	Flg	Harvest
Levels of P								
P_1	32.86	55.46	67.75	69.32	4.23	4.52	4.77	4.81
P_2	33.59	56.43	68.66	68.60	4.32	4.65	5.04	5.04
CD(0.5)	NS	NS	NS	NS	NS	NS	NS	NS
Levels of K								
K_1	32.36	56.89	67.42	66.13	4.40	4.67	5.00	4.96
K_2	33.35	54.81	70.86	70.48	4.23	4.52	4.98	4.81
K_3	33.96	56.75	66.34	70.26	4.18	4.58	4.77	5.00
CD(0.5)	NS	NS	1.80	2.11	NS	NS	NS	NS
Levels of Lime								
L_1	33.08	56.22	67.86	69.04	4.14	4.46	4.69	4.69
L_2	33.36	55.67	68.55	68.88	4.40	4.72	5.15	5.15
CD(0.5)	NS	NS	NS	NS	0.21	0.22	0.31	0.31
Controls								
C_1	34.10	47.66	71.83	74.00	4.33	4.40	4.50	4.50
C_2	35.90	49.43	75.33	75.00	4.30	4.36	4.50	4.50
C_3	32.46	54.06	65.00	65.96	4.00	4.06	4.16	4.16
CD(0.5)	2.43	NS	NS	NS	NS	NS	NS	NS

Table 4.5 Yield and yield attributes of rice(Ottappalam)

Treatments	Grains/panicle (no.)	1000 grain wt (g)	Grain Yield (kgha^{-1})	Straw Yield (kgha^{-1})
Levels of Phosphorus				
P_1	91.17	27.34	3881	3356
P_2	89.33	28.48	3733	3600
CD(0.05)	NS	0.95	NS	NS
Levels of Potassium				
K_1	89.42	26.04	3289	2966
K_2	88.92	29.06	4200	3905
K_3	92.42	28.62	3931	3563
CD(0.05)	NS	1.15	332	375
Levels of Lime				
L_1	88.56	27.06	3676	3610
L_2	91.54	28.76	3938	3346
CD(0.05)	2.70	0.95	215	NS
Controls				
C_1	85.33	25.11	3410	2916
C_2	84.66	25.80	3523	2713
C_3	70.60	23.50	2900	2740
CD(0.05)	6.61	2.01	501	NS

Effect of K

Application of K at 70 kg ha^{-1} significantly increased thousand grain weight, grain yield and straw yield compared to K application at 35 kg ha^{-1}. K_2 (70 kg ha^{-1}) was on par with K_3 (105 kg ha^{-1}) for these characters. Thousand grain weight increased by 11.5 per cent at higher level of K application. Grain yield and straw yield at K_2 increased by 27.6 per cent and 31 per cent respectively compared to K_1.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the grains per panicle, thousand grain weight and grain yield but it failed to influence significantly the grain and straw yield.

Effect of controls

The C_2 (POP) recorded the highest value for the grains per panicle, thousand grain weight. The C_2 was on par with C_1 and significantly superior to C_3 for the grain yield and yield attributes. The POP recorded 17.5 per cent higher grain yield over C_3 but no significant difference was seen in the straw yield.

4.2.1.6 Interaction effect on yield and yield attributes of rice

Interaction effect of P with K and lime significantly influenced the number of grains per panicle, thousand grain weight and straw yield as seen in table 4.6.

Interaction between P and K

Grains per panicle increased either by keeping K at lower level or by increasing K to 70 kg ha^{-1} at lower level of P. Combined application of 17.5 kg ha^{-1} P with 70 kg ha^{-1} K (P_1K_2) gave the highest number of grains per panicle (95.33) followed by P_2K_3 (35 kg ha^{-1} P with 105 kg ha^{-1} of K). P_1K_2 was on par with P_2K_3.

Table 4.6 Effect of P with K and lime on yield and yield attributes of rice (Ottappalam)

Treatment	1000 grain weight(g)		Straw yield(kg ha^{-1})		Treatment	Grains/panicle (no.)		
	L_1	L_2	L_1	L_2		K_1	K_2	K_3
P_1	25.93	28.74	3313	3400	P_1	86.33	95.33	91.83
P_2	28.18	28.77	3907	3293	P_2	92.50	82.50	93.00
CD(0.05)	1.33		433.96			4.67		

Interaction between P and lime

It can be seen from the table 4.6 that thousand grain weight increased when higher level of lime was applied at P_1 or by applying higher level of P at L_1. Highest value for thousand grain weight (28.77 g) was obtained by the combined application of 35 kg ha^{-1} P with 600 kg ha^{-1} of lime (P_2L_2). But this P_2L_2 was on par with P_1L_2 and significantly superior to P_1L_1.Higher level of lime application did not result in higher straw yield whereas higher level of P application at lower level of lime (35 kg ha^{-1} of P with 300 kg ha^{-1} of lime) gave the maximum straw yield and it was significantly superior to P_1L_1 and P_1L_2 by 17.9 and 14.9 per cent respectively.

4.2.1.7 Pooled analysis of yield

Both grain and straw yield were pooled for the two seasons and the two locations. The seasonal influence was found to be non significant while the location effect was significant.

Effect of P

Phosphorus at higher level of 35 kg ha^{-1} significantly increased straw yield compared to lower level of P at 17.5 kg ha^{-1} (Table 4.6b). The grain yield was also significantly higher at P_2 than P_1 and the yield at P_2 and P_1 were respectively 3735 and 3276 kg ha^{-1}.

Effect of K

Potassium at higher level of 70 kg ha^{-1} and 105 kg ha^{-1} significantly increased the straw yield compared to 35 kg ha^{-1} of K (Table 4.6b).

Effect of P and K

Potassium at higher level of 70 kg ha^{-1} and 105 kg ha^{-1} in the presence of 17.5 kg ha^{-1} of P significantly increased the grain yield (Table 4.6a). At higher level of P (35 kg ha^{-1}), K_2 recorded significantly higher yield compared to K_1. At all levels of K higher level of P increased the grain yield.

Table 4.6a Effect of Pand K on grain yield (kg ha^{-1}) of rice

Treatment	K_1	K_2	K_3
P_1	2970	3341	3517
P_2	3518	3800	3887
CD (0.05%)	196		

Table 4.6c Effect of P, lime and location on grain yield (kg ha^{-1}) of rice

Treatment	L_1	L_2
Koyalmannam P_1	3150	3175
Koyalmannam P_2	3618	3774
Ottappalam P_1	3226	3553
Ottapppalam P_2	4059	3730
CD (0.05%)	390	

Table 4.6b Effect of P, K and lime on straw yield (kg ha^{-1}) of rice

Treatment	straw yield
P_1	2979
P_2	3473
K_1	3010
K_2	3198
K_3	3491
CD(0.05)	177
L_1	3133
L_2	3319

Table 4.7 Elemental Composition of rice at MT stage (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	2.60	0.330	2.37	0.130	0.170	3580	431.40	31.33	9.01	2.23
P_2	2.74	0.340	2.43	0.120	0.170	3462	434.80	28.95	9.24	2.18
CD (0.05)	0.03	NS	NS	NS	NS	62	NS	1.7	NS	0.03
Levels of Potassium										
K_1	2.61	0.320	1.92	0.150	0.180	3468	449.00	28.53	8.53	2.23
K_2	2.69	0.340	2.52	0.110	0.160	3518	430.00	30.29	8.13	2.18
K_3	2.72	0.340	2.76	0.110	0.160	3578	419.00	31.59	9.92	2.20
CD (0.05)	0.04	0.008	0.16	0.010	0.002	75.90	4.50	2.13	NS	NS
Levels of Lime										
L_1	2.64	0.330	2.39	0.110	0.170	3610	439.10	30.59	8.93	2.21
L_2	2.71	0.340	2.41	0.140	0.170	3433	426.11	29.69	9.31	2.19
CD (0.05)	0.03	0.006	0.13	0.010	NS	62	3.70	NS	NS	NS
Controls										
C_1	2.63	0.325	2.22	0.123	0.171	3409	468.46	29.30	8.60	2.20
C_2	2.63	0.330	2.12	0.130	0.181	3320	462.00	30.00	9.83	2.17
C_3	2.54	0.300	1.97	0.104	0.182	3539	427.60	27.00	8.26	2.43
CD (0.05)	NS	0.010	NS	NS	0.005	151	9.10	NS	0.54	0.09

Effect of lime

Lime at higher level (600 kg ha^{-1}) significantly increased the straw yield compared to lower level (300 kg ha^{-1}) (Table 4.6b).

Effect of P, lime and location

At both levels of lime application P at higher level significantly increased the grain yield at Koyalmannam. But at Ottappalam, P at higher level increased the yield only at 300 kg ha^{-1} of lime. Between the two locations, Ottappalam recorded significantly higher grain yield at P_1L_2 and P_2L_1 compared to the corresponding treatments at Koyalmannam (Table 4.6c).

4.2.2 Nutrient content of rice

4.2.2.1.1 Elemental composition of rice at MT stage at Koyalmannam

Effects of different levels of P, K and lime and controls on elemental composition of rice are presented in the table 4.7.

Effect of P

It is obvious from the table 4.7 that the main effect of P in influencing the nutrient content of plant was confined only to N, Fe, Zn and Si. P application at higher doses increased the N content of the plant while decreased the Fe, Zn and Si content. The reduction was to the tune of 3.2, 7.5 and 2.24 per cent respectively.

Effect of K

Application of K at different levels significantly influenced the N, P, K, Ca, Mg, Fe, Mn and Zn content of the plant at maximum tillering stage. Increased levels of K application at 70 kg ha^{-1} significantly increased the N, P and Fe content of the plant, while the maximum content of K was observed at 105 kg ha^{-1}. Potassium application at K_2 and K_3 levels were on par for N, P, Ca and Mg content of the plant.

Plate 3. Fe toxicity symptom

Plate 4. Fe toxicity symptom

There was a significant decrease in the Mn content of the plant with increasing levels of K application. Calcium and Mg content of the plant was significantly reduced at K_2 (70 kg ha^{-1}) level compared to K_1 (35 kg ha^{-1}).

Effect of lime

Magnesium, Zn, Cu and Si content of the plant remained unaffected by the two levels of lime application. Lime application at 600 kg ha^{-1} recorded the highest content of N, P, K and Ca and the lowest content of Fe and Mn.

Effect of controls

Phosphorus, Mg, Fe, Mn, Cu and Si were significantly influenced by different control treatments. C_2 (POP) recorded significantly higher quantity of P and Cu to the extend of 9 and 15 per cent respectively compared to the C_3 (farmer's practice). The highest content of Fe and the lowest Mn content was found in the farmer's practice. Minimum content of Fe was observed in POP followed by POP without lime.

4.2.2.1.2 Interaction effect on elemental composition of rice

Interaction between P and lime

It can be seen from the table 4.8a that P and lime interacted significantly to increase the N content of the plant. When lime application was increased at P_1, N content was not affected while at P_2 it increased substantially. Increasing level of P increased N content at both levels of lime application. The P content also registered the maximum value at P_2L_2 which was 6 per cent higher than the lowest value. At 600 kg ha^{-1} of lime application, P content increased with increase in P application rate. Increasing the P and lime to 35 kg ha^{-1} and 600 kg ha^{-1} respectively decreased the Mn content compared to lower levels of P and lime. Application of lime at higher level decreased Mn content more drastically at P_2 than at P_1 .Zn content was reduced drastically when lime and P was applied at higher level. Application of P or lime alone at higher level did not influence Zn content.

Table 4.8a Effect of P and lime on elemental composition of rice at MT stage (Koyalmannam)

Treatment	N (%)		P (%)		Mn (ppm)		Zn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1	2.59	2.62	0.33	0.33	434.73	428.18	30.83	31.82
P_2	2.68	2.80	0.33	0.35	444.30	425.33	30.34	27.56
CD(0.05)	0.05		0.009		5.26		2.46	

Table 4.8b Effect of K and lime on elemental composition of rice at MT stage (Koyalmannam)

Treatment	N (%)		Ca (%)		Mg (%)	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	2.53	2.70	0.12	0.17	0.18	0.18
K_2	2.67	2.71	0.11	0.12	0.17	0.17
K_3	2.71	2.73	0.11	0.12	0.17	0.16
CD(0.05)	0.01		0.003		0.006	

Interaction between K and lime

Effect of K and lime on elemental composition of rice at MT stage is given in table 4.8b.

Increasing the level of K at both levels of lime increased the N content. This increase was more pronounced at lower level of lime. The highest value for the Ca content (0.17%) was obtained by the combined application of 35 kg ha^{-1} of K and 600 kg ha^{-1} of lime. Higher level of lime application at lower level of K significantly increased the Ca content. At 600 kg ha^{-1} of lime application increasing the K levels significantly decreased the Ca content over K_1.The Mg content recorded the highest value at the lowest level of K application. Increasing the K dose at both levels of lime application significantly decreased the Mg content compared to K_1.

4.2.2.1.3 Elemental composition of rice at MT stage at Ottappalam

The effect of P, K and lime and controls on elemental composition of rice is given in table 4.9.

Effect of P

It may be seen from the table 4.9 that at higher level of P application significant increase was observed in P, K and Mn content and the increase was to the tune of 6.6, 14 and 4 per cent respectively.

Effect of K

There was significant increase in P and K content to the tune of 10.3 and 5.3 respectively and a significant decrease in Ca, Fe and Mn content at K_2 level (70 kg ha^{-1}) to the tune of 20, 5.8 and 3.7 per cent respectively over K_1 levels (35 kg ha^{-1}). The maximum content of Zn and Si was observed at K_3 level and it was significantly superior to both K_1 and K_2 levels.

Table 4.9 Elemental composition of rice at MT stage (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	2.36	0.300	2.86	0.130	0.100	4314	432.40	23.91	8.20	2.36
P_2	2.40	0.320	2.90	0.140	0.110	4261	450.90	22.90	8.03	2.38
CD (0.05)	NS	0.009	0.03	NS	NS	NS	6.92	NS	NS	NS
Levels of Potassium										
K_1	2.39	0.290	2.79	0.150	0.120	4452	452.42	23.29	7.68	2.36
K_2	2.37	0.320	2.94	0.120	0.090	4191	435.32	20.78	7.79	2.30
K_3	2.39	0.320	2.91	0.120	0.100	4218	435.17	26.16	8.88	2.46
CD (0.05)	NS	0.01	0.04	0.008	NS	90.00	8.40	0.710	NS	0.04
Levels of Lime										
L_1	2.36	0.300	2.91	0.120	0.100	4361	448.11	22.10	8.19	2.35
L_2	2.40	0.310	2.85	0.140	0.110	4213	435.83	24.20	8.04	2.40
CD (0.05)	NS	0.009	0.03	0.008	NS	74.00	6.90	0.580	NS	0.03
Controls										
C_1	2.35	0.316	2.89	0.136	0.124	4286	477.00	22.00	7.96	2.35
C_2	2.42	0.321	2.86	0.154	0.129	4394	470.23	22.66	8.56	2.42
C_3	2.36	0.290	2.84	0.103	0.080	4673	444.93	21.10	7.63	2.35
CD (0.05)	0.10	0.02	0.08	0.019	0.030	181.39	16.95	NS	NS	NS

Effect of lime

Phosphorus, Ca, Zn and Si content significantly increased by lime application at 600 kg ha^{-1} compared to lime application at 300 kg ha^{-1}. Potassium Fe and Mn showed a significant decline at higher level of lime application.

Effect of controls

There was significant difference between the control treatments for all the nutrients except Zn, Cu and Si. Maximum content of N, P and Ca was present in C_2 (POP) and it was significantly superior to C_3 (farmer's practice). Highest content of K was present in C_1 and it was significantly superior to C_3. C_1 and C_2 were on par for the K content. Farmer's practice recorded the highest content of Fe which was 6 per cent higher than C_2 and the lowest content of Mn was 5.5 per cent lower than C_2. There was no significant difference between C_1 and C_2 for the Fe and Mn content.

4.2.2.1.4 Interaction effect on elemental composition of rice

Interaction between P and K

Combined application of P and K significantly influenced the P and Ca content of the plant (Table 4.10b). Maximum Ca content of 0.16 per cent was observed at P_2K_1 (35 kg ha^{-1} of P with 35 kg ha^{-1} of K) and it was significantly superior to all the combinations of P with K except P_1K_1. P_2K_1 was on par with P_1K_1.Increasing the K dose increased the P content at P_1 while at P_2 the increase occurred only up to 70 kg ha^{-1} of K beyond which it was ineffective.

Interaction between P and lime

Effect of P and lime on elemental composition of rice at MT stage is given in table 4.10a.

Application of 600 kg ha^{-1} of lime in the presence of 17.5 kg ha^{-1} and 35 kg ha^{-1} of P gave the same values for N content. Lowest level of P and Lime (P_1L_1) gave the lowest content of P (0.29%) and the higher level of P and L (P_2L_2) gave the highest

Table 4.10 a Effect of P and lime on elemental composition of rice at MT stage (Ottappalam)

Treatments	N (%)		P (%)		K (%)		Mn (ppm)		Zn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1	2.33	2.40	0.29	0.31	2.91	2.81	443.58	422.31	23.51	24.31
P_2	2.36	2.40	0.31	0.32	2.91	2.90	452.63	449.36	21.70	24.12
CD(0.05)	0.06		0.01		0.05		9.7		0.82	

Table 4.10 b Effect of P and K on elemental composition of rice at MT stage (Ottappalam)

Treatments	Ca (%)			P (%)		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.15	0.10	0.13	0.28	0.31	0.32
P_2	0.16	0.14	0.12	0.31	0.32	0.32
CD(0.05)	0.01			0.009		

content of P (0.32%). P_2L_2 was significantly superior to P_1L_1. P_1L_2 and P_2L_1 were on par and both of them were significantly superior to P_1L_1.

Lower level of lime application combined with lower and higher levels of P (P_1L_1 and P_2L_1) gave the highest content of K (2.91%). It was significantly superior to higher level of lime application. Maximum Mn content was observed at P_2L_1 and the lowest content was recorded by P_1L_2. At lower level of P when the lime application rate was increased from 300 kg ha^{-1} to 600 kg ha^{-1}, there was a significant reduction in the Mn content to the time of 4.7 per cent and this reduction was not observed at higher level of P.

Combined application of 17.5 kg ha^{-1} of P and 600 kg ha^{-1} of lime (P_1L_2) gave the highest zinc content. When the P rate was increased from 17.5 to 35 kg ha^{-1} in the presence of 300 kg ha^{-1} of lime the Zn content of plant has shown a decline to the extent of 7.6 per cent.

4.2.2.2.1 Elemental composition of rice at PI stage at Koyalmannam

Effects of different levels of P, K and lime and the controls on the elemental composition of rice are presented in table 4.11.

Effect of P

It is evident from the data in the table 4.11 that higher levels of P at 35 kg ha^{-1} significantly increased the N, P, K and Mg contents of the plant to the extent of 5.95, 11, 7.6 and 6.6 per cent respectively. The Fe and Zn content of the plant was reduced by 6.6 and 13.6 per cent respectively at this level of P application.

Effect of K

There was an increase in the N content at K_3 level which was significantly superior to K_1 (35 kg ha^{-1}) and K_2 (70 kg ha^{-1}). A steady increase in the P, Zn and Cu content of the plant was noticed with increasing levels of K. Maximum content of K was observed at K application at 70 kg ha^{-1}. Higher level of K application significantly

Table 4.11 Elemental Composition of rice at PI stage (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	2.35	0.270	1.69	0.170	0.150	3976	599	42.01	9.18	2.58
P_2	2.49	0.300	1.82	0.170	0.160	3711	601	36.46	9.16	2.40
CD (0.05)	0.03	0.007	0.28	NS	0.005	76.00	NS	1.24	NS	0.08
Levels of Potassium										
K_1	2.43	0.270	1.71	0.190	0.170	4173	600	36.37	8.32	2.62
K_2	2.31	0.290	1.77	0.170	0.150	3618	616	39.68	9.07	2.47
K_3	2.51	0.300	1.77	0.150	0.140	3734	584	41.66	10.13	2.38
CD (0.05)	0.04	0.009	0.28	0.010	0.007	93.10	7.60	1.50	0.67	0.103
Levels of Lime										
L_1	2.35	0.280	1.78	0.160	0.150	3891	609	39.82	9.03	2.56
L_2	2.49	0.290	1.73	0.180	0.150	3793	591.45	38.65	9.31	2.42
CD (0.05)	0.03	0.007	0.28	0.010	NS	76.08	6.23	NS	NS	NS
Controls										
C_1	2.34	0.278	1.85	0.194	0.172	4174	683.3	39.6	8.50	2.53
C_2	2.42	0.285	1.87	0.196	0.180	4007	632.5	41.2	9.50	2.46
C_3	2.17	0.265	1.67	0.166	0.103	4177	617.5	38.6	8.60	3.11
CD (0.05)	0.09	NS	0.06	NS	0.010	106.34	15.25	NS	1.30	0.20

decreased the Ca and Mg content of the plant. Application of K at 70 kg ha^{-1} recorded the lowest content of Fe while the lowest content of Mn was recorded at 105 kg ha^{-1}.

Effect of lime

N, P and Ca content of the plant was significantly increased by application of lime at 600 kg ha^{-1}, on the other hand this level of lime application decreased the K, Fe and Mn content of the plant.

Effect of controls

It may be seen from the table4.11that the lowest content of N, K, Mg and Mn was registered at C_3 (the farmer's practice). C_2 (POP) recorded significantly higher contents of N, K, Mg and Cu which was 10, 10, 42 and 9 per cent respectively over C_3 (the farmer's practice). The latter however showed the highest content of Si which was 20 per cent higher than POP. Minimum content of Fe was present in C_2 (POP) which was significantly lower than C_3 and C_1, which is by about 4 per cent. The Mn content of the plant at C_2 showed a significant increase over C_3 and a significant decrease over C_1. The P, Ca and Zn content of the plant was not significantly influenced by the control treatments.

4.2.2.2.2 Interaction effect on elemental composition of rice

Interaction between P and K

A perusal of the data in the table 4.12 shows that maximum nitrogen content (2.55%) was observed at P_2K_3 and the minimum content (2.24%) was observed at P_1K_1 registering a significant difference of 13.8 per cent.

For increased application of K corresponding increase in N content was observed when P was given at 17.5 kg ha^{-1} and at higher level of P this increase in N content was only up to 70 kg ha^{-1} of K. For higher level of P higher N content was observed at all levels of K. The P and K interacted significantly and increased the K content of plant registering the maximum value of 1.86 per cent at P_2K_3 compared to the lowest value of 1.67 per cent at P_1K_1. Increasing the P from 17.5 to 35 kg ha^{-1} in

Table 4.12 a Effect of P and K on elemental composition of rice at PI stage (Koyalmannam)

Treatments	N (%)			K (%)			Fe (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	2.24	2.33	2.47	1.67	1.70	1.69	4377	3846	3694
P_2	2.38	2.53	2.55	1.74	1.84	1.86	3621	3670	3542
CD(0.05)	0.06			0.04			131.76		

Table 4.12 b Effect of P and lime on elemental composition of rice at PI stage (Koyalmannam)

Treatments	P (%)		Zn (ppm)	
	L_1	L_2	L_1	L_2
P_1	0.27	0.27	40.96	43.07
P_2	0.28	0.31	38.68	34.23
CD(0.05)	0.01		1.76	

the presence of K_1, K_2 and K_3 respectively increased the K content by 4.1 per cent, 8 per cent and 10 per cent respectively.

Application P and K at the highest levels (P_2K_3) significantly decreased the Fe content by 19 per cent compared to the lowest level (P_1K_1). Increasing the K dose in the presence of P_1 (17.5 kg ha^{-1} of P) significantly decreased the Fe content at K_2 and K_3 by 12 per cent and 15.6 per cent compared to K_1. At P_2 level no significant difference was observed between the different levels of K for the Fe content

Interaction between P and lime

Effect of P and lime on the elemental composition of rice at PI stage is given in the table 4.12b.

Maximum content of P was recorded by P_2L_2 (0.31%) and the minimum content was observed at P_1L_1 (0.27%). P_2L_2 showed a significant increase to the tune of 14.8 per cent over both P_1L_2 and P_1L_1. The Zn content of the plant showed a significant decrease with increasing level of P application, to the extent 5.5 and 20 per cent respectively at L_1 and L_2. P_1 level registered a significant increase and P_2 recorded a significant decrease when the lime dose was increased to 600 kg ha^{-1}.

4.2.2.2.3 Second order interaction effect on elemental composition of rice

Effect of P, K and lime on Ca, Fe and Mn content of the plant is given in table 4.13.

The $P_1K_3L_1$ registered the highest content of N while $P_2K_3L_2$ recorded the maximum content of Ca. when K was increased from 35 kg ha^{-1} to 70 kg ha^{-1} there was a decrease in Fe content of the plant at 300 kg ha^{-1} of lime and an increase in Fe content at 600 kg ha^{-1} of lime. Increasing K application from 70 to 105 kg ha^{-1} resulted in substantial reduction in Fe content of the plant at 600 kg ha^{-1} of lime. However it was ineffective at 300 kg ha^{-1} of lime at P_1 and increased Fe content at P2.Increased lime application resulted in a decrease in Mn content of the plant when P was applied at 17.5 kg ha^{-1} and K either at 35 or at 70 kg ha^{-1}. Increasing the level of application of

Table 4.13 Second order interaction effect on elemental composition of rice at PI stage (Koyalmannam)

Treatment	N (%)		Ca (%)		Fe (ppm)		Mn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	2.36	2.44	0.15	0.16	4148.00	3772.33	619.77	598.87
P_1K_2	2.43	2.40	0.22	0.14	3815.33	4139.67	626.00	602.93
P_1K_3	2.45	2.40	0.16	0.21	3727.00	3610.33	582.43	617.07
P_2K_1	2.40	2.41	0.13	0.15	4237.67	3792.67	608.37	614.00
P_2K_2	2.43	2.26	0.17	0.15	3591.67	4293.67	580.00	610.10
P_3K_3	2.44	2.40	0.16	0.22	3987.33	3808.00	583.67	604.67
CD(0.05)	0.090		0.060		186.340		15.25	

P at 300 kg ha^{-1} of lime resulted in a decrease in Mn content of the plant at 70 kg ha^{-1} and 105 kg $ha^{-1}$of K .The Fe and Mn recorded the lowest value at $P_2K_2L_1$ and it was lower than POP

4.2.2.2.4 Elemental composition of rice at PI stage at Ottappalam

Effects of P, K, lime and controls on the elemental composition of rice at panicle initiation stage are given in table 4.14.

Effect of P

The Mg, Mn and Zn content of the plant was significantly increased by the application of higher levels of P (35 kg ha^{-1}) compared to P_1 (17.5 kg ha^{-1}). The increase in Mg, Mn and Zn at P_2 level was 8.3, 3.5 and 5.2 per cent respectively over P_1.

Effect of K

It can be seen from the table 4.14 that the application of K at 70 kg ha^{-1} significantly increased the P, K, Ca, Zn and Cu content of the plant compared to application of K at 35 kg ha^{-1}. At K_2 levels, Fe and Mn content of the plant decreased by 3.7 and 4.2 per cent respectively over K_1 levels. Fe content at K_2 levels was significantly inferior to K_1 and K_3. Zn and Cu content at K_2 level was significantly higher than K_1 and K_3.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the N, P, Ca, Mg, Zn and Cu content of the plant while it decreased Fe, Mn and Si content of the plant.

Effect of controls

N, P, Ca, Mg and Zn content in the C_2 (POP) was significantly higher to C_3 (the farmer's practice) and C_2 was on par with C_1 (POP without lime) for the P and Ca. Significantly higher quantity of Fe was noticed in C_3 compared to C_1 and C_2.

Table 4.14. Elemental composition of rice at PI stage (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	1.97	0.300	2.50	0.160	0.120	4768	414.50	30.28	8.27	2.74
P_2	2.02	0.300	2.69	0.170	0.130	4738	429.17	31.88	8.53	2.65
CD (0.05)	NS	NS	NS	NS	0.010	NS	6.40	0.73	NS	NS
Levels of Potassium										
K_1	1.90	0.280	2.52	0.180	0.130	4980	432.25	29.03	8.04	2.74
K_2	2.08	0.310	2.64	0.160	0.130	4792	416.50	32.93	8.87	2.74
K_3	2.00	0.300	2.62	0.160	0.120	4886	413.75	31.28	8.29	2.61
CD (0.05)	NS	0.006	0.05	0.004	0.014	77.00	7.85	0.90	0.28	NS
Levels of Lime										
L_1	1.96	0.290	2.61	0.160	0.110	4867	429.83	30.19	8.17	2.72
L_2	2.03	0.310	2.58	0.170	0.140	4639	413.83	31.97	8.63	2.67
CD (0.05)	0.04	0.006	NS	0.007	0.010	63.00	6.40	0.73	0.22	0.15
Controls										
C_1	2.03	0.290	2.68	0.170	0.130	4922	461.33	30.46	8.30	2.78
C_2	2.03	0.290	2.70	0.170	0.160	4733	455.00	31.76	9.06	3.10
C_3	2.06	0.270	2.45	0.136	0.090	5210	434.90	27.80	8.00	2.66
CD (0.05)	NS	0.010	0.116	0.009	0.020	154.80	15.78	1.80	NS	NS

4.2.2.2.5 Interaction effect on elemental composition of rice

Interaction between P and K

Effect of P and K on elemental composition of rice is given in table 4.15a.

Increasing the level of K at 17.5 kg ha^{-1} of P from 35 to 70 kg ha^{-1} increased the K content of the plant and further increase in level of K was ineffective. At all levels of K increase in P application resulted in higher K content. Increasing the levels of K in presence of P at 17.5 kg ha^{-1} decreased the Ca content. The same trend was observed at P_2 level also. P_2K_2 and P_2K_1 were significantly superior to P_1K_2 and P_1K_1 respectively.

Interaction between P and lime

Combined application of P and lime significantly influenced the N, Mn and Zn content of the plant (Table 4.15b). Higher levels of both P and lime significantly increased the N content to the time of 6.12 per cent over lower levels of both p and lime. Data on the Mn content revealed that highest content of Mn was observed at P_2L_1 (L_1 434.78 ppm) and the lowest content of Mn was observed at P_1L_2 (404.11 ppm). Lime application at higher level resulted in a decrease in Mn content at both levels of P. It can be seen from the table 4.15b that a significant reduction in the Zn content was observed in the presence of 300 kg ha^{-1} of lime when the P level was increased from 17.5 kg ha^{-1} to 35 kg ha^{-1}. At P_2 level there was a significant increase in Zn content when the lime rate was increased from 300 kg ha^{-1} to 600 kg ha^{-1}.

4.2.2.2.6 Second order interaction effect on elemental composition of rice

Data on the second order interaction effect of P, K and lime on the elemental composition of plant is given in the table 4.16.

The maximum K content was observed at $P_2K_3L_2$ and Fe content was observed at $P_1K_2L_1$. Lime application at higher level resulted in an increase of K content only when P and K were at 35 kg ha^{-1} and 105 kg ha^{-1} respectively. A significant decrease in K content was observed when lime application was increased in

Table 4.15 a. Effect of P and K on elemental composition of rice at PI stage (Ottappalam)

Treatments	K (%)			Ca (%)		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	2.36	2.59	2.54	0.17	0.15	0.16
P_2	2.67	2.69	2.70	0.18	0.17	0.16
CD(0.05)	0.082			0.006		

Table 4.15 b. Effect of P and lime on elemental composition of rice at PI stage (Ottappalam)

Treatments	N (%)		Mn (ppm)		Zn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	1.96	1.98	424.89	404.11	31.38	32.38
P_2	1.95	2.08	434.78	423.56	29.01	31.56
CD(0.05)	0.06		9.00		1.00	

Table 4.16 Second order interaction effect on elemental composition of rice at PI stage (Ottappalam)

Treatment	K (%)		Fe (ppm)		Mn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	2.45	2.46	4810.33	4748.33	443.33	422.33
P_1K_2	2.60	1.88	4995.33	4561.67	430.33	435.33
P_1K_3	1.80	1.92	4842.67	4972.33	401.23	401.67
P_2K_1	2.47	2.42	4602.00	4715.67	437.67	434.67
P_2K_2	2.65	2.62	4973.33	3338.33	412.00	305.43
P_2K_3	2.50	2.74	3395.00	3586.33	298.43	282.27
CD(0.05)	0.116		154.82		15.70	

plots receiving P at 17.5 kg ha^{-1}and K at 70 kg ha^{-1}. When K was applied at 70 kg ha^{-1}, increased lime application resulted in a decrease in Fe content of the plant. The Fe content showed a sharp decline at $P_2K_2L_2$ (3338 ppm) and it was on par with $P_2K_2L_1$ (3395 ppm). There was a significant decrease in the Fe content at $P_2K_2L_2$ to the tune of 8.6 per cent compared to $P_2K_2L_1$. $P_2K_2L_2$ also showed a significant decrease in Fe content over $P_2K_2L_1$ to the extent of 32 per cent. Increasing the K dose to 105 kg ha^{-1} in the presence of 35 kg ha^{-1} of P at both levels of lime application significantly decreased the Fe content.

Lime application at higher level decreased Mn content at P_1K_1, P_2K_2 and P_2K_3. Increasing the level of application of K decreased the Mn content when P was applied at 35 kg ha^{-1}, while this decrease was noticed only when K was increased from 70 kg ha^{-1} to 105 kg ha^{-1} at P_1.Data on the Mn content revealed that $P_2K_3L_1$ and $P_2K_3L_2$ recorded significantly lower content of Mn i.e., 298.43 ppm and 282.27 ppm respectively compared to all other treatment combinations.

4.2.2.3.1 Elemental composition of rice at flowering stage at Koyalmannam

Nutrient content of rice plant as influenced by different levels of P, K, lime and control treatments are presented in the table 4.17.

Effect of P

A perusal of the data shows that P application at two levels could significantly influence the N, P, K, Mg and Fe content of the plant at the flowering stage. N, P, K and Mg content of the plant at P_2 (35 kg ha^{-1}) level was significantly superior to P_1 (17.5 kg ha^{-1}) levels while the Fe content at P_2 levels was significantly inferior to P_1 levels. The Mn, Zn, Cu and Si content of the plant remained unaffected irrespective of the two levels of P application.

Effect of K

It is clear from the data provided that graded levels of K application significantly increased the N, P, K, Zn and Cu content of the plant and the maximum

Table 4.17 Elemental Composition of rice at flowering stage (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	1.90	0.190	1.33	0.170	0.140	1460	212.51	62.18	6.71	2.82
P_2	1.94	0.220	1.40	0.180	0.150	1271	217.30	59.04	7.00	2.73
CD (0.05)	0.03	0.010	0.01	NS	0.003	111.00	NS	NS	NS	NS
Levels of Potassium										
K_1	1.81	0.210	1.30	0.190	0.150	1763	241.53	56.6	6.24	2.98
K_2	1.92	0.110	1.37	0.170	0.140	1346	209.80	60.03	6.44	2.76
K_3	2.03	0.230	1.43	0.170	0.130	988	193.00	65.13	7.03	2.59
CD (0.05)	0.04	0.010	0.06	0.009	0.004	135	18.30	0.63	0.25	NS
Levels of Lime										
L_1	1.88	0.190	1.39	0.170	0.140	1210	224.8	59.00	6.68	2.82
L_2	1.96	0.220	1.34	0.190	0.140	1522	204.7	60.08	7.06	2.73
CD (0.05)	0.03	0.010	0.02	0.009	NS	NS	6.70	NS	NS	0.09
Controls										
C_1	1.92	0.201	1.41	0.182	0.160	1581.66	258.16	57.5	7.00	2.99
C_2	1.98	0.216	1.39	0.206	0.170	1481.33	255.00	58.9	7.80	2.80
C_3	1.79	0.185	1.29	0.175	0.130	1771.6	239.00	54.16	6.30	3.11
CD (0.05)	0.08	NS	0.04	0.02	0.008	201.9	NS	1.27	0.15	NS

content was observed at K_3 levels. Significant difference in K content was observed between K_1 and K_3 levels and K_3 recorded the maximum content of K. K_1 level recorded the maximum content of lime and Mg and it was significantly superior to K_2 and K_3 levels. The Mn and Fe content of plant decreased with increasing levels of K.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased the N, P, Ca and Fe content of the plant while it decreased the K, Mn and Si content.

Effect of controls

The control treatments C_2 (POP) recorded significantly higher N, Ca, Mg, Zn and Cu contents compared to the farmer's practice. The maximum content of K was seen in the C_1 (POP without lime). The lowest content of Fe was observed at C_2 levels which was significantly inferior to C_3 and on par with C_1.

4.2.2.3.2 Interaction effect on elemental composition of rice

Interaction between K and lime

Potassium and lime interacted significantly to influence the K, Ca, Fe and Zn content of the plant at flowering stage (Table 4.18a). K_3L_1 with 1.44 per cent K content registered significant increase to the tune of 14.2 per cent over K_1L_2. Increasing the lime application rate decreased the K content significantly at K_1 and K_2 levels, while increasing the K dose increase the K content at L_1 and L_2 levels. K_2L_2 and K_3L_2 registered the highest value for Ca content (0.18%) and the lowest value was recorded by K_1L_1 and K_2L_1 (0.17%). Increasing the level of lime application increased the Ca content at K_1 and K_3 levels and at K_2, L_1 and L_2 were on par.

Maximum and minimum content of Mg were observed at K_1L_2 at K_3L_1 respectively. There was an increase in the Mg content with increase in level of lime at all levels of K except K_2. Increasing the K dose decreased the Mg content at 300 kg ha^{-1} of lime application. But at 600 kg ha^{-1} of lime application the Mg content showed an increase at K_3 compared to K_2.

Table 4.18a Effect of K and lime on elemental composition of rice at flowering stage (Koyalmannam)

Treatments	K (%)		Ca (%)		Mg (%)		Fe (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	1.34	1.26	0.17	0.21	0.15	0.16	1822	1705
K_2	1.40	1.34	0.17	0.18	0.14	0.13	1618	1073
K_3	1.44	1.42	0.15	0.18	0.12	0.15	851	1125
CD(0.05)	0.03		0.01		0.005		192	

Table 4.19 Effect of P and lime on elemental composition of rice at flowering stage (Koyalmannam)

Treatments	N (%)		P (%)		K (%)		Mn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1	1.87	1.92	0.19	0.20	1.37	1.29	218.46	206.56
P_2	1.89	2.00	0.20	0.25	1.42	1.39	231.33	202.92
CD(0.05)	0.05		0.01		0.02		9.49	

The lowest content of Fe was recorded at K_3L_1 (851 ppm) and the highest content of Fe at K_1L_1 (1822 ppm). Increasing the lime dose to 600 kg ha^{-1} significantly decreased the Fe content at K_2 by 33 per cent while at K_3 level a significant increase in Fe content was observed. Similarly at 300 kg ha^{-1} of lime application a significant decrease in the Fe content at K_2 and K_3 levels by 11 and 53 per cent respectively compared to K_1 was observed.

Interaction between P and lime

Effect of P and lime on the elemental composition of rice is given in the table 4.19.

Maximum N content was recorded by P_2L_2 (2.00%) and the minimum content by P_1L_1 (1.87%). Increasing the dose of lime at P_1 and P_2 increased the N content. The N content was significantly increased by increasing the P to 35 kg ha^{-1} at 600 kg ha^{-1} of lime application. P content increased with higher level of lime application at P_2 and this increase in P content for higher level of P application was more at 600 kg ha^{-1} of lime application.

P_2L_1 with maximum content of K (1.42%) was significantly superior to P_2L_2 with minimum content of K (1.29%) by 9.1 per cent. The K content of the plant showed a significant decrease with increase in lime application by 5.8 per cent and 2.1 per cent respectively at P_1 and P_2 levels respectively.

Maximum and minimum content of Mn was recorded by P_2L_1 and P_2L_2 respectively. At P_1 and P_2 levels Mn content decreased significantly at 600 kg ha^{-1} of lime application compared to 300 kg ha^{-1} to the extent of 5 and 12 per cent respectively.

4.2.2.3.3 Elemental composition of rice at flowering stage

The effects of different levels of P, K, lime and the effect of controls on elemental composition of rice at flowering stage are given in the table 4.20.

Table 4.20 Elemental composition of rice at flowering stage (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	1.62	0.26	1.280	0.170	0.100	3480	290.33	46.20	5.92	2.77
P_2	1.65	0.28	1.330	0.170	0.120	3333	295.72	47.43	6.25	2.72
CD (0.05)	NS	NS	0.020	NS	0.005	NS	NS	NS	NS	NS
Levels of Potassium										
K_1	1.57	0.25	1.240	0.180	0.120	3662	282.25	47.72	6.11	2.78
K_2	1.65	0.29	1.370	0.180	0.110	3201	295.75	47.27	6.25	3.00
K_3	1.68	0.28	1.300	0.160	0.10	3357	301.08	45.46	5.90	2.46
CD (0.05)	0.05	0.01	0.026	0.012	0.007	177	11.81	NS	NS	0.18
Levels of Lime										
L_1	1.56	0.27	1.330	0.170	0.100	3534	290.28	48.01	6.26	2.82
L_2	1.71	0.28	1.280	0.180	0.120	3279	295.78	45.62	5.92	2.68
CD (0.05)	0.04	0.01	0.020	0.009	0.005	96	NS	1.85	0.22	0.10
Controls										
C_1	1.63	0.26	1.390	0.168	0.127	3472	308	39.36	5.10	2.94
C_2	1.75	0.27	1.370	0.186	0.133	3388	286.33	41.66	5.43	2.77
C_3	1.75	0.24	1.220	0.144	0.080	3890	286.00	43.26	5.66	2.15
CD (0.05)	0.10	NS	0.050	0.020	0.014	235	NS	NS	NS	NS

Effect of P

The two levels of P in modifying the nutrient content of plant was confined only to K and Mg. Application of P at 35 kg ha^{-1} increased the K content by 3.9 per cent and Mg content by 20 per cent over P application at 17.5 kg ha^{-1}.

Effect of K

It is obvious from the table4.20 that K_2 level (70 kg ha^{-1}) showed an increase in the N, P, Mn and Si content of the plant to the tune of 5, 3, 4.7 and 7.9 per cent respectively over K_1 (35 kg ha^{-1}). The K content at K_2 level showed a significant increase over both K_1 and K_3. Ca and Mg content showed the lowest value at K_3 level. The lowest quantity of Fe was present at K_2 level and it was significantly inferior to K_1 and was on par with K_3.

Effect of lime

N, P, Ca and Mg content of rice was increased by lime application at 600 kg ha^{-1} compared to the application at 300 kg ha^{-1} while K, Fe, Zn, Cu and Si was decreased by the application of higher levels of lime. There was no significant effect for the Mn content of the plant.

Effect of controls

Different control treatments significantly affected N, K, Ca, Mg and Fe content of the plant. It is seen that C_2 (POP) and C_3 (farmer's practice) were on par for the N content while C_1 and C_2 were on par for K, Mg and Fe contents of the plant.

Potassium, Ca and Mg content in C_2 was significantly higher compared to C_3. The plant content of Fe in C_3 was significantly higher than C_1 and C_2. P, Mn, Zn, Cu and Si remained unaffected by the control treatments.

4.2.2.3.4 Interaction effects on elemental composition of rice

Interaction between P and K

P and K interacted significantly to influence K and Mg content of the plant (Table 4.21c). Maximum content of K (1.34%) was observed at P_2K_3 and the lowest content (1.23%) at P_1K_1. At P_2 level there was a steady increase in the K content with increasing levels of K. At P_1 level K_3 was significantly superior to K_1 and K_2 for the K content.

Application of increasing levels of K from 35 kg ha^{-1} to 70 kg ha^{-1} in presence of 17.5 kg ha^{-1} of P decreased the Mg content and beyond 70 kg ha^{-1} there was an increase in Mg content. This trend was not seen at P_2 level and the three levels of K were on par at P_2 level.

Interaction between P and lime

Lime application at higher levels decreased the K content at P_1 and P_2 to the extent of 3.1 per cent and 6.4 per cent respectively (Table 4.21b). There was a significant increase in the K content when the P level was increased at both levels of lime.

Highest content of Mg was recorded at the highest level of both P and lime. Increasing the level of lime from L_1 to L_2 increased the Mg content to the extent of 18 per cent at P_2 level. However this trend was not seen at P_1 level.

Lower level of P and lime at 17.5 kg ha^{-1} and 300 kg ha^{-1} respectively recorded the highest content of Fe (3672 ppm) and higher level of both P and lime recorded the lowest content of Fe (3270 ppm). There was significant decrease in the Fe content at P_1 level when the lime dose was increased from 300 kg ha^{-1} to 600 kg ha^{-1}. Increasing the level of P at 300 of lime also decreased the Fe content.

Interaction between K and lime

It can be seen from the table 4.21a that combined application of K and lime significantly influenced the N, P, Ca and Cu content of the plant. Maximum nitrogen content was observed at K_3L_2 followed by K_2L_2. Increasing the level of lime from L_1

Table 4.21a Effect of K and lime on elemental composition of rice at flowering stage (Ottappalam)

Treatments	N (%)		P (%)		Ca (%)		Cu (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	1.54	1.60	0.24	0.25	0.16	0.19	5.87	6.35
K_2	1.55	1.75	0.29	0.29	0.17	0.18	6.77	5.73
K_3	1.57	1.78	0.27	0.30	0.16	0.16	6.13	5.67
CD(0.05)	0.07		0.02		0.01		0.39	

Table 4.21b Effect of P and lime on elemental composition of rice at flowering stage (Ottappalam)

Treatments	K (%)		Mg (%)		Fe (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	1.29	1.25	0.10	0.10	3672	3289
P_2	1.39	1.30	0.11	0.13	3397	3270
CD(0.05)	0.03		0.008		135	

Table 4.21c Effect of P and K on elemental composition of rice at flowering stage (Ottappalam)

Treatments	K (%)			Mg (%)		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	1.23	1.26	1.33	0.11	0.10	0.11
P_2	1.26	1.34	1.41	0.12	0.12	0.12
CD(0.05)	0.03			0.005		

to L_2 significantly increased the N content at K_2 and K_3 levels by 12.9 and 13.3 per cent respectively.

At highest level of K i.e. at K_3 when the lime dose was increased from 300 to 600 kg ha^{-1} there was significant increase in the P content to the extent of 11.11 per cent. At lower levels like K_1 and K_2 this trend was not seen. Similarly at both levels of lime application i.e., at L_1 and L_2 when the K dose was increased from K_1 to K_2 there was a significant increase in the P content.

At K_1 level when the lime application rate was increased from 300 to 600 kg ha^{-1} there was an increase in the Ca content to the extent of 18 per cent. Increasing the level of K from K_1 to K_3 and K_2 to K_3 in presence of 600 kg ha^{-1} of lime significantly decreased the Ca content of the plant.

An increase in the Cu content was noticed when the lime dose increased from L_1 to L_2 at K_1 level, however at K_2 and K_3 levels there was a decrease in Cu content with increase in lime application.

4.2.2.3.5 Second order interaction effect on elemental composition of rice

Data on the interaction effect of P, K and lime on the elemental composition of rice at flowering stage is given in the table 4.22.

Data on the Fe content showed that the lowest content of Fe was observed at $P_2K_2L_2$ (2456 ppm) and the highest content was observed at $P_1K_2L_1$. Significantly lower Fe content was present at $P_1K_2L_2$ compared to $P_1K_2L_1$ to the tune of 7.7 per cent. Similar decrease was observed at $P_2K_2L_2$ also compared to $P_2K_2L_1$, the extent of reduction was 29.3 per cent. On comparing with POP and farmer's practice the Fe content at $P_2K_2L_2$ was decreased by 37 and 58 percent respectively.

$P_1K_1L_1$ recorded the highest content of Mn (329.67 ppm) and $P_2K_3L_2$ registered the lowest content (179.47 ppm) of Mn. An increase in Mn content was observed at $P_1K_2L_2$ compared to $P_1K_1L_1$. However at P_1K_3 increasing the lime dose decreased the Mn content by 11 per cent. At P_2K_2 and P_2K_3 also increasing the lime

Table 4.22 Second order interaction effect on elemental composition of rice at flowering stage (Ottappalam)

Treatment	Fe (ppm)		Mn (ppm)		Zn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	3526.33	3554.00	329.67	316.00	50.17	40.37
P_1K_2	3579.00	3303.00	270.00	313.33	45.60	41.27
P_1K_3	3381.33	3435.00	304.67	268.00	51.93	47.80
P_2K_1	3397.00	3499.33	310.00	291.00	40.47	40.30
P_2K_2	3478.33	2456.00	260.33	206.07	46.23	31.63
P_2K_3	2551.00	2488.00	207.50	179.47	36.93	33.63
CD(0.05)	235.450		23.62		4.54	

dose decreased the Mn content of the plant. Combined application of 35 kg ha^{-1} of P with 300 kg as well as with 600 kg ha^{-1} of lime showed a steady decrease in Mn content with increase in the K dose. Increase in the lime dose decreased the Zn content of the plant with graded levels of P and K.

The lowest content of Zn was observed at $P_2K_2L_2$ and the highest content at $P_1K_3L_1$.

4.2.2.4.1 Elemental composition of straw at harvest at Koyalmannam

Nutrient content of straw as influenced by different levels of P, K, lime and the effect of controls are presented in the table 4.23.

Effect of P

There was an increase noted in the nutrient content of N, P, K and Mg with increasing levels of P application. Higher levels of P application significantly reduced the Zn content of the plant. The two levels of P application did not significantly affect Ca, Fe, Mn, Cu and Si content of the plant.

Effect of K

Application of K at increasing levels significantly increased the N content of the plant. P and K content of the plant were significantly increased at K_2 levels (70 kg ha^{-1}). K_2 and K_3 levels were on par for the P and K content. Ca, Fe and Mn content of the plant showed significant decrease at K_2 compared to K_1 levels. Mg content steadily decreased with increase in K content. Zn content of the plant increased at K_2 levels and it showed a further decreasing trend beyond K_2 level.

Effect of lime

Higher levels of lime application increased the P and Si content of the plant to the time of 10 and 15 per cent respectively while it decreased the K, Fe and Mn content of the plant significantly to the extent of 4, 22 and 12 per cent respectively.

Table 4.23 Elemental Composition of straw at harvest (Koyalmannam))

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	0.97	0.10	1.65	0.20	0.14	706.40	374.17	84.10	7.10	3.88
P_2	1.02	0.11	1.75	0.20	0.15	680.67	400.27	74.50	7.78	3.87
CD (0.05)	0.03	0.004	1.01	NS	0.003	NS	NS	1.6	NS	NS
Levels of Potassium										
K_1	0.89	0.08	1.62	0.22	0.15	919.58	413.31	72.40	7.07	3.78
K_2	1.00	0.12	1.75	0.18	0.14	484.00	375.39	86.03	7.25	3.81
K_3	1.08	0.11	1.73	0.19	0.13	676.00	372.96	79.67	8.01	4.03
CD (0.05)	0.039	0.005	0.02	0.01	0.004	56.00	13.37	1.99	NS	NS
Levels of Lime										
L_1	0.95	0.10	1.74	0.19	0.14	780.00	401.86	76.82	6.93	3.80
L_2	1.03	0.11	1.67	0.20	0.14	607.60	372.58	81.94	7.95	3.95
CD (0.05)	NS	0.004	0.01	NS	NS	46.50	10.91	NS	NS	0.08
Controls										
C_1	1.0	0.09	1.81	0.197	0.16	737.3	427.26	74.9	6.86	4.3
C_2	1.12	0.12	1.77	0.22	0.17	630	421.33	76.26	8.00	4.08
C_3	1.02	0.08	1.69	0.179	0.13	953.3	397.00	72.70	6.60	3.96
CD (0.05)	0.07	NS	0.04	NS	0.008	113.94	26.74	NS	0.78	NS

Effect of controls

POP recorded the highest content of N, Mg and Cu. The highest content of Fe was recorded at C_3 (farmer's practice) and maximum Mn content was at C_1 (POP without lime). The K content of C_2 (POP) was on par with C_1 and was higher than the farmer's practice. Various control treatments could not change the P, Ca and Zn content of the plant.

4.2.2.4.2 Interaction effect on elemental composition of straw at harvest

Interaction between P and lime

It can be seen from the table 4.24a that combined application of 35 kg ha^{-1} of P and 600 kg ha^{-1} of lime (P_2L_2) registered the highest content of N (1.08%) while P_1L_1 and P_2L_1 recorded the lowest content (0.95%). Maximum and minimum content of P was recorded by P_2L_2 and P_1L_1 respectively. Both levels of lime application significantly increased the P content when the P dose increased to 35 kg ha^{-1}.

The K content of the straw decreased with increase in lime application both at P_1 and P_2 by 5 per cent and 2.2 per cent respectively. K content registered its highest value at P_2L_1 (1.77%) and the lowest value (1.6%) at P_1L_2 and these two differed by 10 per cent. Combined application of 17.5 kg ha^{-1} of P and 600 kg ha^{-1} of lime recorded the lowest Mn content (349.10 ppm) while the highest value (404 ppm) was recorded by 35 kg ha^{-1} of P combined with 300 kg ha^{-1} of lime. A significant decrease in Mn content with increase in lime dose was observed at P_1 and P_2 to the tune of 12.5 per cent and 11.1 per cent respectively.

Interaction between K and lime

It can be seen from table 4.24 b that K and lime interacted significantly to influence the K, Ca, Mg and Fe content of the plant. K_2L_1 and K_3L_1 recorded the highest value for K content (1.76%) while K_1L_2 registered the lowest value of 1.57 per cent. Increasing the level of K in the presence of 300 kg ha^{-1} of lime increased the K content significantly at K_2 and K_3 compared to K_1 but K_2 was on par with K_3. When the K level increased in the presence of 600 kg ha^{-1} of lime K there was a significant

Table 4.24 a Effect of P and lime on elemental composition of straw at harvest (Koyalmannam)

Treatments	N (%)		P (%)		K (%)		Mn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1	0.95	0.99	0.09	0.10	1.70	1.60	399.17	349.10
P_2	0.95	1.08	0.10	0.12	1.77	1.73	404.56	359.99
CD(0.05)	0.04		0.006		0.02		15.43	

Table 4.24 b Effect of K and lime on elemental composition of straw at harvest (Koyalmannam)

Treatments	K (%)		Ca (%)		Mg (%)		Fe (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	1.68	1.57	0.19	0.26	0.15	0.16	962.50	876.67
K_2	1.76	1.70	0.19	0.20	0.14	0.15	699.00	653.00
K_3	1.76	1.74	0.16	0.19	0.13	0.12	578.00	391.00
CD(0.05)	0.03		0.02		0.005		80.57	

increase in the K content. Calcium content recorded the highest value at K_1L_2 and lowest value at K_3L_1. An increase in the Ca content with increase in lime dose was observed at K_1 and K_3. At both levels of lime application, the Ca content at K_3 level significantly decreased over both K_1 and K_2.

The Fe content of the straw significantly decreased with increasing levels of K and lime. The lowest content (391 ppm) and the highest value (962.5 ppm) were recorded at K_2L_2 and K_1L_1 respectively. Increasing the K dose in the presence of 300 kg ha^{-1} of lime showed a steady decline in the Fe content.

4.2.2.4.3 Elemental composition of straw at harvest at Ottappalam

Effect of P, K, lime and controls on elemental composition of straw at harvest are given in the table 4.25.

Effect of P

Phosphorus application at two levels significantly influenced N, Mn and Cu content of the straw. It is evident from the table that higher levels of P application significantly increased the N, Mn and Cu content of the straw to the extent of 4.8 per cent, 6.8 per cent and 9 per cent respectively.

Effect of K

K and Ca content at K_2 levels was significantly higher compared to K_1. Cu content at K_2 level was significantly superior to both K_1 and K_3 levels. The highest content of Mg was observed at K_1 level and it was significantly superior to both K_2 and K_3. The lowest content of Fe and Si was observed at K_2 level and was significantly inferior to both K_1 and K_2 levels.

Effect of lime

The content of P and lime significantly increased 600 kg ha^{-1} of lime application compared to 300 kg ha^{-1} of lime application whereas the Fe, Zn and Si

Table 4.25 Elemental composition of straw at harvest (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	0.82	0.140	1.68	0.190	0.09	1516	249.00	61.46	6.36	2.86
P_2	0.86	0.150	1.71	0.190	0.09	1580	266.00	61.50	6.76	2.95
CD (0.05)	0.03	NS	NS	NS	NS	NS	11.29	NS	0.18	NS
Levels of Potassium										
K_1	0.74	0.13	1.63	0.180	0.10	1945	247.75	62.68	6.50	3.17
K_2	0.93	0.160	1.70	0.190	0.08	1179	255.00	61.13	6.84	2.68
K_3	0.88	0.150	1.74	0.180	0.08	1520	270.00	60.64	6.30	2.89
CD (0.05)	NS	NS	0.04	0.007	0.01	121.20	NS	NS	0.22	0.13
Levels of Lime										
L_1	0.82	0.120	1.71	0.180	0.09	1688	253.94	62.99	6.73	3.03
L_2	0.88	0.170	1.69	0.200	0.09	1408	261.39	59.97	6.38	2.78
CD (0.05)	NS	0.010	NS	0.010	NS	98.98	NS	1.30	NS	0.10
Controls										
C_1	0.84	0.136	1.76	0.191	0.09	1916	267.60	56.03	5.56	3.30
C_2	0.93	0.106	1.78	0.201	0.11	1882	234.00	59.00	5.50	3.11
C_3	0.98	0.125	1.67	0.184	0.08	2295	236.00	60.86	5.76	3.19
CD (0.05)	0.09	NS	0.09	NS	NS	242.40	NS	3.20	NS	NS

content showed a reverse trend. The N, K, Mg, Mn and Cu content of the straw was not significantly influenced by the two levels of lime application.

Effect of controls

Different control treatments significantly influenced the N, K, Fe and Zn content of the straw. Maximum N was present in C_3 (the farmer's practice) but it was on par with C_2 (POP) and significantly higher than C_1. The highest content of K was present in C_2 (POP) and it was 6.1 per cent higher than C_3. The highest content of Fe was noticed in C_3, which was significantly superior to C_1 and C_2. Similarly the Zn content in C_3 recorded the highest value and it was significantly superior to C_1 and was on par with C_2.

4.2.2.4.4 Interaction effect on elemental composition of straw

Interaction between P and K

It can be seen from the table4.26a that maximum content of N was observed at P_2K_2 level (0.93%) and the lowest content at P_1K_1 level (0.71%). Significant increase in the N content at K_2 level was observed when the P dose was increased from P_1 to P_2 level. Similarly at P_2 level a significant increase was observed when the K dose increased from 35 kg ha^{-1} to 70 kg ha^{-1} and to 105 kg ha^{-1}.

Increasing the level of K from 35 kg ha^{-1} to 105 kg ha^{-1} at P_1 decreased the Ca content by 23 per cent. But at P_2 level the decrease was to the tune of only 15 per cent. Higher level of P application at K_3 level significantly decreased the zinc content of the straw by 5.2 per cent.

Interaction between P and lime

It can be seen from the table 4.26b that P_2L_2 recorded the highest content of N and P and it was significantly superior to all other combinations. At 600 kg ha^{-1} of lime application there was a significant increase in the N and P content by 14.6 and 23 per cent respectively when the P level was increased from P_1 to P_2. The Fe content of

Table 4.26 a Effect of P and K on elemental composition of straw at harvest stage (Ottappalam)

Treatments	N (%)			Ca (%)			Zn (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.71	0.83	0.92	0.20	0.20	0.16	62.13	59.98	62.29
P_2	0.77	0.93	0.92	0.20	0.19	0.17	63.22	62.24	59.02
CD (0.05)	0.06			0.01			2.27		

Table 4.26 b Effect of P and lime on elemental composition of straw at harvest stage (Ottappalam)

Treatments	N (%)		P (%)		Fe (ppm)		Mn (ppm)		Zn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1	0.82	0.82	0.13	0.16	1709	1324	242.67	255.53	61.86	64.12
P_2	0.81	0.94	0.12	0.19	1967	1193	265.22	267.44	61.07	58.88
CD (0.05)	0.05		0.01		139		15.90		1.86	

the straw showed a significant decrease to the tune of 30 per cent at higher level of both P and lime compared to lower levels. At P_1 level when lime dose was increased there was a significant reduction in the Fe content by 22.5 per cent. But at P_2 level the extent of reduction was still higher i.e., 39.34 per cent. The Mn content of the straw recorded the highest value at P_1L_2 and the lowest value at P_1L_1. No significant difference was observed between the levels of lime dose at both levels of P application.

Lowest zinc content was observed at higher level of both lime and phosphorus application. Increasing P at 600 kg ha^{-1} lime reduced Zn content.

4.2.2.4.5 Elemental composition of grain at Koyalmannam

The effect of different levels of P K, and lime and the controls on elemental composition of grain are presented in the table 4.27.

Effect of P

A perusal of the data shows that the influence of the two levels of P on modifying the nutrient content of the grain was confined only to Ca, Mn and Zn. Application of P at the rate of 35 kg ha^{-1} significantly increased the Ca and Mn content of grain and decreased the Zn content.

Effect of K

Different levels of K significantly influenced the content of all the nutrients of grain except N and Zn. There was significant difference between K_1 (35 kg ha^{-1}) and K_2 (70 kg ha^{-1}) for P, Mg, Fe, Mn and Cu content of the grain. Higher levels of K application i.e., K_2 (70 kg ha^{-1}) significantly increased the P, K and Cu content of the grain while it decreased the Mg, Fe and Mn content. K_2 was on par with K_3 for P, Mg, Fe, Mn and Cu content. Graded level of K significantly increased the K content of the grain. There was a significant reduction in the Ca content of the grain from K_2 to K_3 while K_1 was on par with K_2.

Table 4.27 Elemental Composition of grain (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
p_1	1.01	0.160	0.440	0.020	0.110	176.22	38.70	27.77	5.87	2.18
P_2	1.10	0.170	0.490	0.030	0.120	167.56	43.79	25.26	6.01	2.22
CD (0.05)	NS	NS	NS	0.002	NS	NS	1.63	1.22	NS	NS
Levels of Potassium										
K_1	0.99	0.160	0.410	0.030	0.120	253.00	46.15	29.63	5.50	2.28
K_2	1.09	0.170	0.460	0.030	0.110	146.50	38.11	26.76	6.16	2.15
K_3	1.10	0.170	0.510	0.010	0.110	115.42	39.48	25.85	6.16	2.18
CD (0.05)	NS	0.005	0.01	0.003	0.006	31.92	2.00	NS	0.27	NS
Levels of Lime										
L_1	1.02	0.160	0.460	0.020	0.110	209.50	43.49	28.09	5.82	2.24
L_2	1.09	0.170	0.460	0.030	0.120	134.28	39.01	24.94	6.06	2.16
CD (0.05)	0.04	NS	NS	0.002	0.005	NS	NS	NS	NS	0.03
Controls										
C_1	1.09	0.160	0.490	0.033	0.126	234.33	50.00	30.20	5.63	2.31
C_2	1.16	0.166	0.492	0.039	0.136	169.33	48.50	31.30	6.20	2.24
C_3	0.93	0.151	0.436	0.013	0.110	269.66	42.66	27.33	6.66	2.32
CD (0.05)	0.109	0.010	0.030	0.006	0.013	63.83	4.00	NS	0.55	0.08

Effect of lime

Lime application at the two levels significantly influenced the N, Ca, Mg and Si content of the grain. Between 300 kg ha^{-1} and 600 kg $ha^{-1}$of lime, 600 kg ha^{-1} significantly increased N, Ca and Mg content of grain but it decreased the Si content.

Effect of controls

Among the controls C_3 (farmer's practice) recorded the lowest content of N, P, K, Ca, Mg and Mn content in the grain. The C_2 (POP) was significantly superior to C_3 for the above nutrients and the percentage increase was 19.8, 9, 5.6, 2.6, 12.3 and 12.1 per cent for N, P, K, Ca, Mg and Mn respectively. The maximum Fe content was seen in C_3 and it was significantly superior to C_2. For the grain nutrients C_1 and C_2 were on par for N, P, K, Ca, Mg and Mn while C_1 was superior to C_2 for Fe and significantly inferior to C_2 for Cu contents.

4.2.2.4.6 Interaction effect on elemental composition of grain

Interaction between P and K

Effect of P and K on elemental composition of grain is given in table 4.28a.

The maximum and minimum content of K was observed at P_2K_3 and P_1K_1 respectively and these two treatments differed by 35 per cent. Both levels of P showed an increase in K content with increase in K dose. At K_2 and K_3 levels the increase in P dose to 35 kg ha^{-1} significantly increased the K content by 19 per cent and 10 per cent respectively.

P_2K_1 and P_1K_2 registered the maximum and minimum value for Mn content, which was respectively 47.50 ppm and 32.50 ppm. At P_1 level increasing the K dose decreased the Mn content compared to K_1, but an increase in K dose from 70 to 105 kg ha^{-1} increased the Mn content. At P_2 level, a steady decline in Mn content with increasing levels of K was noted. But increasing the P dose to 35 kg ha^{-1} in the presence of 70 kg ha^{-1} of K increased the Mn content. The Zn content of the grain was maximum in P_1K_1 (29.08 ppm) and minimum in P_2K_3 (24.60 ppm). At P_1 level there was a decrease in Zn content with graded levels of K. But at P_2 level, Zn content increased with 70 kg ha^{-1} of K and beyond 70 kg ha^{-1} it showed a decrease. The Cu content recorded the maximum value at P_1K_2 and P_2K_3 and minimum value at P_1K_1. At P_2 level increasing the K content to 105 kg ha^{-1} significantly increased the Cu content while at P_1 level K at 70 kg ha^{-1} increased the Cu content and beyond K_2 it decreased.

Interaction between K and lime

A perusal of the data in the table 4.28b showed that increasing lime dose to 600 kg ha^{-1} in the presence of 35 kg ha^{-1} of K significantly increased the Ca content of the grain. But at K_2 and K_3 the increase in content of Ca was not seen. At 600 kg ha^{-1} of lime increasing the K dose decreased the Ca content. The maximum content of Fe was observed at K_1L_1 and the minimum content was observed at K_2L_2. Increasing the K dose to 70 kg ha^{-1} in the presence of 300 kg ha^{-1} and 600 kg ha^{-1} of lime decreased the Fe content by 47 per cent. K_3L_1 registered a decrease in Fe content compared to K_2L_1 while K_3L_2 showed an increase in Fe content. K_1L_2 and K_2L_2 showed a decrease in Fe content to the tune of 34 per cent and 44 per cent respectively over K_1L_1 and K_2L_1. Maximum content of Mn (47.42 ppm) and minimum content of Mn (32.88 ppm) were registered by K_1L_1 and K_2L_2 respectively. Application of increasing levels of K with 300 kg ha^{-1} of lime significantly decreased the Mn content. Increasing levels of K with 600 kg ha^{-1} of lime also showed a decrease in Mn content. Higher level of line application showed a decreasing trend at all levels of K application except K_3 level. The Zn content of the grain decreased significantly at 600 kg ha^{-1} of lime compared to 300 kg ha^{-1} in the presence of various levels of K. Combined application of 300 kg ha^{-1} of lime with various levels of K were on par for the Zn content. Similar effect was noticed with 600 kg ha^{-1} of lime also.

4.2.2.4.7 Second order interaction effect on elemental composition of grain

Data on the combined effect of P, K and lime on elemental composition of grain is given in the table 4.29.

Table4.28a Effect of P and K on elemental composition of grain (Koyalmannam)

Treatments	K (%)			Mn (ppm)			Zn (ppm)			Cu (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.40	0.42	0.49	44.80	32.50	38.80	29.08	27.12	27.10	5.37	6.55	5.78
P_2	0.42	0.50	0.54	47.50	43.72	40.17	24.78	26.40	24.60	5.63	5.87	6.53
CD (0.05)	0.02			2.82			1.10			0.39		

Table4.28 b Effect of K and lime on elemental composition of grain (Koyalmannam)

Treatments	Ca (%)		Fe (ppm)		Mn (ppm)		(Zn (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	0.03	0.04	307.50	200.00	47.42	44.80	28.62	24.25
K_2	0.03	0.03	188.00	104.33	43.33	32.88	28.07	25.50
K_3	0.01	0.01	132.33	198.50	39.72	39.25	26.58	25.12
CD (0.05)	0.004		45.15		2.82		2.11	

Table 4.29 Second order interaction effect on elemental composition of grain (Koyalmannam)

Treatment	Mg (%)		Fe (ppm)		Mn (ppm)		Zn (ppm)	
	L1	L2	L1	L2	L1	L2	L1	L2
P_1K_1	0.12	0.13	204.00	160.00	37.00	36.17	31.83	28.07
P_1K_2	0.12	0.11	173.33	114.67	43.00	38.33	25.67	25.70
P_1K_3	0.12	0.10	159.00	187.33	40.33	45.43	29.37	24.67
P_2K_1	0.11	0.12	207.00	164.67	38.47	40.63	28.43	30.80
P_2K_2	0.10	0.12	185.00	222.33	46.77	40.37	24.93	26.47
P_2K_3	0.13	0.12	174.00	183.67	42.53	48.77	30.00	24.37
CD (0.05)	0.01		63.83		4.00		2.90	

It is clear from the table 4.29 that at P_1 level a decrease in the Mg content was observed with 600 kg ha^{-1} of lime when the K dose increased to 105 kg ha^{-1}. At P_2 level an increase was observed at K_3 in the presence of 300 kg ha^{-1} of lime. Lowest content of Fe (114.67 ppm) was observed at $P_1K_2L_2$. $P_1K_1L_2$ registered lowest quantity of Mn. The lowest Zn content of the grain was observed at $P_2K_3L_2$. POP registered higher quantity of Fe compared to $P_1K_2L_2$ and $P_1K_1L_2$.

4.2.2.4.8 Elemental composition of grain at Ottappalam

The effect of different levels of P, K, lime and controls on the elemental composition of grain is given in table 4.30.

Effect of P

It is obvious from the table4.30 that P application at the higher level i.e., P_2 (35 kg ha^{-1}) could in no way modify the content of Ca, Mg, Fe, Mn, Cu and Si in the grain. However, the N, P, K and Zn content of the grain was increased significantly at higher level of P application (35 kg ha^{-1}).

Effect of K

There was a steady increase in the K content of the grain with increasing levels of K application. Mg and Mn contents of the grain showed significant decrease at K_2 level (70 kg ha^{-1}) compared to K_1 (35 kg ha^{-1}). The Zn content of K_2 level was significantly higher than the content of Zn at K_3 level.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the Ca, Mg and Cu content of the grain, however it decreased the K and Fe content compared to lime application at 300 kg ha^{-1}.

Effect of controls

Significant effect was noticed in the elemental composition of the grain except N and Si. The content of P, Ca, Mg, Zn and Cu content was maximum for the

Table 4.30 Elemental composition of grain (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
	%					ppm				%
Levels of Phosphorus										
P_1	0.94	0.14	0.380	0.030	0.090	226.00	37.27	22.22	3.97	2.18
P_2	1.05	0.15	0.430	0.030	0.090	172.00	43.68	20.43	4.34	2.17
CD (0.05)	0.03	0.003	0.008	NS	NS	NS	NS	1.20	NS	NS
Levels of Potassium										
K_1	0.98	0.15	0.360	0.040	0.100	218.75	46.73	21.75	4.07	2.23
K_2	1.01	0.15	0.390	0.030	0.080	194.17	37.20	22.14	4.24	2.12
K_3	1.00	0.15	0.470	0.030	0.090	185.67	37.48	20.09	4.50	2.18
CD (0.05)	NS	NS	0.01	NS	0.008	NS	2.44	1.47	NS	0.05
Levels of Lime										
L_1	0.98	0.15	0.440	0.030	0.090	240.00	41.75	22.01	3.92	2.20
L_2	1.01	0.15	0.370	0.040	0.100	158.00	39.79	20.94	4.32	2.15
CD (0.05)	NS	NS	0.008	0.003	0.006	26.68	NS	NS	0.13	NS
Controls										
C_1	0.933	0.148	0.470	0.042	0.103	250.66	47.40	23.73	4.06	2.22
C_2	0.956	0.156	0.440	0.046	0.114	190.66	41.33	24.66	4.36	2.18
C_3	0.933	0.125	0.400	0.014	0.092	334.33	50.10	21.33	3.50	2.36
CD (0.05)	NS	0.007	0.020	0.008	0.016	65.35	4.89	2.95	0.33	NS

C_2 (POP). However, for the Fe, the content was lowest for C_2. The maximum K content was observed in C_1 (POP without lime). C_3 (farmer's practice) registered the highest content of Fe and Mn.

4.2.2.4.9 Interaction effect on elemental composition of grain

Interaction between P and K

Combined application of P at P_2 level (35 kg ha^{-1}) and K at K_3 level (105 kg ha^{-1}) recorded the maximum content of grain N, but this was on par with lower levels of K. At K_1 and K_3 levels P_2 registered significantly higher content of N compared to P_1 (Table 4.31a).

At K_1 and K_2 level increasing the level of P increased P content but the increase was more at K_1 level (13%) compared to K_2 level (6.6%). Increasing levels of K application at P_2 level significantly increased the K content at K_2 and K_3 by 18.9 per cent and 27 per cent respectively compared to K_1. At K_1 and K_2 levels increase in level of P application increased the K content by 5.7 and 25 per cent respectively.

At P_1 level there was a decrease in Mn content from K_1 to K_2 and slight increase at K_3. At P_2 level a steady decrease was observed compared to K_1. There was a significant increase in the Mn content at all levels of K when the P application rate was increased from 17.5 kg ha^{-1} to 35 kg ha^{-1}.

Interaction between P and lime

A perusal of the data in the table 4.31b showed that the combined application of P and lime at two levels significantly influenced the Fe, Mn and Cu content of the grain. The lowest content of Fe (146.7 ppm) was observed at P_2L_2 and this was significantly less than P_1L_1 by 48 per cent. Increasing the dose of lime from 300 kg ha^{-1} to 600 kg ha^{-1} at P_1 and P_2 levels respectively decreased the Fe content by 39 per cent and 26 per cent.

Manganese content in the grain decreased at P_1 level when the lime dose increased from 300 kg ha^{-1} to 600 kg ha^{-1}. Both levels of lime showed an increase in Mn contact with increase in P dose.

There was an increase in the Cu content with increasing levels of P at both higher and lower levels of lime. Application of lime at higher level in presence of 35 kg ha^{-1} of P increased the Cu content significantly.

4.2.3 Nutrient uptake studies

4.2.3.1 Nutrient uptake of straw at Koyalmannam

Effect of P, K, lime and controls on nutrient uptake of straw is given in the table 4.32.

Effect of P

The two levels of P significantly influenced the uptake of N, P, Mg, Mn, Zn and Si by the straw. An increase in the uptake of N, P, Mg, Mn, Zn and Si to the tune of 27, 42, 27, 42, 8.3, 20 per cent respectively at P_2 level (35 kg ha^{-1}) was observed. Phosphorus application at higher levels could not influence the K, Ca, Fe and Cu content of the straw.

Effect of K

There was a significant increase in the uptake of N and K to the tune of 21 per cent and 16.3 per cent at K_2 level (70 kg ha^{-1}) compared to K_1 (35 kg ha^{-1}). K_2 was on par with K_3 for N and K uptake. There was an increase in the uptake of P at K_2 but over K_1, but beyond K_2 it showed a decline. The uptake of Ca and Mg was minimum at K_3 level and it was significantly inferior to K_2. No significant difference was observed between K_1 and K_2 for the uptake of Ca and Mg. Iron uptake showed a significant decrease at K_2 level compared to both K_1 and K_3 while Zn and Si showed a significant increase in uptake at K_2 compared to K_1. K_2 and K_3 were on par for the uptake of Zn and Si.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased the uptake of P, Ca and Zn compared to lime application at 300 kg ha^{-1} and the increase was 15, 19.3,

Table 4.32 Nutrient uptake in straw (kg ha^{-1}) (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	28.10	2.79	47.88	5.87	4.03	2.20	1.09	0.24	0.02	113.46
P_2	35.72	3.93	61.55	6.80	5.13	2.13	1.39	0.26	0.03	133.87
CD (0.05)	1.64	0.19	NS	NS	0.24	NS	0.14	0.01	NS	5.19
Levels of Potassium										
K_1	27.34	2.62	49.59	6.86	4.71	2.75	1.24	0.22	0.02	114.66
K_2	33.26	3.91	57.68	6.48	4.82	2.19	1.24	0.26	0.02	123.41
K_3	35.14	3.56	56.87	5.67	4.21	2.55	1.23	0.27	0.03	128.00
CD (0.05)	2.01	0.24	3.14	0.68	0.29	0.24	NS	0.01	NS	6.36
Levels of Lime										
L_1	30.16	3.12	55.21	5.79	4.56	2.39	1.26	0.24	0.02	118.00
L_2	33.66	3.60	54.22	6.88	4.60	1.93	1.22	0.26	0.03	125.87
CD (0.05)	NS	0.19	NS	0.56	NS	0.20	NS	0.01	0.001	NS
Controls										
C_1	27.87	2.69	50.49	5.50	4.45	2.00	0.82	0.20	0.019	121.76
C_2	39.78	4.55	62.87	7.83	6.05	2.23	1.35	0.27	0.028	131.27
C_3	28.85	2.43	47.61	5.03	3.64	2.66	1.26	0.20	0.018	113.26
CD (0.05)	4.03	0.48	6.29	1.37	NS	0.49	0.36	0.03	0.003	12.72

Table 4.31a Effect of P and K on elemental composition of grain (Ottappalam)

Treatments	N (%)			P (%)			K (%)			Mn (ppm)		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.90	0.99	0.92	0.13	0.15	0.15	0.35	0.35	0.46	45.17	32.55	34.08
P_2	1.06	1.03	1.07	0.15	0.16	0.15	0.37	0.44	0.47	48.30	41.85	40.88
CD(0.05)	0.05			0.005			0.01			3.4		

Table 4.31b Effect of P and lime on elemental composition of grain (Ottappalam)

Treatments	Fe (ppm)		Mn (ppm)		Cu (ppm)	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	281.67	170.56	39.57	34.97	3.88	4.06
P_2	199.11	146.78	43.93	43.42	4.09	4.59
CD(0.05)	37.73		1.77		0.19	

Table 4.33 . Effect of P and K on nutrient uptake by straw (Koyalmannam)

Treatments	P (kg ha^{-1})			Fe (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	2.22	3.01	3.15	2.71	2.38	1.51
P_2	3.06	4.10	4.66	2.79	2.00	1.55
CD(0.05)	0.34			0.25		

19.3 and 8.3 per cent respectively. Higher level of lime application decreased Fe and Mn uptake to the extent of 19.2 per cent and 8.3 per cent respectively. No significant difference was observed for the uptake N, K, Mg and Si.

Effect of controls

Maximum uptake was observed in C_2 (POP) for all the nutrients except Fe and it was significantly superior to C_3 (the farmer's practice). The uptake in C_2 was increased to the extent of 27, 46, 24.2, 35.7, 39, 29, 25, 36 and 13.7 per cent respectively for N, P, K, Ca, Mg, Mn, Zn, Cu and Si over the C_3 (farmer's practice). The maximum Mn uptake was observed in C_2 (POP) and it was significantly superior to C_1 (POP without lime) and C_3 (the farmer's practice.

4.2.3.2 Interaction effect on nutrient uptake by straw

Interaction between P and K

Phosphorus and K interacted significantly to influence the P and Fe uptake by straw (Table 4.33). P_2K_3 registered the highest value for P uptake (4.66 kg ha^{-1}) followed by P_2K_2 (4.10 kg ha^{-1}). Lowest uptake was observed at P_1K_1 (2.22 kg ha^{-1}). At P_1 level with increased K dose at 70 kg ha^{-1} and 105 kg ha^{-1} significantly increased the P uptake compared to 35 kg ha^{-1} of K dose. Similarly P_2K_2 and P_2K_3 also showed an increased uptake compared to P_2K_1. Increasing the P to 35 kg ha^{-1} significantly increased the P uptake by 37 per cent, 36 per cent and 47 per cent respectively at K_1, K_2 and K_3.

P_2K_1 recorded the highest Fe uptake and P_1K_3 recorded the lowest uptake of Fe. The Fe uptake in P_1K_3 decreased by 44 per cent compared to the uptake in P_1K_1. A decrease to the tune of 44 per cent was observed at P_2K_3 also compared to P_2K_1.

Interaction between K and lime

Potassium and lime interacted significantly to influence the P, Ca, Mg and Fe uptake of straw (Table 4.34). K_3L_2 and K_1L_1 recorded respectively the highest and lowest value for P uptake and these two differed significantly by 41 per cent.

Increased lime application increased the P uptake at K_1, K_2, K_3 respectively by 26 per cent, 22 per cent and 2.8 per cent. It is also to be noted that higher levels of lime application in the presence of K_1 and K_2 increased the P uptake. Application of lime at 600 kg ha^{-1} significantly increased the Ca uptake at K_1 level. But at K_2 and K_3 levels no difference was observed between the two levels of lime application.

K_1L_2 recorded the maximum value for Mg uptake 4.99 followed by K_2L_2. Increasing the lime application at K_1 level significantly increased the Mg uptake. But at K_3 level increasing the lime dose decreased the Mg uptake. Maximum value for the Fe uptake was observed at K_1L_1 and K_1L_2 (2.75 kg ha^{-1}) and the minimum uptake was observed at K_3L_2 (1.23 kg ha^{-1}). At 300 kg ha^{-1} and 600 kg ha^{-1} of lime application in increasing the K levels decreased the Fe uptake. The Fe uptake at K_3L_1 decreased by 11.6 per cent compared K_1L_1. Similarly Fe uptake at K_3L_2 decreased by 55 per cent compared to K_1L_2. At K_2 and K_3 increasing the lime dose to 600 kg ha^{-1} decreased the Fe uptake by 28 per cent and 34 per cent respectively.

4.2.3.3 Second order interaction effect on nutrient uptake by straw

The uptake of N and P was maximum at $P_1K_1L_2$ and $P_1K_2L_2$ respectively (Table 4.34a) .The Ca and Mg recorded the maximum uptake at $P_1K_2L_2$ and $P_1K_1L_1$ respectively . The Fe uptake was minimum at $P_1K_2L_2$.The Fe uptake in POP and farmer's practice increased by 12.3 and 25 percent respectively compared to $P_1K_2L_2$.

4.2.3.4 Nutrient uptake of straw at Ottappalam

Effect of P, K, lime and controls on nutrient uptake of straw is given in the table 4.35.

Effect of P

The two levels of P application significantly influenced the uptake of N, K and Si of straw by increasing their uptake at P_2 (35 kg ha^{-1}) over P_1 (17.5 kg ha^{-1}).

Table 4.34 a Second order interaction effect on nutrient uptake of straw (Koyalmannam)

Treatment	N (kg ha^{-1})		P (kg ha^{-1})		Ca (kg ha^{-1})		Mg (kg ha^{-1})		Fe (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	35.75	37.21	3.82	3.60	6.97	6.44	5.56	5.18	2.52	2.36
P_1K_2	31.20	32.94	3.48	4.05	7.05	6.46	4.99	4.70	2.59	1.78
P_1K_3	35.58	31.64	3.46	3.29	5.70	6.14	4.03	4.25	1.94	2.56
P_2K_1	31.72	31.17	3.48	3.13	5.18	5.39	4.80	3.86	2.77	1.79
P_2K_2	26.63	34.28	2.76	3.78	5.16	7.60	3.56	5.24	2.01	2.22
P_2K_3	32.04	28.99	3.30	2.98	6.34	6.26	4.49	4.30	2.29	2.51
CD(0.05)	4.03		0.48		1.37		0.59		0.49	

Table 4.34 Effect of K and lime on nutrient uptake by straw (Koyalmannam)

Treatments	P (kg ha^{-1})		Ca (kg ha^{-1})		Mg (kg ha^{-1})		Fe (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	2.32	2.93	5.57	8.15	4.44	4.99	2.75	2.75
K_2	3.20	3.91	6.24	6.73	4.74	4.89	2.56	1.82
K_3	3.85	3.96	5.57	5.76	4.49	3.93	1.87	1.23
CD(0.05)	0.34		0.97		0.41		0.35	

Table4.36a Effect of P and K on nutrient uptake by straw (Ottappalam)

Treatments	N (kg ha^{-1})			Mn (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	21.27	29.31	33.11	0.69	0.86	0.96	0.19	0.21	0.22
P_2	22.80	39.48	32.83	0.78	1.13	0.97	0.19	0.27	0.21
CD(0.05)	5.47			0.12			0.03		

Table 4.36b Effect of P and lime on nutrient uptake by straw (Ottappalam)

Treatments	K (kg ha^{-1})		Ca (kg ha^{-1})		Mn (kg ha^{-1})		Zn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1	56.13	57.05	5.71	6.66	0.80	0.87	0.21	0.21
P_2	67.94	56.25	6.88	6.39	1.03	0.88	0.25	0.19
CD(0.05)	7.80		0.70		0.10		0.02	

Table 4.35 Nutrient uptake in straw (kg ha^{-1}) (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	27.90	4.84	56.59	6.18	2.92	8.39	0.83	0.21	0.02	95.39
P_2	31.70	5.36	62.11	6.63	3.19	9.19	0.96	0.22	0.02	106.08
CD (0.05)	3.11	NS	5.55	NS	NS	NS	NS	NS	NS	8.66
Levels of Potassium										
K_1	22.04	3.82	48.39	6.01	3.09	8.78	0.73	0.19	0.02	93.94
K_2	34.40	5.80	62.99	7.40	3.12	9.85	0.99	0.24	0.03	112.20
K_3	32.97	5.68	66.66	5.82	2.95	7.75	0.96	0.22	0.02	96.06
CD (0.05)	3.82	0.78	6.79	0.614	NS	1.15	NS	0.02	0.002	NS
Levels of Lime										
L_1	29.96	4.47	62.03	6.29	3.10	9.70	0.91	0.23	0.02	108.66
L_2	29.64	5.73	56.66	6.52	3.01	7.88	0.88	0.20	0.02	92.80
CD (0.05)	NS	0.640	5.55	NS	NS	0.944	NS	0.01	NS	8.66
Controls										
C_1	24.36	3.99	51.60	5.61	2.85	8.42	0.78	0.163	0.016	96.55
C_2	25.32	4.57	48.40	5.51	2.85	7.71	0.63	0.159	0.015	94.60
C_3	26.85	3.41	45.94	5.06	2.28	9.91	0.64	0.166	0.015	87.49
CD (0.05)	NS	1.07	NS	NS	NS	2.01	NS	NS	NS	NS

Effect of K

The uptake of N, P, K was maximum at K_2 (70 kg ha^{-1}) level and it was significantly superior to K_1 and on par with K_3. The lowest value for lime uptake was at K_3 which was significantly inferior to K_1 and K_2. Fe uptake at K_3 level was significantly lower than K_2 and K_1 by 21 per cent and 11.7 per cent respectively. The uptake of Zn and K_2 level was significantly higher than K_1. Application of K at 70 kg ha^{-1} recorded the highest nutrient uptake and it was significantly superior to K_1 and K_3.

Effect of lime

Application of lime at 600 kg ha^{-1} increased the uptake of P compared to lime application at 300 kg ha^{-1}. The former significantly decreased the uptake of K, Fe, Zn and Si to the content of 8.6 per cent, 18.7 per cent, 13 per cent and 14.6 per cent respectively.

Effect of controls

It is clear from the table4.35 that there is a significant increase in the uptake of P and decrease in the uptake of Fe at C_2 (POP) level compared to C_3 (the farmer's practice).

4.2.3.5 Interaction effect on nutrient uptake by straw

Interaction between P and K

At P_1 and P_2 level N uptake was significantly increased when the K dose was increased to 70 kg ha^{-1}. No significant difference was observed between P_1 and P_2 levels for the uptake at K_1 and K_3 levels (Table 4.36a). At K_2 level a significant increase in the N uptake was observed when the P dose was increased.

At P_1 level there was an increase in the Mn uptake with increasing levels of K. But at P_2 level there was an increase up to K_2 level and beyond K_2 it decreased P_2K_2 recorded the maximum uptake of Mn and it was significantly superior to all other combination. Lowest value for Mn uptake was observed at P_1K_1.

There was an increase in the Zn uptake by the combined application of 35 kg ha^{-1} of P and 70 kg ha^{-1} of K compared to all other levels. At K_2 level Zn uptake was increased by 28 per cent when the P increased from P_1 to P_2.

Interaction between P and lime

The data in the table 4.36b showed that the uptake of K was significantly increased by 21 per cent when the P dose increased from 17.5 kg ha^{-1} to 35 kg ha^{-1} at 300 kg ha^{-1} of lime application. This treatment combination P_2L_1 was significantly superior to all other combination for the uptake of K. Maximum Ca uptake was recorded by P_2L_1 and it was significantly superior to P_1L_1 and on par with P_2L_2. Lime application at 300 kg ha^{-1} in presence of 35 kg ha^{-1} of P (P_1L_2) recorded the highest value for Mn uptake and it was significantly higher than P_1L_1 and P_1L_2 by 26 per cent and 18.3 per cent respectively. The zinc uptake showed significant increase at P_2 level when the lime dose increased from 300 kg ha^{-1} to 600 kg ha^{-1}. This P_2L_1 was significantly superior to all other treatment combinations.

4.2.3.6 Nutrient uptake by grain at at Koyalmannam

The effect of P, K, lime and controls on nutrient uptake of grain is given in the table 4.37.

Effect of P

The two levels of P significantly influenced the uptake of P, K, Ca, Mn and Si to the extent of 17.1, 22, 26, 23 and 12.8 per cent respectively.

Effect of K

Graded levels of K significantly influenced the N, P, K, Ca, Fe, Zn and Si uptake. The uptake of N and P at K_3 was significantly higher compared to K_1. The uptake of K showed a steady increase with increasing levels of K while Ca and Fe showed as significant decrease at K_2 over K_1. Zinc and Si uptake increased significantly at K_3 compared to K_1.

Table 4.37 Nutrient uptake in grain (kg ha^{-1}) (Koyalmannam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	34.02	5.47	14.88	0.72	3.72	0.56	0.13	0.09	0.020	73.10
P_2	41.12	6.41	18.18	0.91	4.33	0.61	0.16	0.09	0.019	82.49
CD(0.05)	NS	0.43	1.29	0.10	NS	NS	0.01	NS	NS	4.99
Levels of Potassium										
K_1	31.61	5.24	13.02	1.03	3.83	0.81	0.15	0.09	0.020	72.70
K_2	38.48	5.90	16.40	0.67	3.95	0.50	0.14	0.09	0.020	77.14
K_3	42.61	6.09	20.18	0.46	4.30	0.45	0.15	0.10	0.020	83.54
CD(0.05)	8.13	0.53	1.58	0.12	NS	0.21	NS	0.009	NS	6.12
Levels of Lime										
L_1	35.48	5.64	16.11	0.75	3.75	0.71	0.15	0.10	0.020	77.72
L_2	39.66	6.25	16.95	0.89	4.30	0.47	0.14	0.09	0.019	77.87
CD(0.05)	2.55	0.43	NS	0.10	NS	0.10	0.01	NS	NS	NS
Controls										
C_1	39.13	5.70	17.59	1.19	4.51	0.83	0.17	0.107	0.020	82.46
C_2	38.78	5.54	16.41	1.27	4.54	0.55	0.12	0.103	0.020	74.73
C_3	27.95	4.55	13.14	0.40	3.32	0.80	0.16	0.080	0.019	70.00
CD(0.05)	6.26	NS	3.16	0.24	0.84	NS	0.02	0.010	NS	NS

Effect of lime

The two levels of lime application significantly influenced the uptake of N, P, Ca, Fe and Mn. The uptake of N, P and Ca increased by 11.7, 10 and 14.6 per cent respectively while Fe and Mn decreased by 33 per cent and 6 per cent respectively at the higher level of lime application.

Effect of controls

Maximum N and K uptake was observed in C_1 (POP without lime) and it was on par with C_2 (POP) and significantly superior to C_3 (farmer's practice). C_2 (POP) recorded the highest value for Ca and Mg uptake and it was significant superior to C_3. Maximum Mn and Zn uptake was seen in C_1 and it was significantly superior to C_2.

4.2.3.7 Interaction effect on nutrient uptake by grain

Interaction between P and K

The uptake of P, K, Mn and Zn was significantly influenced by P and K interaction as evident from the table4.38a. P_1K_3 recorded the maximum value (6.79 kg ha^{-1}) for P uptake and P_1K_1 recorded the minimum value (4.49 kg ha^{-1}) with increase in P level the P uptake showed an increase to the tune of 33 per cent and 28.9 per cent respectively at K_1 and K_2 levels. At K_3 level P_1 and P_2 were on par.

Maximum value for the grain uptake of K (20.46 kg ha^{-1}) was observed at P_2K_3 and the minimum value (11.16 kg ha^{-1}) was observed at P_1K_1. The K uptake at P_1K_2 and P_1K_3 increased by 21 per cent and 78 per cent respectively compared to P_1K_1. Similarly the K uptake at P_2K_2 and P_2K_3 increased by 29 per cent and 37 per cent respectively compared to P_2K_1. Increasing the P to 35 kg ha^{-1} increased K uptake at K_1 and K_2 by 33 per cent and 41 per cent respectively. P_2K_1 and P_2K_2 recorded the highest value for Mn uptake and P_1K_2 recorded the lowest value.

The Mn uptake at P_1K_2 significantly decreased by 28 per cent compared to P_1K_1. Increasing the P dose increased Mn uptake at K_1 and K_2 but at K_3 significant change was not observed.

Maximum value for Zn uptake was registered by P_1K_3. At K_3 level increasing the P application decreased the Zn uptake by 18 per cent. The Zn uptake at P_1K_3 significantly increased by 37.5 per cent and 22 per cent respectively compared to P_1K_1 and P_1K_2.

Interaction between K and lime

Potassium and lime interacted significantly to influence the N, P, K, Fe and Zn uptake by grain (Table 4.38b).

K_3L_2 recorded the highest value for N uptake (46.11 kg ha^{-1}) and K_1L_2 registered the lowest value (30.35 kg ha^{-1}). Lime application at 600 kg ha^{-1} significantly increased the N uptake at K_2 and K_3 levels by 23 per cent and 17.8 per cent respectively. K_3L_1 was significantly superior to K_1L_1 by 19 per cent.

The uptake of P significantly increased at K_2L_2 to the tune of 36 per cent compared to K_1L_2. At K_2 level P uptake increased by 34 per cent with the application of 600 kg ha^{-1} of lime. K_3L_1 and K_3L_2 showed significant increase in the N uptake compared to K_1L_1 and K_1L_2 respectively.

K_3L_2 and K_1L_2 registered the highest and lowest K uptake respectively and these two differed by 66 per cent. At K_2 level increase in lime application increased the K uptake by 17 per cent K_3L_1 and K_3L_2 significantly increased the K uptake by 30 and 44 per cent respectively over K_1L_1 and K_1L_2. There was a significant decrease in the Zn uptake at K_1L_2 by 30 per cent compared to K_1L_1. K_2L_2 showed significant increase in the Zn uptake to the extent of 30 per cent compared to K_1L_1.

The Fe uptake decreased significantly at K_3L_2 (0.38 kg ha^{-1}) and maximum uptake was noted with K_1L_1 (1.02 kg ha^{-1}). Increasing the lime application significantly decreased the Fe uptake at all levels of K. Potassium application at 70 kg ha^{-1} significantly decreased the Fe uptake in the presence of lime at 300 kg ha^{-1} and 600 kg ha^{-1} respectively by 40 per cent and 34 per cent.

Table 4.38a Effect of P and K on nutrient uptake by grain (Koyalmannam)

Treatments	P (kg ha^{-1})			K (kg ha^{-1})			Mn (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	4.49	5.15	6.79	11.16	13.59	19.90	0.14	0.10	0.16	0.08	0.09	0.11
P_2	6.00	6.64	6.60	14.87	19.22	20.46	0.17	0.17	0.15	0.09	0.10	0.09
CD(0.05)	0.75			2.23						0.01		

Table 4.38b Effect of K and lime on nutrient uptake by grain (Koyalmannam)

Treatments	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})		Zn (kg ha^{-1})		Fe (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
K_1	32.87	30.25	5.33	5.15	13.70	12.34	0.10	0.07	1.02	0.61
K_2	34.43	42.53	5.21	7.01	14.85	17.96	0.09	0.10	0.61	0.40
K_3	39.12	46.11	6.38	6.58	19.79	20.56	0.10	0.10	0.51	0.39
CD(0.05)	4.40		0.75		2.23		0.01		0.10	

Table 4.41 Effect of P and K on nutrient uptake by grain (Ottappalam)

Treatments	Fe (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.91	1.05	0.62	0.08	0.10	0.08
P_2	0.85	0.59	0.42	0.07	0.08	0.08
CD(0.05)	0.21			0.01		

4.2.3.8 Second order interaction effect on nutrient uptake by grain

It is clear from the table4.39 that the uptake of P and K is maximum at $P_2K_2L_2$ and $P_1K_1L_2$ recorded the maximum uptake for Ca. Higher level of lime application increased Ca uptake of grain at P_1K_1 and decreased at P_1K_2. The grain uptake of Fe and Mn was minimum at $P_1K_2L_2$ and $P_1K_1L_2$ respectively. $P_1K_3L_1$ recorded the maximum value for Zn uptake. Higher level of lime application decreased Zn uptake at P_1K_3 and P_2K_3 and increased at P_2K_2.

4.2.3.9 Nutrient uptake in grain at Ottappalam

The effects of P, K, lime and controls on nutrient uptake by grain are given in the table 4.40.

Effect of P

The two levels of P significantly influenced the nutrient uptake of K, Fe, Mn and Zn. With increasing level of P there was an increase in the uptake of K and Mn to the tune of 7.3 per cent and 14 per cent respectively. Application of P at 35 kg ha^{-1} significantly reduced the Fe and Zn uptake by 27 and 11 per cent respectively.

Effect of K

It is observed from the table 4.40 that application of different levels of K significantly influenced the uptake of N, P, K, Ca, Fe, Zn and Si. Application of K at 70 kg ha^{-1} significantly increased the N and P uptake to the tune of 34 per cent and 16.6 per cent respectively compared to K application at 35 kg ha^{-1}, K_2 was on par with K_3 for the nutrient uptake. Calcium uptake decreased by 11.5 per cent at K_2 compared to K_1. The uptake of Fe was decreased by 12.3 per cent from K_2 to K_3 and K_1 was on par with K_2. The uptake of Zn increased from K_1 to K_2 and beyond K_2 the uptake was decreased.

Table 4.39 Second order interaction effect on nutrient uptake by grain (Koyalmannam)

Treatment	P (kg ha^{-1})		K (kg ha^{-1})		Ca (kg ha^{-1})		Fe (kg ha^{-1})		Mn (kg ha^{-1})		Zn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
P_1K_1	5.33	4.99	16.12	13.75	0.779	1.263	0.640	0.494	0.117	0.111	0.090	0.098
P_1K_2	5.88	6.47	16.48	19.60	1.036	0.543	0.602	0.411	0.156	0.145	0.092	0.098
P_1K_3	6.58	5.97	18.92	16.48	0.922	0.642	0.594	0.657	0.159	0.166	0.116	0.088
P_2K_1	6.33	5.18	16.27	16.11	0.514	0.514	0.688	0.464	0.142	0.126	0.098	0.096
P_2K_2	5.74	6.81	15.92	17.41	0.560	0.766	0.599	0.849	0.162	0.152	0.086	0.100
P_2K_3	5.96	6.14	18.74	15.58	1.016	0.907	0.609	0.652	0.149	0.176	0.104	0.087
CD(0.05)	1.06		3.16		0.240		0.250		0.020		0.010	

Table 4.40 Nutrient uptake in grain(kg ha^{-1}) (Ottappalam)

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	SiO_2
Levels of Phosphorus										
P_1	38.25	5.63	14.87	1.25	3.50	0.86	0.14	0.09	0.02	84.36
P_2	36.19	5.79	15.97	1.24	3.46	0.62	0.16	0.08	0.02	80.97
CD (0.05)	NS	NS	1.17	NS	NS	0.12	0.01	0.007	NS	NS
Levels of Potassium										
K_1	29.10	4.60	11.69	1.30	3.39	0.88	0.15	0.07	0.01	73.58
K_2	41.28	6.26	16.33	1.45	3.75	0.82	0.14	0.09	0.02	88.78
K_3	41.28	6.26	18.25	0.98	3.30	0.52	0.15	0.08	0.02	85.63
CD (0.05)	3.29	0.55	1.43	0.23	NS	0.15	NS	0.008	NS	6.62
Levels of Lime										
L_1	35.04	5.35	16.02	1.10	3.13	0.87	0.15	0.08	0.01	80.99
L_2	39.40	6.07	14.83	1.39	3.83	0.62	0.15	0.08	0.02	84.34
CD (0.05)	NS	0.45	NS	0.19	0.41	0.12	NS	NS	NS	NS
Controls										
C_1	31.26	5.22	15.56	1.48	3.64	0.88	0.16	0.083	0.014	77.87
C_2	32.22	5.34	16.28	1.57	3.87	0.65	0.17	0.083	0.014	73.95
C_3	26.22	3.62	13.47	0.49	3.13	1.12	0.13	0.071	0.018	79.80
CD (0.05)	NS	0.11	NS	0.47	NS	0.30	NS	NS	NS	NS

Effect of lime

Application of lime at 600 kg ha^{-1} increased the uptake of P, Ca and Mg by 13.4, 26 and 22 per cent respectively. Increasing the level of lime application decreased the Fe uptake by 28.7 per cent.

Effect of controls

Between the control treatments the P and Ca uptake was highest in C_2 (POP) compared to C_3 (the farmers practice). The Fe uptake was highest in C_3 (the farmer's practice) and significantly higher than the C_2 (POP).

4.2.3.10 Interaction effect on nutrient uptake by grain

Interaction between P and K

Different levels of P and K significantly influenced the Fe and Zn uptake by the grain. It can be seen from the table 4.41 that increasing the level of K to 105 kg ha^{-1} from 35 kg ha^{-1} and 70 kg ha^{-1} decreased the Fe uptake by 31 per cent and 40 per cent respectively at P_1 level. Similarly at P_2 level also a significant decrease to the time of 50 per cent was observed when K dose increased from K_1 to K_3 and the percentage decrease was 30.5 per cent when K dose increased from K_1 to K_2. However the minimum Fe uptake was observed at P_2K_3.

When the P dose increased from 17.5 kg ha^{-1} to 35 kg ha^{-1} in the presence of 70 kg ha^{-1} of K, the Zn uptake was decreased by 20 per cent. At P_1 level Zn uptake showed an increase from K_1 to K_2 and beyond K_2 it showed a decrease.

4.2.4 Nutrient content of soil

4.2.4.1.1 Nutrient content of soil at MT stage at Koyalmannam

Effect of P, K, lime and controls on nutrient content of soil at maximum tillering stage is given in the table 5.1.

Effect of P

Application of P at two levels significantly influenced the P, Mg, Zn and Cu content of the soil. Phosphorus application at 35 kg ha^{-1} significantly increased the P, Mg and Cu content of soil and decreased the Zn content.

Effect of K

It can be seen from the table 5.1that K application at 70 kg ha^{-1} and 105 kg ha^{-1} significantly increased the P content of the soil by 9.4 and 4.9 per cent respectively compared to 35 kg ha^{-1} of K application.

Potassium application at higher levels significantly increased the available K content of the soil by 3.3 and 5.8 per cent at K_2 and K_3 respectively. The Ca content of the soil showed a decreasing trend with increasing levels of K. The Mg content increased significantly at K_2 and K_3 compared to K_1. But K_2 was on par with K_3. The Fe content decreased with increase in K levels and the decrease at K_3 was to the tune of 3.3 per cent compared to K_1 and K_2. Potassium application at 105 kg ha^{-1} significantly decreased the Mn content by 9.3 per cent compared to K application at 35 kg ha^{-1}.

Effect of lime

Lime application at higher level significantly increased the P and Ca content of the soil by 5 and 36 per cent respectively.

Effect of controls

C_2 (POP) recorded the highest content of P, K, Ca and Mg and C_3 (the farmer's practice) registered the lowest content. The soil K content was significantly low in the farmer's practice by 9.4 per cent compared to C_2. C_1 and C_2 were on par for the K content. The Ca and Mg content significantly increased in C_2 compared to C_1. The Zn content of the soil showed a significant decrease in the C_3 over C_2 by 32 per cent.

Table 5.1 Nutrient content of soil at MT stage (Koyalmannam)

Treatments	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	206.54	21.22	212.01	0.42	0.28	526.25	32.68	2.85	1.12
P_2	208.29	24.46	213.69	0.4 2	0.29	532.87	32.63	2.27	1.38
CD(0.05)	NS	0.62	NS	NS	0.003	NS	NS	0.39	0.119
Levels of Potassium									
K_1	206.85	21.80	206.80	0.47	0.28	537.59	34.29	2.54	1.16
K_2	209.25	23.85	213.71	0.44	0.29	532.06	32.57	2.48	1.30
K_3	206.50	22.87	218.04	0.36	0.29	519.03	31.10	2.67	1.29
CD(0.05)	NS	0.76	3.35	0.02	0.003	20.60	1.60	NS	NS
Levels of Lime									
L_1	205.59	22.22	213.17	0.33	0.29	537.90	33.04	2.63	1.19
L_2	209.24	23.46	212.54	0.52	0.28	521.22	32.27	2.49	1.31
CD(0.05)	NS	0.62	NS	0.02	NS	NS	NS	NS	NS
Controls									
C_1	209.50	20.29	201.90	0.30	0.281	574.51	34.32	2.08	1.40
C_2	205.65	22.88	201.16	0.58	0.288	572.33	31.53	2.17	1.63
C_3	211.60	17.34	182.50	0.32	0.274	586.03	31.33	1.46	1.42
CD(0.05)	NS	1.50	6.70	0.05	0.007	NS	NS	0.30	NS

4.2.4.1.2 Interaction effect on nutrient content of soil

Interaction effect of P, K and lime on the nutrient content of soil is given hereunder.

Interaction between P and K

Phosphorus and K interacted significantly to influence the N, P, K, Mg, Fe and Zn content of the soil (Table 5.2a). There was a significant increase in the available N of the soil at P_1K_2, but at P_1K_3 a significant decrease was observed compared to P_1K_2. No significant difference was observed between the various levels of K at P_2. At K_1 and K_3 increasing the P dose increased the N content of soil. There was a significant increase in the P content at P_1K_3 compared to P_1K_1 and P_1K_2.At P_2 level a significant increase was observed at K_2 and K_3. Increasing the P dose at K_2 level significantly increased the P content of the soil by 14 per cent.

The available K content of the soil was significantly increased by 2.9 and 10 per cent at K_2 and K_3 respectively compared to K_1 in the presence of 17.5 kg ha^{-1} of P. At P_2 level increasing the K dose to K_2 and K_3 significantly increased the K content of the soil by 3 and 4 per cent respectively. Increasing the P dose at K_1 and K_2 level also significantly increased the K content of the soil. Increasing level of K significantly increased the Mg content of soil at K_2 and K_3 in the presence of 17.5 kg ha^{-1} of P. But in the presence of 35 kg ha^{-1} of P Mg content of the soil significantly decreased at K_2. However K_1 and K_3 were on par for the content of Mg.

The Fe content of the soil showed a significant decrease at K_2 and K_3 by 7.6 and 12.2 per cent respectively in the presence of 17.5 kg ha^{-1} of P. But this trend was not noticed at P_2 level. Increasing the P dose at K_1 level significantly decreased the Fe content by 8.1 percent. The Zn content of the soil significantly increased at P_1K_2 by 3 per cent compared to P_1K_1. But at P_2 level a significant decrease was observed at K_2 over K_1 to the tune of 32 per cent. At K_2 and K_3 level increasing the P dose to 35 kg ha^{-1} significantly decreased the Zn content of the soil.

Table 5.2a Effect of P and K on nutrient content of soil at MT stage (Koyalmannam)

Treatment	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	205.52	209.61	204.49	21.69	21.62	23.35	202.54	208.95	224.54
P_2	208.18	208.89	207.80	21.92	24.12	24.34	211.06	218.47	220.54
CD(0.05)	2.4			1.02			4.70		

Treatment	Mg (cmol (+) kg^{-1})			Fe (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.28	0.29	0.29	563.49	520.59	494.65	2.38	3.12	3.07
P_2	0.29	0.28	0.29	517.69	543.52	520.40	2.72	1.83	2.26
CD(0.05)	0.005			29.15			0.69		

Table5.2 b Effect of K and lime on nutrient content of soil at MT stage (Koyalmannam)

Treatment	Ca (meq 100 g^{-1})		Fe (kg ha^{-1})		Mn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	0.33	0.62	538.61	536.58	34.66	33.93
K_2	0.32	0.56	524.43	539.69	34.85	30.29
K_3	0.33	0.38	550.65	487.41	29.81	32.59
CD(0.05)	0.03		29.10		2.8	

Interaction between K and lime

It can be seen from the table 5.2b that increasing the lime dose in the presence of K_1, K_2 and K_3 significantly influenced the Ca content of the soil. Increasing the K dose in the presence of 600 kg ha^{-1} of lime significantly decreased the Ca content of the soil. The maximum content of Ca was present at K_1L_2 and the minimum content was observed at K_2L_1 and both differed significantly by 46 per cent. The Fe content of the soil showed a significant decrease at K_3L_2 and it was significantly inferior to all other treatment combinations. K_3L_2 and K_3L_1 differed significantly by 9.4 per cent. In the presence of 600 kg ha^{-1} of lime the Fe content decreased significantly at K_3 compared to K_1 by 9.1 per cent. The treatment K_2L_1 registered the highest content of Mn (34.85 kg ha^{-1}) and K_3L_1 registered the lowest content of Mn (29.81 kg ha^{-1}).

4.2.4.1.3 Nutrient content of soil at MT stage at Ottappalam

Effect of P, K, lime and controls on the nutrient content of soil at maximum tillering stage is given in the table 5.3.

Effect of P

Phosphorus application at higher level significantly influenced the N, P, K, Fe and Cu content of the soil. The N, P, K and Cu content significantly increased at higher level while the Fe content decreased with increase in P.

Effect of K

Application of K at higher levels significantly increased the P, K and Zn content of the soil (Table5.3). There was a significant increase in the available P at 105 kg ha^{-1} of K application to the tune of 11.5 per cent while the K content increased by 2.7 and 6.8 per cent respectively at K_2 and K_3. The Ca content of the soil showed a significant decrease at K_2 and K_3 to the tune of 5.2 per cent. The Fe content of soil significantly decreased at K_2 and K_3 by 10 and 7.3 per cent respectively.

Table 5.3 . Nutrient content of soil at MT stage (Ottappalam)

Treatments	Available nutrients ($kg\ ha^{-1}$)			Exchangeable nutrients $cmol\ kg^{-1}$		Available nutrients ($kg\ ha^{-1}$)			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	268.72	24.65	174.81	0.36	0.11	744.00	50.65	5.15	1.06
P_2	275.00	31.88	178.05	0.37	0.11	721.73	50.68	4.54	1.30
CD(0.05)	3.40	1.44	2.41	NS	NS	26.85	NS	NS	0.11
Levels of Potassium									
K_1	271.47	27.17	174.41	0.38	0.11	779.84	51.91	4.50	1.07
K_2	273.12	27.31	179.16	0.36	0.11	696.18	50.18	4.92	1.24
K_3	271.28	30.32	186.52	0.36	0.11	722.57	49.96	5.11	1.22
CD(0.05)	NS	1.39	2.96	0.01	NS	32.89	NS	0.275	NS
Levels of Lime									
L_1	269.50	27.85	183.48	0.35	0.10	755.84	50.92	4.90	1.23
L_2	274.41	28.69	176.59	0.39	0.12	709.89	50.41	4.79	1.13
CD(0.05)	3.46	NS	2.54	0.02	0.006	26.85	NS	NS	NS
Controls									
C_1	269.78	23.36	173.13	0.30	0.101	784.76	51.70	4.11	0.979
C_2	267.40	23.25	176.48	0.36	0.114	749.30	50.58	4.20	0.896
C_3	264.12	19.84	168.57	0.30	0.090	833.46	57.65	3.03	1.005
CD(0.05)	NS	2.79	5.90	0.05	0.015	65.78	5.40	0.55	NS

Effect of lime

Lime application at higher level significantly increased the Ca and Mg by 11 and 20 per cent respectively while the available Fe decreased by 6 per cent.

Effect of controls

The P, K, Ca, Mg and Zn content registered the lowest value in C_3 (farmers practice) while the highest value was recorded by C_2 (POP) and C_1 was on par with C_2 for these nutrients.

4.2.4.1.4 Interaction effect on nutrient content of soil

Interaction between P and K

Phosphorus and K interacted significantly to influence the K, Mg, Zn and Cu content of the soil (Table 5.4a)

Increasing the K dose to 105 kg ha^{-1} in the presence of 17.5 kg ha^{-1} of P significantly increased the available K content of the soil. However at P_2 level significant increase was observed both at 70 and 105 kg ha^{-1} of K compared to 35 kg ha^{-1} of K. At K_2 level increasing the P dose to 35 kg ha^{-1} significantly increased the K content of the soil. A significant decrease in Mg content was observed at K_2 and K_3 over K_1 in the presence of 17.5 kg ha^{-1} of P. But with 35 kg ha^{-1} of P this trend was not observed. Significant increase in the available Zn content was observed with increase in K dose at P_1 level. But at P_2 level no significant difference was observed between various K levels. At K_2 and K_3 level increasing the P to 35 kg ha^{-1} significantly decreased the Zn content of the soil.

Interaction between P and lime

Phosphorus and lime interacted significantly to influence the N, Fe and Zn content of soil (Table 5.4b). Combined application of P and lime at 35 kg ha^{-1} and 600 kg ha^{-1} respectively increased the available N content of the soil while the available Fe and Zn content was significantly decreased compared to the lowest level of P and lime.

Table 5.4a. Effect of P and K on nutrient content of soil at MT stage (Ottappalam)

Treatment	K (kg ha^{-1})			Mg (cmol (+) kg $^{-1}$)			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	173.76	170.78	180.49	0.12	0.10	0.10	4.56	5.20	5.70
P_2	175.07	187.54	183.55	0.11	0.11	0.11	4.43	4.65	4.53
CD(0.05)	4.10			0.01			0.38		

Table 5.4 b Effect of P and lime on nutrient content of soil at MT stage (Ottappalam)

	N (kg ha^{-1})		Fe (kg ha^{-1})		Zn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	268.98	268.45	755.12	732.89	5.29	5.02
P_2	270.03	280.36	756.56	686.90	4.51	4.55
CD(0.05)	4.80		37.98		0.31	

4.2.4.2.1 Nutrient content of soil at PI stage at Koyalmannam

Effect of P, K, lime and controls on available nutrients of soil at panicle initiation stage is presented in the table 5.5.

Effect of P

Phosphorus application at 35 kg ha^{-1} significantly increased the N, P, K and Mg content of the soil by 1.8, 18, 2.1 and 2 per cent respectively. However the Mn and Zn content of the soil decreased by 7.7 and 6.1 per cent respectively at higher level of P application.

Effect of K

Potassium application at higher levels significantly increased the N and K content of the soil. Increase in the N and K content of the soil at 105 kg ha^{-1} of K application was to the tune of 1.8 and 14.8 per cent respectively compared to 35 kg ha^{-1} of K application.

It is clear from the table 5.5 that there was a significant decrease in the Ca, Mg, Fe and Mn content of the soil at higher levels of K application. The Ca content significantly decreased at K_3 by 16.2 per cent compared to K_1 while the Mg content decreased by 2.7 per cent at K_2 and K_3. The Fe content of the soil showed a significant decrease at K_2 and K_3 by 7.9 and 10.7 per cent respectively while the Mn content decreased by 1.8 per cent at K_3 level. The P, Cu and Zn content remained unaffected by higher level of K application.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased the N, P and Ca content of the soil by 1.8, 5.9 and 33 per cent respectively while the Fe content decreased by 6.3 per cent at higher level of lime application.

Table 5.5 . Nutrient content of soil at PI stage (Koyalmannam)

Treatments	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	214.82	23.41	231.09	0.40	0.36	536.76	31.54	2.42	1.06
P_2	218.30	27.68	236.91	0.41	0.37	529.52	29.10	2.27	1.29
CD(0.05)	1.33	1.32	3.40	NS	0.002	NS	1.50	0.14	NS
Levels of Potassium									
K_1	214.21	25.30	216.43	0.43	0.37	568.52	30.36	2.38	1.12
K_2	217.01	25.55	236.67	0.41	0.36	523.91	28.00	2.28	1.14
K_3	218.45	25.79	248.91	0.36	0.36	507.00	29.80	2.37	1.26
CD(0.05)	1.60	NS	4.19	0.03	0.003	22.40	1.90	NS	NS
Levels of Lime									
L_1	214.62	24.81	235.31	0.32	0.36	550.90	30.02	2.41	1.20
L_2	218.50	26.28	232.69	0.48	0.36	515.69	30.62	2.28	1.15
CD(0.05)	1.30	1.30	NS	0.02	NS	18.35	NS	NS	NS
Controls									
C_1	219.50	24.76	218.17	0.32	0.368	587.00	31.70	2.48	1.26
C_2	220.00	25.48	219.40	0.46	0.370	582.25	30.58	2.41	1.42
C_3	213.50	20.02	190.16	0.31	0.358	616.33	30.99	2.23	1.30
CD(0.05)	3.26	3.24	8.30	0.06	0.006	14.50	NS	NS	NS

Effect of controls

The N, P, K, Ca and Mg content of the soil significantly higher in C_2 (POP) compared to C_3 (farmer's practice) while the Fe content was significantly low in C_2.

4.2.4.2.2 Interaction effect on nutrient content of soil

Interaction effect on the nutrient content of soil at panicle initiation stage is given in the table 5.6a.

Interaction between P and K

Phosphorus and K interacted significantly to influence the K, Mg and Zn content of the soil.

In the presence of 17.5 kg ha^{-1} of P the available K content of the soil significantly increased at K_2 and K_3 by 5.0 and 10.9 per cent respectively. At P_2 level the increase at K_2 and K_3 level was to the lime of 8.5 and 9.4 per cent respectively. Magnesium content of the soil significantly decreased at K_2 and K_3 in the presence of 17.5 kg ha^{-1} of P. But at P_2 level an increase in the Mg content was observed at K_2 and K_3. The Zn content of the soil showed a significant decrease at P_2K_2. Increasing the level of P at K_2 level significantly decreased the Zn content of soil by 12.4 per cent.

Interaction between P and lime

Phosphorus and lime interacted significantly to influence the N, P, Mg and Fe content of the soil (Table 5.6b). A significant increase in N content was observed at P_2L_2 compared to all other treatment combinations. Increasing the P dose in the presence of 600 kg ha^{-1} of lime significantly increased the N content of the soil. Increasing the level of P and lime significantly increased the available P of the soil.

Data on the Fe content showed that combined application of 35 kg ha^{-1} of P and 600 kg ha^{-1} of lime could significantly decrease the Fe content of the soil by 7.7 per cent compared to 17.5 kg ha^{-1} of P and 300 kg ha^{-1} of lime.

Table5.6a Effect of P and K on nutrient content of soil at PI stage (Koyalmannam)

Treatment	K (kg ha^{-1})			Mg (cmol (+) kg^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	219.25	230.57	243.45	0.37	0.36	0.36	2.33	2.49	2.44
P_2	223.61	242.70	244.37	0.36	0.37	0.37	2.44	2.18	2.31
CD (0.05)	5.90			0.004			0.24		

Table5.6 b Effect of P and lime on nutrient content of soil at PI stage (Koyalmannam)

Treatment	N (kg ha^{-1})		P (kg ha^{-1})		Fe (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	214.06	215.58	24.5	24.31	544.5	529.01
P_2	215.18	221.42	25.11	28.25	556.67	502.38
CD (0.05)	1.80		1.80		25.90	

Table 5.7. Nutrient content of soil at PI stage (O Ottappalam)

Treatment	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	277.70	20.56	198.65	0.48	0.22	656.05	46.23	4.95	1.20
P_2	284.30	24.88	203.58	0.45	0.23	668.40	48.40	4.31	1.44
CD(0.05)	3.39	1.83	3.90	NS	0.004	NS	NS	0.20	0.129
Levels of Potassium									
K_1	279.00	24.74	178.11	0.52	0.23	676.83	48.13	4.28	1.19
K_2	280.34	24.59	207.42	0.47	0.23	680.74	49.05	4.67	1.41
K_3	284.22	27.82	217.80	0.41	0.22	629.12	44.72	4.93	1.36
CD(0.05)	NS	2.27	4.78	0.05	NS	31.24	2.23	NS	NS
Levels of Lime									
L_1	276.00	25.31	202.57	0.37	0.22	682.89	46.77	4.66	1.37
L_2	286.39	26.13	199.96	0.56	0.23	641.56	47.86	4.60	1.27
CD(0.05)	3.39	NS	NS	0.04	0.004	25.51	NS	NS	NS
Controls									
C_1	278.67	20.65	186.10	0.377	0.233	648.10	49.56	4.03	1.05
C_2	282.56	21.43	184.98	0.610	0.234	642.64	49.02	4.30	0.96
C_3	263.51	18.76	182.34	0.380	0.221	763.46	48.35	2.94	1.05
CD(0.05)	NS	4.50	3.50	0.11	0.01	NS	NS	0.51	NS

4.2.4.2.3 Nutrient content of soil at PI stage at Ottappalam

Effect of P, K, lime and controls on the nutrient content of soil at PI stage is given in the table 5.7.

Effect of P

Application of P at 35 kg ha^{-1} significantly increased the N, P, K, Mg and Cu content of the soil while the Zn showed a significant decrease with increase in P application.

Effect of K

Potassium application at 105 kg ha^{-1} significantly increased the available P and K content of soil by 12.7 and 21.9 per cent while the Ca content was decreased by 21 per cent. Available Fe and Mn content of the soil showed a significant decrease at K_3 to the tune of 6.9 and 7.0 per cent respectively.

Effect of lime

N, Ca and Mg content of the soil was significantly increased and that of Fe content was significantly decreased by the application of lime at 600 kg ha^{-1}.

Effect of controls

C_3 recorded the lowest content of P, K, Ca, Mg and Zn while the highest content was observed in C_2 (POP).

4.2.4.2.4 Interaction effect on nutrient content of soil

Interaction between P and K

The Mg content of the soil significantly decreased at P_{1K3} compared to P_1K_1 (Table 5.8). At P_2 level no significant difference was observed between various levels of K. At P_1 level available Fe content of the soil decreased with increase in K dose. P_2K_3 recorded the lowest content of Fe. The Zn content of the soil increased with

Table5.8 Effect of P and K on nutrient content of soil at PI stage (Ottappalam)

Treatment	Mg (cmol (+) kg^{-1})			Fe (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.23	0.22	0.21	689.24	641.02	637.90	4.36	4.97	5.52
P_2	0.23	0.23	0.23	664.42	720.45	620.33	4.20	4.38	4.34
CD (0.05)	0.007			44.10			0.36		

increase in K dose at P_1 level. However, increasing the P dose at K_2 and K_3 level decreased the Zn content of the soil.

4.2.4.3.1 Nutrient content of soil at flowering stage at Koyalmannam

Effect of P, K, lime and controls on the nutrient of soil at flowering stage is given in the table 5.9.

Effect of P

Data on the effect of P revealed that increasing the P dose significantly increased the available P of the soil while the Fe, Mn and Zn content of the soil was decreased by 8.6, 5.4 and 5.7 per cent respectively.

Effect of K

Data on the effect of K show that application of K at higher levels significantly increased the N, K and Ca content of the soil. The Fe and Mn content of the soil decreased by 4.7 and 12.5 per cent respectively at K_3 compared to K_1.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the P and Ca content of the soil and decreased the K, Fe and Mn content of the soil.

Effect of controls

Significantly higher content of Ca and Mg was present in C_2 compared to C_3. But the Fe content was maximum in C_1 followed by C_3 while the Mn content was maximum in C_3.

4.2.4.3.2 Interaction effect on the nutrient content of soil

Interaction effect of P with K and lime on the nutrient content of soil at flowering stage is given in the (Table 5.10a and 5.10b).

Table 5.9. Nutrient content of soil at flowering stage (Koyalmannam)

Treatments	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	zn	Cu
Levels of Phosphorus									
P_1	215.39	18.83	222.24	0.36	0.13	543.26	28.49	2.28	0.84
P_2	215.79	20.55	223.70	0.37	0.13	496.45	26.93	2.15	1.08
CD(0.05)	NS	0.88	NS	NS	NS	18.08	1.01	0.104	NS
Levels of Potassium									
K_1	214.11	18.11	204.64	0.35	0.13	526.69	29.08	2.24	1.01
K_2	215.65	21.52	227.44	0.37	0.13	530.98	28.63	2.14	0.98
K_3	217.00	19.44	236.78	0.37	0.13	501.90	25.44	2.26	0.89
CD(0.05)	1.18	NS	4.08	0.01	NS	22.14	1.24	NS	NS
Levels of Lime									
L_1	215.21	19.07	225.00	0.32	0.13	528.69	28.08	2.27	0.94
L_2	215.96	20.31	220.37	0.40	0.13	511.02	27.35	2.16	0.98
CD(0.05)	NS	0.88	3.33	0.01	NS	18.08	NS	0.104	NS
Controls									
C_1	210.08	15.60	205.81	0.32	0.131	586.50	28.70	2.21	1.03
C_2	212.20	16.90	208.06	0.46	0.132	475.67	27.33	2.25	1.09
C_3	212.76	16.52	201.80	0.31	0.125	580.36	33.30	2.06	1.02
CD(0.05)	NS	NS	NS	0.02	0.005	70	2.49	NS	NS

Interaction between P and K

Phosphorus and K interacted significantly to influence the K, Ca, Mg, Mn and Zn content of the soil (Table 5.10a).

Significant increase in the available K content of the soil with increase in K dose at P_1 and P_2 level was observed. It can be seen from the table that increasing the K to 70 kg ha^{-1} significantly decreased Ca content compared to K at 35 kg ha^{-1} but beyond K_2 an increase was observed. At P_2 level the K level were on par for Ca content and the Mg content of the soil showed that increasing the K dose to 105 kg ha^{-1} significantly decreased the content of Mg in the presence of 17.5 kg ha^{-1} of P. But at P_2 level this variation was not observed.

P_2K_3 registered the lowest content of Mn and it was significantly inferior to the P_2K_1 which recorded the highest content of Mn by 21 per cent. At K_3 level increasing the P dose significantly decreased the Mn content by 17.4 per cent. P_2K_2 showed a significant decrease in the Zn content compared to all other treatment combinations.

Interaction between K and lime

Interaction of K and lime significantly influenced the N, Ca and Fe content of the soil (Table5.10b).

Lime application at 600 kg ha^{-1} in the presence of 35 kg ha^{-1} of K significantly increased the available N content of the soil. K_2L_1 and K_3L_1 registered significantly higher content of N compared to K_1L_1. Available N content of the soil registered the maximum value at K_3L_1 (217.57 kg ha^{-1}). The Ca content of the soil significantly increased when the lime dose increased to 600 kg ha^{-1} in the presence of various levels of K. Significant increase in the Ca content was observed in the presence of 600 kg ha^{-1} of lime when the K increased to 70 kg ha^{-1} from 35 kg ha^{-1}. However at K_3 level a significant was observed. Highest dose of K and lime (K_3L_2) showed a significant decrease in the Fe content of the soil compared to all other

Table5.10a . Effect of P and K on nutrient content of soil at flowering stage (**Koyalmannam**)

Treatment	K (kg ha^{-1})			Ca (cmol (+) kg^{-1})			Mg (cmol (+) kg^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	202.20	223.57	240.94	0.37	0.32	0.38	0.13	0.13	0.12
P_2	207.08	231.41	232.62	0.37	0.37	0.37	0.13	0.13	0.13
CD(0.05)	5.7			0.01			0.004		

Treatment	Mn (kg ha^{-1})			**Zn** (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3
P_1	28.69	28.92	27.87	2.17	2.32	2.30
P_2	29.47	28.33	23.00	2.31	1.96	2.23
CD(0.05)	1.7			0.18		

Table 5.10 b Effect of K and lime on nutrient content of soil at flowering stage (Koyalmannam)

Treatment	N (kg ha^{-1})		Ca (cmol (+) kg^{-1})		Fe (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	212.61	215.62	0.32	0.41	532.18	521.19
K_2	215.45	215.84	0.32	0.43	528.54	533.42
K_3	217.57	216.43	0.32	0.37	525.35	478.46
CD(0.05)	1.60		0.01		31.3	

treatment combinations. In the presence of 600 kg ha^{-1} of lime the Fe content showed a significant decrease at K_3 compared to K_1 and K_2.

4.2.4.3.3 Nutrient content of soil at flowering stage at Ottappalam

Effect of P, K, lime and controls on the nutrient content of soil is given in the table 5.11.

Effect of P

Phosphorus application at higher level significantly affected only the K content of soil and it was significantly increased at higher level of P application.

Effect of K

There was a significant increase in the available K content of soil with increase in K application to the tune of 3.7 and 2.6 per cent at K_2 and K_3 respectively. The Ca, Mg and Fe content of the soil decreased by 20, 9.2 and 7.5 per cent respectively at K_3 compared to K_1. The Zn content of soil increased with increase in K application.

Effect of lime

Significant increase in the available Ca and Mg content of the soil with increase in lime application was observed. The Fe content was decreased by 7.5 per cent at 600 kg ha^{-1} of lime application.

Effect of controls

C_2 (POP) was significantly superior to C_3 (farmers practice) for the available N, P, K and Zn content of the soil. The Fe content was maximum in C_3 and it was significantly superior to C_1 and C_2 by 15 and 16 per cent respectively.

Table 5.11. Nutrient content of soil at flowering stage (Ottappalam)

Treatments	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	258.60	25.66	189.48	0.40	0.150	646.89	26.05	3.90	0.97
P_2	261.94	27.94	193.63	0.41	0.160	651.18	27.00	3.36	1.20
CD(0.05)	NS	NS	2.80	NS	NS	NS	NS	NS	NS
Levels of Potassium									
K_1	259.06	26.27	187.78	0.45	0.165	666.83	24.95	3.28	1.01
K_2	260.02	26.62	194.09	0.40	0.150	663.65	27.67	3.68	1.11
K_3	261.74	27.50	192.80	0.36	0.150	616.62	27.03	3.93	1.15
CD(0.05)	NS	NS	3.40	0.05	0.003	30.43	NS	0.23	NS
Levels of Lime									
L_1	259.05	26.94	191.52	0.35	0.150	674.28	27.26	3.66	1.06
L_2	261.50	26.65	191.59	0.46	0.160	623.78	25.83	3.60	1.11
CD(0.05)	NS	NS	NS	0.04	0.001	24.85	NS	NS	NS
Controls									
C_1	263.58	24.44	177.10	0.373	0.150	638.10	25.20	3.03	0.96
C_2	264.91	27.74	178.32	0.510	0.151	629.30	23.92	3.36	0.76
C_3	251.92	17.14	172.68	0.360	0.148	753.46	27.48	2.54	0.906
CD(0.05)	9.40	9.50	9.40	NS	NS	60.87	NS	0.462	NS

4.2.4.3.4 Interaction effect on available nutrient content of soil

Interaction between P and K

Effect of P and K on the available nutrient content of soil is given in table 5.12a. The Mg content of the soil decreased with increase in K dose at P_1 level. K_2 and K_3 significantly increased the Mg content of the soil at P_2 level. Potassium application at 70 kg ha^{-1} significantly decreased the Fe content beyond which there was no effect at P_1 level. At P_2 level increasing the K from 70 to 105 kg ha^{-1} decreased the Fe content.P_2K_3 registered the lowest content of Fe.

Available Zn content of the soil significantly increased at P_1K_3 compared to P_1K_1 and P_1K_2. At all levels of K there was a decrease in Zn content with higher dose of P.

Interaction between K and lime

Potassium and lime interacted significantly to influence the K, Ca, Fe and Zn content of the soil (Table 5.12b). Increasing the K dose to 70 kg ha^{-1} significantly increased the available K content of the soil by 2.6 and 4.8 per cent respectively at L_1 and L_2. Maximum available K content was observed at K_3L_2 (194.69 kg ha^{-1}) and the minimum content was observed at K_1L_1 (189.73 kg ha^{-1}). An increase in the lime dose significantly increased the Ca content of the soil at K_1 and K_2 levels. K_3L_2 recorded significantly lower content of Ca compared to K_1L_2. The available Fe content of the soil showed a significant decrease with increasing levels of K and lime. An increase in the lime dose at K_2 and K_3 significantly decreased the Fe content by 12.4 and 7 per cent respectively.

4.2.4.4.1 Nutrient content of the soil at harvest at Koyalmannam

Effect of P, K, lime and controls on the nutrient status of soil at harvest stage is given in the table 5.13.

Table5.12a . Effect of P and K on nutrient content of soil at flowering stage (Ottappalam)

Treatment	Mg (cmol (+) kg^{-1})			Fe (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	0.15	0.14	0.14	679.24	630.19	631.23	3.81	3.97	4.52
P_2	0.15	0.15	0.15	654.42	697.12	602.01	3.20	3.38	3.34
CD(0.05)	0.003			43.04			0.32		

Table5.12 b Effect of K and lime on nutrient content of soil at flowering stage (Ottappalam)

Treatment	K (kg ha^{-1})		Ca (cmol (+) kg^{-1})		Fe (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
K_1	189.73	185.83	0.36	0.53	675.91	657.74
K_2	194.91	194.27	0.33	0.47	707.87	619.44
K_2	190.92	194.69	0.35	0.37	639.06	594.17
CD(0.05)	4.90		0.07		43.04	

Table 5.13. Nutrient content of soil at harvest (Koyalmannam)

Treatments	Available nutrients (kg ha^{-1})			Exchangeable nutrients cmol kg^{-1}		Available nutrients (kg ha^{-1})			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	184.56	18.22	207.03	0.35	0.14	493.26	26.11	1.74	0.81
P_2	190.90	21.38	209.33	0.35	0.13	440.90	24.42	1.55	1.03
CD(0.05)	NS	1.17	NS	NS	NS	30.77	1.60	NS	0.06
Levels of Potassium									
K_1	184.25	18.02	199.45	0.35	0.14	485.00	26.53	1.50	0.95
K_2	187.56	20.28	207.02	0.35	0.14	472.64	25.98	1.75	0.94
K_3	191.39	21.10	218.08	0.33	0.13	443.57	23.29	1.68	0.87
CD(0.05)	2.35	1.43	3.63	NS	NS	NS	2.07	NS	NS
Levels of Lime									
L_1	185.87	18.90	209.78	0.32	0.14	495.36	25.53	1.64	0.91
L_2	189.59	20.70	206.58	0.38	0.13	438.00	25.01	1.64	0.93
CD(0.05)	NS	1.17	2.96	0.02	NS	30.77	NS	NS	NS
Controls									
C_1	193.62	17.88	198.83	0.319	0.135	580.00	22.91	1.63	0.806
C_2	194.19	18.90	191.63	0.330	0.141	470.67	23.25	1.40	0.916
C_3	188.00	15.52	191.50	0.310	0.131	588.36	28.91	1.00	1.060
CD(0.05)	4.70	2.86	7.20	0.007	NS	75.38	4.10	NS	NS

Effect of P

Phosphorus application at 35 kg ha^{-1} significantly increased the P and Cu contents of the soil. But the Fe and Mn content of the soil decreased significantly by higher level of P application.

Effect of K

The N, P and K content of the soil showed an increase with increase in K application and the significant increase was observed only at K_3 to the tune of 3.8, 14 and 9.5 per cent respectively. The Mn content of the soil decreased by 12.9 per cent at K_3 compared to K_1.

Effect of lime

Application of lime at 600 kg ha^{-1} significantly increased the P and Ca content of the soil and decreased the K and Fe content of the soil.

Effect of controls

The POP recorded the highest content of N, P and Ca content of soil. Maximum K content was observed in C_1. Maximum content of Fe and Mn was present in C_3 (farmers practice). The minimum content Fe and Mn was present in C_2 and C_1 respectively.

4.2.4.4.2 Interaction effect on nutrient content of soil

Interaction between P and lime

Combined application of P and lime significantly influenced the Mg, Mn and Zn content of the soil (Table 5.14). A significant decrease in the Mg content was observed at P_2L_2 compared to other treatment combinations. Significant decrease in the Mn content was observed at higher level of P and lime. The zinc content of soil at harvest showed a significant decrease at higher level of lime application. Significant decrease in Zn content was observed at P_2L_1 compared to P_1L_1.

4.2.4.4.3 Nutrient content of soil at harvest at Ottappalam

Effect of P, K, lime and controls on the available nutrient content of soil at harvest is given in the table5.15

Effect of P

Phosphorus application at 35 kg ha^{-1} significantly increased the available P content of the soil and decreased the Ca content of the soil.

Effect of K

Higher levels of K application significantly increased the available N and K content of the soil. The Ca and Fe content of the soil showed a significant decrease at K_3 to the extent of 10 and 7 per cent respectively.

Effect of lime

Lime application at 600 kg ha^{-1} significantly increased the Ca content of the soil and decreased the Fe content of the soil.

Effect of controls

The C_3 registered the lowest content of N, P and Zn content. The maximum Fe content was observed in C_3 and the minimum in C_2 (POP).

4.2.4.4.4 Interaction effect on nutrient content of soil

Interaction between P and K

Available N content of the soil significantly increased at P_2K_3 compared to all other treatment combinations (Table5.16). The available Mn content of the soil at harvest registered the lowest value at P_2K_3 and it was significantly inferior to all other treatment combinations. Application of P at 35 kg ha^{-1} in the presence of 105 kg ha^{-1} of K significantly decreased the available Zn content of the soil compared to P_1K_2 andP_1K_3.

Table 5.14 Effect of P and lime on nutrient content of soil at harvest (Koyalmannam)

Treatment	Mg (cmol (+) kg^{-1})		Mn (kg ha^{-1})		Zn (kg ha^{-1})	
	L_1	L_2	L_1	L_2	L_1	L_2
P_1	0.14	0.14	28.16	26.07	1.91	1.57
P_2	0.14	0.13	24.89	23.94	1.37	1.42
CD(0.05)	0.006		2.3		0.32	

Table 5.16 Effect of P and K on nutrient content of soil at harvest (Ottappalam)

Treatment	N (kg ha^{-1})			Mn (kg ha^{-1})			Zn (kg ha^{-1})		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
P_1	240.31	241.91	243.86	23.89	27.20	26.20	2.72	3.52	4.02
P_2	238.64	243.39	250.03	26.53	26.04	21.90	2.79	2.61	2.87
CD(0.05)	5.5			3.5			0.37		

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Table 5.15 . Nutrient content of soil at harvest (Ottappalam)

Treatments	Available nutrients ($kg\ ha^{-1}$)			Exchangeable nutrients $cmol\ kg^{-1}$		Available nutrients ($kg\ ha^{-1}$)			
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Levels of Phosphorus									
P_1	242.08	20.88	187.65	0.40	0.12	630.59	25.76	3.42	0.91
P_2	244.02	21.74	188.71	0.38	0.12	647.20	24.82	2.76	1.03
CD(0.05)	NS	0.45	NS	0.02	NS	NS	NS	NS	NS
Levels of Potassium									
K_1	239.47	21.41	179.24	0.39	0.12	653.69	25.21	2.75	0.94
K_2	242.65	21.28	189.22	0.40	0.12	655.77	26.62	3.07	0.97
K_3	246.95	21.24	196.07	0.37	0.12	607.28	24.05	3.44	0.99
CD(0.05)	3.92	NS	5.40	0.02	NS	30.68	NS	NS	NS
Levels of Lime									
L_1	242.03	21.07	190.54	0.36	0.12	664.52	25.78	3.15	0.94
L_2	244.01	21.55	185.81	0.42	0.12	613.27	24.81	3.03	0.99
CD(0.05)	NS	NS	NS	0.02	NS	25.05	NS	NS	NS
Controls									
C_1	253.76	20.43	165.20	0.36	0.113	630.88	27.00	2.53	0.90
C_2	250.80	20.43	163.56	0.43	0.120	620.71	26.14	2.86	0.72
C_3	243.96	18.34	168.90	0.33	0.113	737.90	26.80	2.09	0.90
CD(0.05)	7.80	1.01	NS	NS	NS	61.37	NS	0.53	NS

4.2.4.5 Correlation studies

4.2.4.5.1 Correlation of nutrient ratios with yield

The correlation pattern of nutrient ratios in soil and plant at MT and PI stage with total yield was studied. The results showed that the N/K ratio of plant and soil at maximum tillering stage showed significant negative correlation with total yield at Koyalmannam (Table 6.1) where as the N/Fe and N/Mn ratio of plant showed significant positive correlation with total yield. The N/K ratio of the plant was negatively and significantly correlated with N/Ca, N/Mg and N/Fe. Significant positive correlation was observed between N/K ratio of plant and soil. Soil N/K ratio showed significant negative correlation with N/Fe and positive correlation with N/Zn ratio of the soil.

Among the P based ratios total dry matter yield was positively correlated with P/Ca, P/Mg, P/Fe, P/Mn and P/Zn ratios of the plant and soil (Table6.3). But it showed negative correlation with P/K ratio of the plant. P/K ratio of the plant showed negative correlation with P/Ca and P/Mn ratios of the plant and with P/Ca and P/Fe ratios of the soil.

The correlation pattern of K based nutrient ratios in soil and plant with yield was studied at MT and PI stage. The results showed that the total yield was significantly and positively correlated with all K based ratios of plant where as in the soil significant relation with yield was observed with only K/Mg and K/Mn ratios of soil (Table 6.4). The K/Ca and K/Mg ratios of plant showed significant positive correlation with K/Fe, K/Mn, K/Zn and K/Ca + Mg ratios of the plant. K/Ca, K/Mg and K/Fe ratios of the soil were significantly and positively correlated with K/(Ca + Mg) ratio of the soil.

At PI stage total yield was significantly and positively correlated with K/Ca, K/Fe, K/Mn, K/Zn and K/Ca + Mg ratios of both plant and soil (Table 6.5). The K/Ca ratio of plant was significantly and positively correlated with K/(Ca + Mg) ratio of both plant and soil but for K/Mg ratio significant relation was observed only with

Table 6.1 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield (Koyalmannam)

	plant							soil							
	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/ZN	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	-0.288	-0.399(**)	0.227	0.181	0.416(**)	0.486(**)	0.216	-0.577(**)	-0.421(**)	-0.150	0.232	0.138	0.188	-0.078
N/P	-0.288	1.000	0.265	0.219	-0.139	0.234	0.167	0.203	0.161	0.367(*)	0.049	0.156	-0.257	0.065	0.128
N/K	-0.399(**)	0.265	1.000	-0.379(*)	-0.611(**)	-0.468(**)	-0.045	-0.012	0.320(*)	0.454(**)	-0.352(*)	-0.047	-0.238	-0.084	0.207
N/Ca	0.227	0.219	-0.379(*)	1.000	0.157	-0.045	0.205	0.070	-0.165	-0.217	0.485(**)	-0.404(**)	-0.113	0.209	-0.074
N/Mg	0.181	-0.139	-0.611(**)	0.157	1.000	0.117	0.193	0.231	0.153	-0.431(**)	-0.092	0.160	0.319(*)	0.144	-0.124
N/Fe	0.416(**)	0.234	-0.468(**)	-0.045	0.117	1.000	0.607(**)	0.672(**)	-0.129	0.036	-0.304(*)	-0.283	0.076	-0.006	-0.183
N/Mn	0.486(**)	0.167	-0.045	0.205	0.193	0.607(**)	1.000	0.474(**)	-0.410(**)	-0.288	-0.166	-0.040	0.201	0.146	-0.103
N/Zn	0.216	0.203	-0.012	0.070	0.231	0.672(**)	0.474(**)	1.000	-0.002	0.209	-0.181	-0.135	-0.120	0.033	0.083
N/P	-0.577(**)	0.161	0.320(*)	-0.165	0.153	-0.129	-0.410(**)	-0.002	1.000	0.674(**)	0.185	0.175	-0.221	-0.214	0.063
N/K	-0.421(**)	0.367(*)	0.454(**)	-0.217	-0.431(**)	0.036	-0.288	0.209	0.674(**)	1.000	-0.132	0.108	-0.384(**)	-0.015	0.417(**)
N/Ca	-0.150	0.049	-0.352(*)	0.485(**)	-0.092	-0.304(*)	-0.166	-0.181	0.185	-0.132	1.000	-0.060	-0.072	-0.156	0.007
N/Mg	0.232	0.156	-0.047	-0.404(**)	0.160	-0.283	-0.040	-0.135	0.175	0.108	-0.060	1.000	0.100	0.162	0.249
N/Fe	0.138	-0.257	-0.238	-0.113	0.219	0.076	0.201	-0.120	-0.221	-0.384(**)	-0.072	0.100	1.000	-0.099	-0.151
N/Mn	0.188	0.065	-0.084	0.209	0.144	-0.006	0.146	0.033	-0.214	-0.015	-0.156	0.162	-0.099	1.000	0.164
N/Zn	-0.078	0.328(*)	0.207	-0.074	-0.124	-0.183	-0.103	0.083	0.063	0.417(**)	0.007	0.249	-0.151	0.164	1.000

Table 6.2 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield (Koyalmannam)

	plant							soil							
	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/ZN	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	0.361(*)	0.120	0.428(**)	-0.012	0.509(**)	0.542(**)	0.526(**)	-0.418(**)	-0.492(**)	-0.094	0.069	0.489(**)	0.301(*)	0.185
N/P	0.361(*)	1.000	0.017	0.442(**)	-0.105	0.275	0.448(**)	0.256	-0.129	-0.379(*)	0.038	-0.135	-0.057	0.047	-0.060
N/K	0.120	0.017	1.000	-0.199	0.574(**)	0.487(**)	0.304(*)	-0.125	-0.167	-0.325(*)	-0.329(*)	0.484(**)	0.413(**)	0.280	0.017
N/Ca	0.428(**)	0.442(**)	-0.199	1.000	-0.070	0.108	0.418(**)	0.344(*)	0.003	-0.455(**)	0.341(*)	-0.362(*)	0.217	-0.270	-0.017
N/Mg	-0.012	-0.105	0.574(**)	-0.070	1.000	0.498(**)	0.318(*)	-0.307(*)	0.104	-0.087	0.127	0.638(**)	0.358(*)	0.257	0.166
N/Fe	0.509(**)	0.275	0.487(**)	0.108	0.498(**)	1.000	0.820(**)	0.127	-0.401(**)	-0.562(**)	-0.207	0.670(**)	0.622(**)	0.491(**)	0.116
N/Mn	0.542(**)	0.448(**)	0.304(*)	0.418(**)	0.318(*)	0.820(**)	1.000	0.374(*)	-0.490(**)	-0.533(**)	-0.291	0.452(**)	0.649(**)	0.259	0.160
N/Zn	0.526(**)	0.256	-0.125	0.344(*)	-0.307(*)	0.127	0.374(*)	1.000	-0.392(**)	-0.051	-0.212	-0.135	0.167	0.107	0.284
N/P	-0.418(**)	-0.129	-0.167	0.003	0.104	-0.401(**)	-0.490(**)	-0.392(**)	1.000	0.337(*)	0.336(*)	-0.217	-0.444(**)	-0.392(**)	-0.085
N/K	-0.492(**)	-0.379(*)	-0.325(*)	-0.455(**)	-0.087	-0.562(**)	-0.533(**)	-0.051	0.337(*)	1.000	-0.126	-0.148	-0.486(**)	-0.130	0.166
N/Ca	-0.094	0.038	-0.329(*)	0.341(*)	0.127	-0.207	-0.291	-0.212	0.336(*)	-0.126	1.000	-0.124	-0.258	-0.110	-0.163
N/Mg	0.069	-0.135	0.484(**)	-0.362(*)	0.638(**)	0.670(**)	0.452(**)	-0.135	-0.217	-0.148	-0.124	1.000	0.487(**)	0.388(**)	0.073
N/Fe	0.489(**)	-0.057	0.413(**)	0.217	0.358(*)	0.622(**)	0.649(**)	0.167	-0.444(**)	-0.486(**)	-0.258	0.487(**)	1.000	0.205	0.147
N/Mn	0.301(*)	0.047	0.280	-0.270	0.257	0.491(**)	0.259	0.107	-0.392(**)	-0.130	-0.110	0.388(**)	0.205	1.000	0.004
N/Zn	0.185	-0.060	0.017	-0.017	0.166	0.116	0.160	0.284	-0.085	0.166	-0.163	0.073	0.147	0.004	1.000

Table 6.3 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield (Koyalmannam)

	plant							soil					
	Total Yield	**P/K**	**P/Ca**	**P/Mg**	**P/Fe**	**P/Mn**	**P/Zn**	**P/K**	**P/Ca**	**P/Mg**	**P/Fe**	**P/Mn**	**P/Zn**
Total Yield	1.000	-0.220	0.292	0.596(**)	0.604(**)	0.288	0.332(*)	0.459(**)	0.077	0.490(**)	0.473(**)	0.474(**)	0.123
P/K	-0.220	1.000	-0.453(**)	-0.134	-0.240	-0.460(**)	-0.126	-0.114	-0.483(**)	-0.072	-0.320(*)	-0.240	0.028
P/Ca	0.292	-0.453(**)	1.000	0.143	-0.136	0.152	-0.018	0.085	0.573(**)	-0.222	0.150	0.288	-0.094
P/Mg	0.596(**)	-0.134	0.143	1.000	0.307(*)	0.168	0.187	0.271	0.111	0.547(**)	0.269	0.341(*)	-0.087
P/Fe	0.604(**)	-0.240	-0.136	0.307(*)	1.000	0.528(**)	0.624(**)	0.152	-0.278	-0.081	0.218	0.068	-0.258
P/Mn	0.288	-0.460(**)	0.152	0.168	0.528(**)	1.000	0.352(*)	0.257	0.013	0.212	0.532(**)	0.334(*)	-0.132
P/Zn	0.332(*)	-0.126	-0.018	0.187	0.624(**)	0.352(*)	1.000	0.178	-0.196	-0.003	0.028	0.059	-0.014
P/K	0.459(**)	-0.114	0.085	0.271	0.152	0.257	0.178	1.000	-0.003	0.227	0.523(**)	0.679(**)	0.178
P/Ca	0.077	-0.483(**)	0.573(**)	0.111	-0.278	0.013	-0.196	-0.003	1.000	-0.033	0.186	0.112	-0.076
P/Mg	0.490(**)	-0.072	-0.222	0.547(**)	-0.081	0.212	-0.003	0.227	-0.033	1.000	0.277	-0.005	0.242
P/Fe	0.473(**)	-0.320(*)	0.150	0.269	0.218	0.532(**)	0.028	0.523(**)	0.186	0.277	1.000	0.533(**)	-0.033
P/Mn	0.474(**)	-0.240	0.288	0.341(*)	0.068	0.334(*)	0.059	0.679(**)	0.112	-0.005	0.533(**)	1.000	0.171
P/Zn	0.123	0.028	-0.094	-0.087	-0.258	-0.132	-0.014	0.178	-0.076	0.242	-0.033	0.171	1.000

Table 6.4 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield (Koyalmannam)

	plant							soil					
	Total yield	**K/Ca**	**K/Mg**	**K/Fe**	**K/Mn**	**K/Zn**	**K/Ca +Mg**	**K/Ca**	**K/Mg**	**K/Fe**	**K/Mn**	**K/Zn**	**K/Ca +Mg**
Total yield	1.000	0.367(*)	0.289	0.374(*)	0.471(**)	0.415(**)	0.496(**)	-0.046	0.339(*)	0.279	0.346(*)	-0.003	0.242
K/Ca	0.367(*)	1.000	0.708(**)	0.608(**)	0.739(**)	0.609(**)	0.832(**)	0.536(**)	-0.203	0.262	0.361(*)	-0.128	0.417(**)
K/Mg	0.289	0.708(**)	1.000	0.828(**)	0.972(**)	0.763(**)	0.977(**)	0.274	0.186	0.478(**)	0.313(*)	-0.151	0.445(**)
K/Fe	0.374(*)	0.608(**)	0.828(**)	1.000	0.889(**)	0.874(**)	0.828(**)	0.094	-0.101	0.330(*)	0.200	-0.229	0.139
K/Mn	0.471(**)	0.739(**)	0.972(**)	0.889(**)	1.000	0.815(**)	0.971(**)	0.254	0.097	0.437(**)	0.307(*)	-0.163	0.377(*)
K/Zn	0.415(**)	0.609(**)	0.763(**)	0.874(**)	0.815(**)	1.000	0.775(**)	0.108	-0.074	0.169	0.163	-0.089	0.126
K/Ca +Mg	0.496(**)	0.832(**)	0.977(**)	0.828(**)	0.971(**)	0.775(**)	1.000	0.369(*)	0.080	0.447(**)	0.350(*)	-0.159	0.463(**)
K/Ca	-0.046	0.536(**)	0.274	0.094	0.254	0.108	0.369(*)	1.000	0.013	0.197	0.055	-0.055	0.838(**)
K/Mg	0.339(*)	-0.203	0.186	-0.101	0.097	-0.074	0.080	0.013	1.000	0.199	-0.257	0.162	0.502(**)
K/Fe	0.279	0.262	0.478(**)	0.330(*)	0.437(**)	0.169	0.447(**)	0.197	0.199	1.000	0.259	-0.192	0.420(**)
K/Mn	0.346(*)	0.361(*)	0.313(*)	0.200	0.307(*)	0.163	0.350(*)	0.055	-0.257	0.259	1.000	0.032	0.029
K/Zn	-0.003	-0.128	-0.151	-0.229	-0.163	-0.089	-0.159	-0.055	0.162	-0.192	0.032	1.000	-0.008

Table 6.5 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield (Koyalmannam)

	plant							soil					
	Total yield	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg
Total yield	1.000	0.333(*)	-0.071	0.493(**)	0.380(**)	0.395(**)	0.285	0.104	0.230	0.558(**)	0.477(**)	0.481(**)	0.427(**)
K/Ca	0.333(*)	1.000	-0.038	0.266	0.648(**)	0.536(**)	0.774(**)	0.470(**)	0.047	0.189	-0.083	0.191	0.452(**)
K/Mg	-0.071	-0.038	1.000	0.283	0.083	-0.303(*)	0.489(**)	0.244	0.209	0.143	0.131	0.137	0.167
K/Fe	0.493(**)	0.266	0.283	1.000	0.748(**)	0.240	0.609(**)	0.140	0.541(**)	0.490(**)	0.518(**)	0.387(**)	0.343(*)
K/Mn	0.380(**)	0.648(**)	0.083	0.748(**)	1.000	0.595(**)	0.800(**)	0.090	0.193	0.269	0.134	0.258	0.215
K/Zn	0.395(**)	0.536(**)	-0.303(*)	0.240	0.595(**)	1.000	0.404(**)	-0.057	-0.226	-0.077	-0.082	0.150	0.020
K/Ca +Mg	0.285	0.774(**)	0.489(**)	0.609(**)	0.800(**)	0.404(**)	1.000	0.445(**)	0.170	0.213	0.061	0.259	0.398(**)
K/Ca	0.104	0.470(**)	0.244	0.140	0.090	-0.057	0.445(**)	1.000	0.415(**)	0.231	0.226	0.164	0.723(**)
K/Mg	0.230	0.047	0.209	0.541(**)	0.193	-0.226	0.170	0.415(**)	1.000	0.847(**)	0.666(**)	0.517(**)	0.716(**)
K/Fe	0.558(**)	0.189	0.143	0.490(**)	0.269	-0.077	0.213	0.231	0.847(**)	1.000	0.549(**)	0.558(**)	0.723(**)
K/Mn	0.477(**)	-0.083	0.131	0.518(**)	0.134	-0.082	0.061	0.226	0.666(**)	0.549(**)	1.000	0.331(*)	0.450(**)
K/Zn	0.481(**)	0.191	0.137	0.387(**)	0.258	0.150	0.259	0.164	0.517(**)	0.558(**)	0.331(*)	1.000	0.464(**)
K/Ca +Mg	0.427(**)	0.452(**)	0.167	0.343(*)	0.215	0.020	0.398(**)	0.723(**)	0.716(**)	0.723(**)	0.450(**)	0.464(**)	1.000

plant. The K/Fe ratio of the plant was significantly and positively correlated with K/(Ca + Mg) ratio of both plant and soil. However the K/Mn and K/Zn ratio of the plant was significantly and positively correlated with K/Ca + Mg ratio of only plant. The K/Ca K/Mg, K/Fe and K/Mn ratios of soil showed significant and positive correlation with K/(Ca + Mg) ratio of the soil.

A review of the correlation studies at Ottappalam showed that total yield was positively correlated with N/Mg, N/Fe and N/Mn ratios of the plant (Table 6.6). N/P ratio of the plant showed significant positive correlation with N/K ratio of plant at MT stage. Similarly N/Fe was positively correlated with N/Ca and N/Mg ratios of the plant.

At panicle initiation stage yield was positively correlated with N/Fe and N/Mn ratios of the plant and negatively correlated with N/P and N/Zn ratios of the plant (Table 6.7). The N/P ratio showed significant positive correlation with N/K and N/Ca ratios of the plant.

Among the P based ratios P/Fe and P/Mn were positively correlated with total yield (Table 6.9). At PI stage yield was positively correlated with P/Ca, P/Fe and P/Mn ratios of the plant. P/K ratio of the plant showed significant positive correlation with P/Fe, P/Mn and P/Zn of the plant.

Significant positive correlation of total yield with K/Fe, K/Mn and K/Ca + Mg ratios of the plant and soil was observed at MT stage (Table 6.10). Similarly K/Ca ratio of the plant showed significant positive correlation with K/Fe and K/Ca + Mg ratios of the plant. K/Mg ratio also showed significant positive correlation with K/Ca + Mg ratio. K/Fe showed significant positive correlation with K/Ca + Mg ratios of the plant. K/Ca + Mg ratio of the soil was significantly and positively correlated with the same ratio of the plant. K/Ca of the soil showed significant positive correlation with K/Mg of the soil. In the soil also K/Mg showed significant positive correlation with K/Ca + Mg. K/Fe of the soil showed significant positive correlation with K/Fe and K/Mn of the plant.

Table 6.6 Correlation coefficient of nutrient ratios of plant at MT stage with **yield** (Ottappalam)

	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	-0.136	0.028	0.231	0.308(*)	0.369(*)	0.457(**)	-0.260
N/P	-0.136	1.000	0.322(*)	0.094	0.035	0.231	0.036	0.187
N/K	0.028	0.322(*)	1.000	0.033	0.218	0.246	0.209	0.250
N/Ca	0.231	0.094	0.033	1.000	0.136	0.356(*)	0.069	-0.133
N/Mg	0.308(*)	0.035	0.218	0.136	1.000	0.323(*)	0.036	0.214
N/Fe	0.369(*)	0.231	0.246	0.356(*)	0.323(*)	1.000	0.373(*)	0.123
N/Mn	0.457(**)	0.036	0.209	0.069	0.036	0.373(*)	1.000	-0.083
N/Zn	-0.260	0.187	0.250	-0.133	0.214	0.123	-0.083	1.000

Table 6.7 Correlation coefficient of nutrient ratios of plant at PI stage with yield (Ottappalam)

	Total yield	N/P	N/K	N/Ca	N/Mg	N/Fe	N/Mn	N/Zn
Total yield	1.000	-0.346(*)	-0.152	0.168	0.065	0.299(*)	0.294(*)	-0.298(*)
N/P	-0.346(*)	1.000	0.366(*)	0.336(*)	-0.177	0.286	0.296	0.264
N/K	-0.152	0.366(*)	1.000	-0.101	0.243	0.284	0.212	0.558(**)
N/Ca	0.168	0.336(*)	-0.101	1.000	-0.192	0.049	0.589(**)	-0.049
N/Mg	0.065	-0.177	0.243	-0.192	1.000	-0.058	-0.249	0.066
N/Fe	0.299(*)	0.286	0.284	0.049	-0.058	1.000	0.605(**)	0.168
N/Mn	0.294(*)	0.296	0.212	0.589(**)	-0.249	0.605(**)	1.000	-0.102
N/Zn	-0.298(*)	0.264	0.558(**)	-0.049	0.066	0.168	-0.102	1.000

Table 6.8 Correlation coefficient of nutrient ratios of plant at **MT** stage with yield (Ottappalam)

	Total Yield	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn
Total Yield	1.000	0.153	0.272	0.217	0.451(**)	0.483(**)	-0.204
P/K	0.153	1.000	0.023	0.162	0.596(**)	0.666(**)	0.359(*)
P/Ca	0.272	0.023	1.000	0.132	0.336(*)	0.086	-0.207
P/Mg	0.217	0.162	0.132	1.000	0.318(*)	0.016	0.194
P/Fe	0.451(**)	0.596(**)	0.336(*)	0.318(*)	1.000	0.418(**)	0.039
P/Mn	0.483(**)	0.666(**)	0.086	0.016	0.418(**)	1.000	-0.023
P/Zn	-0.204	0.359(*)	-0.207	0.194	0.039	-0.023	1.000

Table 6.9 Correlation coefficient of nutrient ratios of plant at **PI** stage with yield (Ottappalam)

	Total Yield	P/K	P/Ca	P/Mg	P/Fe	P/Mn	P/Zn
Total Yield	1.000	0.290	0.439(**)	0.179	0.600(**)	0.646(**)	0.092
P/K	0.290	1.000	-0.181	0.411(**)	0.575(**)	0.429(**)	0.548(**)
P/Ca	0.439(**)	-0.181	1.000	-0.108	0.047	0.549(**)	-0.174
P/Mg	0.179	0.411(**)	-0.108	1.000	0.141	-0.002	0.217
P/Fe	0.600(**)	0.575(**)	0.047	0.141	1.000	0.679(**)	0.244
P/Mn	0.646(**)	0.429(**)	0.549(**)	-0.002	0.679(**)	1.000	-0.002
P/Zn	0.092	0.548(**)	-0.174	0.217	0.244	-0.002	1.000

Table 6.10 Correlation coefficient of nutrient ratios of soil and plant at MT stage with yield (Ottappalam)

	plant							soil					
	Total yield	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg
Total yield	1.000	0.221	0.311(*)	0.457(**)	0.519(**)	-0.309(*)	0.391(**)	0.054	0.033	0.603(**)	0.359(*)	-0.397(**)	0.185
K/Ca	0.221	1.000	0.108	0.373(*)	0.092	-0.163	0.667(**)	0.331(*)	0.356(*)	-0.016	-0.120	-0.043	0.287
K/Mg	0.311(*)	0.108	1.000	0.272	-0.119	0.107	0.653(**)	0.121	0.142	0.031	-0.103	-0.046	0.163
K/Fe	0.457(**)	0.373(*)	0.272	1.000	0.031	-0.237	0.449(**)	0.118	0.045	0.411(**)	0.075	-0.119	0.175
K/Mn	0.519(**)	0.092	-0.119	0.031	1.000	-0.381(**)	0.003	0.028	-0.038	0.513(**)	0.601(**)	-0.199	0.158
K/Zn	-0.309(*)	-0.163	0.107	-0.237	-0.381(**)	1.000	-0.278	0.071	-0.344(*)	-0.389(**)	-0.286	0.487(**)	-0.161
K/Ca +Mg	0.391(**)	0.667(**)	0.653(**)	0.449(**)	0.003	-0.278	1.000	0.300(*)	0.638(**)	0.099	-0.106	-0.218	0.459(**)
K/Ca	0.054	0.331(*)	0.121	0.118	0.028	0.071	0.300(*)	1.000	0.433(**)	-0.074	0.097	0.150	0.852(**)
K/Mg	0.033	0.356(*)	0.142	0.045	-0.038	-0.344(*)	0.638(**)	0.433(**)	1.000	-0.023	-0.018	-0.221	0.721(**)
K/Fe	0.603(**)	-0.016	0.031	0.411(**)	0.513(**)	-0.389(**)	0.099	-0.074	-0.023	1.000	0.602(**)	-0.213	0.190
K/Mn	0.359(*)	-0.120	-0.103	0.075	0.601(**)	-0.286	-0.106	0.097	-0.018	0.602(**)	1.000	-0.191	0.318(*)
K/Zn	-0.397(**)	-0.043	-0.046	-0.119	-0.199	0.487(**)	-0.218	0.150	-0.221	-0.213	-0.191	1.000	-0.013
K/Ca +Mg	0.185	0.287	0.163	0.175	0.158	-0.161	0.459(**)	0.852(**)	0.721(**)	0.190	0.318(*)	-0.013	1.000

Table 6.11 Correlation coefficient of nutrient ratios of soil and plant at PI stage with yield (Ottappalam)

	plant							soil					
	Total yield	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg	K/Ca	K/Mg	K/Fe	K/Mn	K/Zn	K/Ca +Mg
Total yield	1.000	-0.248	-0.020	0.097	0.239	0.089	-0.045	-0.103	0.229	-0.034	0.287	-0.130	0.039
K/Ca	-0.248	1.000	0.562(**)	0.202	0.212	0.132	0.790(**)	0.213	0.165	-0.071	-0.081	-0.072	0.188
K/Mg	-0.020	0.562(**)	1.000	0.441(**)	0.140	-0.182	0.925(**)	0.088	0.504(**)	-0.158	-0.126	-0.078	0.074
K/Fe	0.097	0.202	0.441(**)	1.000	0.252	-0.002	0.491(**)	0.233	0.205	0.019	0.141	-0.018	0.299(*)
K/Mn	0.239	0.212	0.140	0.252	1.000	0.271	0.284	0.386(**)	0.206	0.153	0.210	0.010	0.503(**)
K/Zn	0.089	0.132	-0.182	-0.002	0.271	1.000	0.014	0.005	-0.038	0.014	0.121	-0.005	0.031
K/Ca +Mg	-0.045	0.790(**)	0.925(**)	0.491(**)	0.284	0.014	1.000	0.204	0.461(**)	-0.089	-0.051	-0.095	0.213
K/Ca	-0.103	0.213	0.088	0.233	0.386(**)	0.005	0.204	1.000	-0.046	0.082	-0.035	-0.189	0.930(**)
K/Mg	0.229	0.165	0.504(**)	0.205	0.206	-0.038	0.461(**)	-0.046	1.000	0.075	0.130	0.118	0.135
K/Fe	-0.034	-0.071	-0.158	0.019	0.153	0.014	-0.089	0.082	0.075	1.000	0.483(**)	0.610(**)	0.278
K/Mn	0.287	-0.081	-0.126	0.141	0.210	0.121	-0.051	-0.035	0.130	0.483(**)	1.000	0.309(*)	0.231
K/Zn	-0.130	-0.072	-0.078	-0.018	0.010	-0.005	-0.095	-0.189	0.118	0.610(**)	0.309(*)	1.000	0.011
K/Ca +Mg	0.039	0.188	0.074	0.299(*)	0.503(**)	0.031	0.213	0.930(**)	0.135	0.278	0.231	0.011	1.000

Table 6.12 Correlation coefficient of nutrient ratios of rice with yield (Koyalmannam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	0.470(**)	0.126	K/Ca	0.128	0.418(**)
K/Mg	0.279	0.279	K/Mg	0.102	-0.249
K/Fe	0.298(*)	0.278	K/Fe	0.393(*)	0.427(**)
K/Mn	0.440(**)	0.265	K/Mn	0.173	0.443(**)
K/Zn	0.343(*)	0.288	K/Zn	0.057	0.614(**)
K/Ca+Mg	0.486(**)	0.254	K/Ca+Mg	0.169	0.284

Table 6.13 Correlation coefficient of nutrient ratios of soil with yield (Koyalmannam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	0.109	-0.215	K/Ca	0.206	-0.077
K/Mg	0.172	0.374(*)	K/Mg	0.492(**)	0.132
K/Fe	0.349(*)	0.000	K/Fe	0.529(**)	0.309(*)
K/Mn	0.400(**)	0.101	K/Mn	0.442(**)	0.279
K/Zn	-0.091	0.108	K/Zn	0.353(*)	0.394(*)
K/Ca+Mg	0.289	0.059	K/Ca+Mg	0.406(**)	0.235

Table 6.14 Correlation coefficient of nutrient ratios of rice with yield (Ottappalam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	0.231	0.139	K/Ca	0.178	0.181
K/Mg	0.145	0.354(*)	K/Mg	0.098	0.105
K/Fe	0.421(**)	0.337(*)	K/Fe	0.478(**)	0.284
K/Mn	0.482	0.380(*)	K/Mn	0.393(*)	0.245
K/Zn	-0.384(*)	-0.141	K/Zn	-0.210	-0.116
K/Ca+Mg	0.276	0.363(*)	K/Ca+Mg	0.231	0.251

Table 6.15 Correlation coefficient of nutrient ratios of soil with yield (Ottappalam)

MT stage	grainYield	Strawyield	PI stage	grainYield	Strawyield
K/Ca	-0.063	0.139	K/Ca	0.043	0.328(*)
K/Mg	-0.015	0.064	K/Mg	0.371(*)	0.422(**)
K/Fe	0.434(**)	0.554(**)	K/Fe	0.521(**)	0.430(**)
K/Mn	0.222	0.367(*)	K/Mn	-0.162	0.450(**)
K/Zn	-0.428(**)	-0.238	K/Zn	-0.055	-0.055
K/Ca+Mg	-0.015	0.300(*)	K/Ca+Mg	0.288	0.489(**)

4.2.4.5.2 Correlation studies of K based nutrient ratios with grain and straw yield

Grain yield was significantly and positively correlated with K/Ca and K/(Ca + Mg) ratio of the plant at maximum tillering stage (Table 6.12). At PI stage the nutrient ratios K/Fe and K/Mn showed significant positive correlation with grain and straw yield where as the K/Ca was significantly and positively correlated only with grain yield. A study of the above ratios of soil showed that at MT and PI stage, K/Fe ratio was significantly and positively correlated with grain yield. The K/Ca + Mg ratio of the soil at PI stage was significantly and positively correlated with grain yield.

At Ottappalam both grain and straw yield were significantly and positively correlated with K/Fe and K/Mn ratios of the plant at MT stage (Table 6.14). The straw yield was positively correlated with K/Ca + Mg of the plant. However at PI stage the K/Fe and K/Mn ratios of the plant were significantly and positively correlated only with grain yield.

K/Fe ratio of soil showed significant positive correlation with straw and grain yield (Table 6.15). The straw yield was significantly and positively correlated with K/Ca, K/Mg, K/Fe, K/Mn and K/Ca + Mg ratio of the soil at PI stage.

Discussion

5. DISCUSSION

The project entitled "Critical analysis of the soil plant atmosphere continuum for increasing the productivity of rice in lateritic soil" was carried out during 1999-2001 at two locations in Palakkad district, Ottappalam and Koyalmannam. The experiment in the project, aimed to identify the yield limiting factors and measures to overcome them, have evaluated the influence of P, K and Ca in correcting nutrient deficiencies and toxicities at Ottappalam and Koyalmannam. A general discussion summing up the results of the experiment is included.

5.1 First crop of rice

5.1.1 Yield and Yield attributes of rice

A review of the influence of P, K and lime on growth and yield of rice crop have shown that phosphorus application at higher level could not significantly influence the yield and yield attributes in rice at both locations (table 8 and table 11). Phosphorus from native source itself is generally considered adequate to meet the P requirement of rice crop grown under submerged conditions. However response to K was noted for the yield and growth attributes. Potassium at 70 kg ha^{-1} showed significant increase in the number of productive tillers per hill. Response of K to rice plant height and tillers was observed by Venkatasubbiah *et al.* (1982). Higher level of K at 70 kg ha^{-1} significantly increased both grain and straw yield at Koyalmannam (Fig 5). Similar results of increased grain and straw yield with increased K rates in lateritic soils were reported by Gurumani *et al.* (1984) and Gosh *et al.* (1994). Yield response of K up to 80 kg ha^{-1} was observed by Agarwal (1980). However Bridgit *et al.* (1999) have reported a yield increase up to 120 kg ha^{-1} of K application. A positive significant response to lime at 600 kg ha^{-1} was also obtained for yield and yield attributes in rice at both locations. Significant increase in the grain yield was observed at both locations with lime while positive response of straw yield to lime was observed

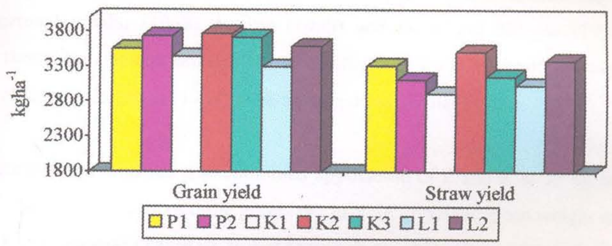

Fig. 5. Grain and straw yield at Koyalmannam

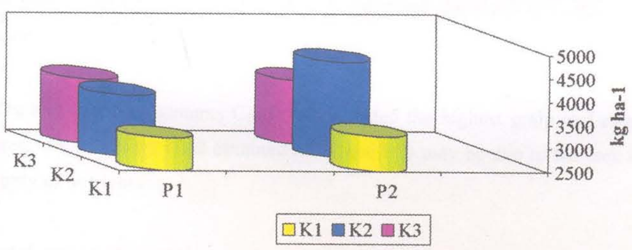

Fig. 6. Effect of P and K on straw yield Ottappalam

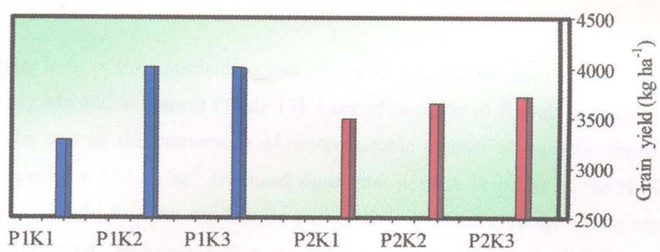

Fig. 7. Effect of P and K on grain yield of rice Ottappalam

only at Koyalmannam. Such favourable effects of lime on yield and yield attributes of rice was reported by Sahu (1968), Laskar (1990) and Dixit and Sharma (1993). According to them lime application rectified the illeffects of Fe and Al and increased the yield. Padmaja and Varghese (1972) have also reported similar results.

Interaction effects showed that combined application of P and K at 35 kg ha^{-1} and 70 kg ha^{-1} respectively increased the grains per panicle, thousand grain weight and grain yield at Koyalmannam (Table 9). But at Ottappalam application of 70 kg ha^{-1} of K with 17.5 kg ha^{-1} of P significantly increased the grain yield (Fig 7). However P at 35 kg ha^{-1} showed significant increase in straw yield (Fig 6). The grain yield obtained by the combined application of P and K was superior to POP. Singh *et al.* (1989) found that increasing rates of N, P and K increased the yield and uptake of nutrients in rice.

Among the control treatments C_2 (POP) recorded the highest grain and straw yield compared to C_3. Lowest yield obtained in C_3 and this may be due to the lack of sufficient supply of nutrients.

5.1.2 Elemental composition of rice

The results on elemental composition of plant at various critical stages are discussed hereunder. Nutrient content of plant showed varied response to different levels of P, K and lime.

Higher level of P on nutrient content of rice showed that it could significantly influence only Mn and Si content (Table 13). Lack of response of P applied at higher level may be due to the conversion of water soluble P into unavailable forms. Potassium applied at 105 kg ha^{-1} produced significant positive response on the N, K and Zn content while the lime application positively influenced only the N and Mg content of the plant. However higher level of K and lime applied significantly decreased the Mn and Fe content respectively. Lime application is reported to have reduced the Fe and Al toxicity problems (Sahu, 1968).

Interaction between P and K showed that N, P and Zn content of the plant increased by the combined application (Table 14). The Zn content increased with increase in K level at lower level of P. But at higher level the increase was observed only at K_3. This may be due to the antagonistic effect of P and Zn.

At Ottappalam nutrient content of rice as influenced by various levels of P, K and lime showed that N, Mg and Cu content of the plant increased by P application at 35 kg ha^{-1}(Table15). Alan and Azmi (1989) made similar reports of increased nutrient at higher level of P application. Potassium application at higher level significantly decreased the Ca content while lime application at higher level increased N, P, Ca and Mg content of the plant. Reddy *et al.* (1978) reported a significant decrease in the Ca and Mg content in plants with increasing K levels. A significant increase in the K and Ca was observed by the combined application of P and K (Table 16). Synergism between K and P was reported by Lahar (1972) and Mellow and Kaminski (1990). Datta and Gomez (1982) confirmed that response to P was more when applied with potassium. From the response to P and K applied together it was also observed that application of K at the highest level i.e. 105 kg ha^{-1} decreased the Ca content. Similar antagonistic relation between K and Ca and between K and Mg were reported by Barber (1986) and Sindhu (2001).

Among the control treatments C_2 recorded the maximum N, Ca and Mg and farmer's practice recorded the lowest value for the above nutrients. Here the farmer applies only nitrogenous fertilizers and no source of P and K (Table 13). The low content of plant nutrients may be due to the insufficient supply of P and K containing fertilizers.

At panicle initiation stage at Koyalmannam a decrease in the Fe, Zn and Si was observed at higher level of P application (Table 17). Potassium application at higher level increased the N, K and Zn content of the plant and decreased the Ca, Fe and Mn content. Rajdhar (1989) reported that increasing K concentration increased N, P, K contents but decreased the Ca and Mg contents. Singh (1987) reported the antagonistic effects of K and Fe. Lime application at higher level increased the N, Ca and decreased the K and Fe content of plant. Interaction between P and K indicated that at lower level of P the increase in K dose decreased the Ca content but at higher level of P the decreasing trend was not observed (Table 18a). Combined application of P and K decreased the Fe content of the plant. It has been observed that 70 kg ha^{-1} of K along with recommended dose of 600 kg ha^{-1} of lime and 35 kg ha^{-1} of P significantly decreased the Fe content of the plant. Datta and Gomez (1982) reported that response to P was more when K was applied.

A perusal of the data at Ottappalam depicts some what similar pattern of variations in the nutrient content. Phosphorus application at higher level showed a decrease in Fe content (Table 20). Rosmini and Mukhlis (1989) have reported that increased levels of P could offset Fe toxicity and increase yield. A significant decrease in Ca, Mg, Fe and increase in P content was observed at highest level of K application. Alvarenga and Lopa (1988) have reported that increasing K dose increased the N, P, K and decreased Ca and Mg content of plant. Lime application at 600 kg ha^{-1} significantly increased N, P and Ca content and decreased Fe content of the plant. Lime is a key factor in deciding the pH and thereby the availability of other nutrients. Devi *et al.* (1996) reported similar results of reduced Fe concentration in soil as well as plant at panicle initiation stage, when the lime was applied at 600 kg ha^{-1}. Tripati (1987) reported a decrease in Fe concentration with lime application. Similarly higher level of K and lime increased N and K content of plant (Table 21b) while Mn and Fe content showed a decrease (Fig 11and Fig 12). But with increase in K dose the Ca and Mg content of plant decreased at both levels of lime application. Chakravorti (1989) observed a similar decrease in Ca and Mg content with increase in K dose. Combined application of P at 35 kg ha^{-1} with 70 kg ha^{-1} of K and 300 kg ha^{-1} of lime significantly decreased the Fe and Mn content (Table 22). $P_2K_2L_1$ was inferior to POP for the Fe content. Singh and Singh (1987) have reported K-Fe antagonism in rice plant. Similarly a decrease in Fe and Mn content with increase in K dose was observed by

Dixit and Sharma (1993). Significant decrease in the Fe content with liming in the presence of P was reported by Mandal (1988).

Both Koyalmannam and Ottappalam location showed a decrease in Fe and Zn content with increase in P application. According to Gupta and Singh (1989) higher level of P application could decrease the toxic effects of Fe. Alan and Azmi (1989) also made similar reports. Sindhu (2001) reported a decrease in Zn content of rice plant with increase in P dose. Potassium application at 70 kg ha^{-1} at Ottappalam significantly increased the P and Mg content and decreased the Ca content of the plant at flowering stage. (Table 25). The Fe content of the plant increased at K_2 while the Mn content decreased at K_2 level. This may be due to the antagonistic effect of Fe and Mn. However at K_3 level the Fe recorded the lowest content and Cu content significantly increased at this level. Singh (1987) reported that increasing level of K significantly increased N, P, K and Mg content while the Fe and Mn decreased with increase in K dose in rice.

Lime application at 600 kg ha^{-1} significantly increased the N, P, Ca and Mg content of plant while Fe and Zn content were decreased (Table 25). Borlan (1964) studied the effect of liming on the mobility of N, P, K, Ca and Mg and showed that liming increased the mobility of N, P and Mg but decreased that of K. The studies of Kalia *et al.* (1969) showed that liming increased exchangeable Ca and Mg and decreased exchangeable K. Mandal (1986) observed a decrease in Fe, Mn and Zn content of the plant with lime application. As noted earlier, at flowering stage also the POP registered the highest content of N, P, K and Ca while the lowest content of these nutrients were present in C_3 (farmers' practice). A significant decrease in Ca content with increase in K dose at lower level of P was observed (Table 26a). But at 35 kg ha^{-1} of P the decrease was observed only at K_3.This might be due to the positive influence of P on Ca. Increasing the P and K to the highest level significantly decreased the Fe, Mn and Zn content of the plant as noted earlier. Low and unbalanced supply of P, K and Ca caused Fe toxicity in rice (Ottow *et al.*, 1981). Higher level of P and K supply increased the oxidizing capacity and Fe excluding power of roots, thus reducing the uptake of Fe and Mn. Combined application of P and lime decreased the Fe content and increased the N content (Table 26c). Similarly K and lime interacted significantly to increase the P and K content of the plant (Table 26b). The K content of the plant decreased with increase in lime dose at lower level of K. But at higher level of K this decrease was not observed. An increase in Mg content and decrease in K content at higher level of lime application has been reported by Kabeerathumma (1969), Nair (1970) and Butorac (1978).

At harvest stage at Koylmannam, combined application of P and K showed that at lower level of P, increase in K decreased the Ca content significantly but at higher level the decrease was observed only at K_3. Similarly the Fe content decreased with increase in K dose up to 70 kg ha^{-1} at P_1 level. But at P_2 level the decrease was observed at 105 kg ha^{-1} of K also (Table 28). Ismunandj and Ardjasa (1989) reported a decrease in Fe toxicity by the application of P, K and Ca.

At Ottappalam a decrease in Zn content with increase in P was noted. Significant increase in P and Mg was also observed with increase in P dose (Table 29). Patra (1981) and Sahu (1993) have made similar observations for rice crop. Potassium application at higher level significantly increased the N, Zn and Mn while the Fe and Mg decreased with increasing K dose. Singh and Singh (1987), Rajdhar (1989), Sreemannarayana and Sairam (1995) have made similar observations. According to Mandal *et al.* (1996) K application caused an increase in Zn content in soil and the content and uptake of Zn increased with increase in K dose. This was attributed to the increase in water soluble and exchangeable and organically complexed form of Zn in soil due to K application. Application of K at higher levels increased the oxidizing power of roots, reducing the soluble Fe concentration and hence the uptake of Fe. Decreased Fe concentration might have enhanced the Mn and Zn uptake at higher levels of K. Singh *et al.* (1978) and Singh and Singh (1975) observed antagonism between Fe and Mn and Fe and Zn. The N, P and Ca content were significantly increased while K, Fe, Mn and Zn content were decreased at higher level of lime application (Table 29). Kamprath (1967) envisaged the lime requirement to overcome the toxicities and deficiencies rather than raising the soil pH. A notable increase in the content and uptake of N, P, Ca and Mg with increased dose of lime has been reported by Kabeerathumma (1969) and Anilakumar (1980). Hati *et al.* (1979) and Mongia and Bandyopadhyay (1993) have found negative relation of lime on the plant content of Fe and Mn.

Farmers' practice recorded the lowest content of Ca and Mg and highest content of Fe and this revealed the importance of balanced application of fertilizers for reducing the toxicity problem and enhancing the nutrient content.

5.1.3 Elemental composition of grain

Data on the nutrient content of grain showed a decrease in Fe, Mn, Zn at 70 kg ha^{-1} of K (Table 31). Similar decrease in Fe content was observed with 35 $kgha^{-1}$ of P and 600 kg ha^{-1} of lime application also. The grain content of nutrients on combined application of P at 35 kg ha^{-1} and K at 70 kg ha^{-1} significantly increased the N and P content of the grain and decreased the Fe content (Table 32). As seen earlier the grain content of N and Mg were increased and the Fe content was decreased by the lime application at 600 kg ha^{-1}.

A perusal of the data on grain nutrient content at Ottappalam location also showed a decrease in Fe content with increase in P and lime application. (Table 34). Here also K application at 70 kg ha^{-1} showed significant decrease in the Fe content of grain. Mitra (1992) reported that K application decreased Fe uptake by rice plant and created a favourable environment for the absorption of other essential nutrients. Combined application of 70 kg ha^{-1} of K and 600 kg ha^{-1} of lime significantly decreased the Fe and Mn contents and increased the P content of the grain. Benckiser (1983) reported that K and Ca reduced the uptake of iron significantly and this was ascribed to a decrease in root exudation caused by decreased permeability of root membrane. Combined application of P and K significantly increased the K and Mg contents at P_2K_2 (Table 35). Singh *et al.* (1989) made similar findings that increasing the rate of P and K increased K content in rice. However, the Zn content registered the highest value at P_1K_2 and at P_2 level there was a decrease in Zn content which might be due to the antagonistic effect of Zn and P.

5.1.4 Nutrient uptake studies

Phosphorus application at 35 kg ha^{-1} significantly decreased the Fe and Zn uptake in straw compared to lower level of P at 17.5 kg ha^{-1} (Table 36). Application of K at 70 kg ha^{-1} registered the highest uptake of N, K, Ca, Mg and Zn. However 105 kg ha^{-1} of K significantly decreased the uptake of Ca and Mg. Turner and Barkus (1983) observed similar results. At 35 kg ha^{-1} of P and 105 kg ha^{-1} of K the Ca uptake was decreased compared to lower levels of P and K (Table 37). Increasing level of P and K significantly decreased the uptake of Fe and Zn. Antagonism between P and Zn (Patra, 1981) and K and Zn (Singh and Kumar, 1993) have been reported in rice. Ottow (1981) reported Fe toxicity resulting from increased Fe uptake as an indirect physiological disorder caused by low and unbalanced supply of nutrients particularly P, K and Ca. Here it is observed in the experiment that Fe uptake decreased with increase in P and K dose. Increased supply of K and Ca decreased the root permeability and addition of high level of K and P might have resulted in a decrease in accumulation of low molecular weight metabolites thereby increasing the Fe oxidising and Fe excluding power of roots. Lime application at 600 kg ha^{-1} increased the N, Ca, Zn and Cu uptake (Table 36). Nutrient uptake of straw at Ottappalam showed that higher level of P application significantly increased the uptake of N, P, Mg and Cu (Table 38). Munda and Patel (1989) also found greater effect of P fertilizer on plant N, P and K uptake than K fertilizer. Increasing the P dose increased the yield and uptake of N and P by rice (Singh *et al.*, 1989). Effect of P, K and lime on straw N and K uptake is given in Fig 9. Potassium application at higher level (70 kg ha^{-1}) significantly increased the uptake of N, P, K, Mn, Zn and Si by straw while 105 kg ha^{-1} of K decreased Ca, Mg and Fe uptake as observed earlier. An increase in the uptake of N, P and K (Singh and Singh, 1987) and a decrease in Ca and Mg by rice (Chakravorti, 1989) with increasing levels of K were reported which are in conformity

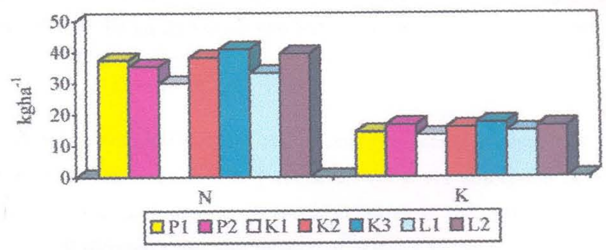

Fig. 8. Grain uptake of N and K at Ottappalam

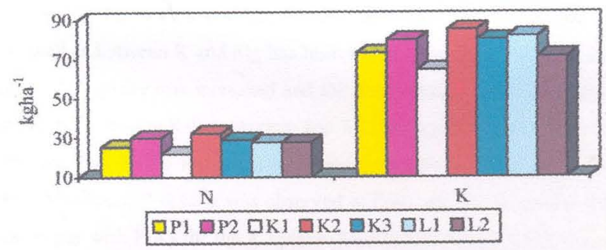

Fig. 9. Straw uptake of N and K at Ottappalam

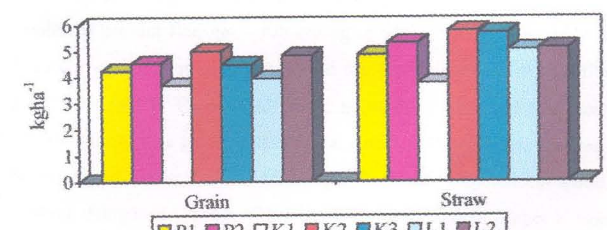

Fig. 10. Grain and straw uptake of P at Ottappalam

with the present findings. It can be seen that reduced uptake of Fe enhanced the uptake of Zn, Cu and Mn. Antagonistic effect of Fe on Mn (Singh and Singh, 1975) and depressing effect of Fe on Zn (Singh and Sakal, 1983) were reported in earlier works in rice.

Lime application at 600 kg ha^{-1} significantly decreased the uptake of K, Fe and Mn (Table 38). Sudhir *et al.* (1987) found an enhanced absorption of K at low concentrations of Ca but at higher concentration decreased the uptake of K by plants. Hati *et al.* (1979) reported a negative relation of calcium on the plant available Fe and Mn. Mandal (1968) found that liming depress the Fe and Mn uptake by rice plants. The present findings are in conformity with the earlier reports. The grain uptake of nutrients has shown that P application at higher level increased the N, P, K, Mn and Si uptake (Table 40). Potassium application at 70 kg ha^{-1} increased N, P, K, Ca and Mg uptake but at 105 kg ha^{-1} Ca and Mg uptake decreased. The antagonism between K and Ca as well as between K and Mg has been reported by Barber (1986). It is noticed that the K and P uptake was increased and the Fe uptake was decreased drastically at 70 kg ha^{-1} of K indicating K-P synergism and K-Fe antagonism. Interaction between P and K showed that P and K uptake increased with increase in P and K appication (Table 41). Maximum P uptake was observed at P_2K_2 and the K uptake at P_1K_3. But P_2K_2 was on par with P_1K_3 for the K uptake. Munda and Patel (1989) reported that K uptake was maximum at higher rate of P application. The Zn and Mn uptake was also significantly increased at P_2K_2 but at P_2K_3 a significant decrease was observed. Lime application at higher level increased the N, P, K, Ca, Mg and Zn uptake and decreased the (Table 40). Liming increased the uptake of Ca and Mg (Kalia *et al.* 1969). Erdei and Zsoldos (1977) observed stimulatory effect of Ca on the uptake of K which is in conformity with the present finding. According to Mello and Kaminski (1990) while applying Ca as correctors of soil acidity, K and dry matter yield were not affected but both increased with rate of Ca applied. Ionic activities of Ca and Mg increased in accordance with liming. The grain uptake of nutrients at Ottappalam showed that the uptake of K was significantly increased by higher level of P application while the Ca, Fe and Zn uptake decreased ((Table 42). Similar observations of higher K uptake and decreased Fe and Zn uptake with increase in P dose was reported by Munda and Patel (1989) and Ismunadj and Ardjasa (1989). The highest level of K application registered the maximum uptake of K while the Ca, Fe and Mn recorded the lowest uptake. C_3 (the farmers practice) registered the highest Fe uptake by grain and straw. Application of K at higher levels increased the K availability in soils and hence enhanced the uptake of K. Sufficient supply of K in the soil increase the oxidizing power of roots. It can precipitate soluble Fe in soil preventing excessive uptake of Fe. A sensitive balance between the Fe oxidation on one side and the reductive dissolution of these precipitated Fe by micro organisms metabolizing exudates and mucilaginous compounds on the other enables the plant to prevent excessive Fe^{2+} from entering plants.

Higher level of lime application increased the uptake of N, P, K, Ca and Mg. Tripati (1987) reported that application of lime under flooded condition increased Mn content and decreased Fe content. However lime application alone could not bring down the Fe content below the critical level (Marykutty, 1986).

The Fe uptake in grain and straw was significantly influenced by the combined application of K and lime (Table 39b and 43b). The uptake of Fe in grain and straw significantly decreased at K_3L_2 but it was on par with K_2L_2. The insufficient supply of K as an essential factor governing the tolerance of rice to high concentrations of Fe^{2+} has been noted before, but K fertilization alone was not an effective remedy. Similar partial improvements have been observed by liming. Besides the improving effect of lime the favourable influence of Ca on the root permeability can also be considered. Interaction between K and lime in straw (Table 39b) showed that combined application of K and lime significantly increased the uptake of Zn. Baruah *et al.* (1996) observed that high Fe level decreased the uptake of N, P, K, and Zn. Generally the nutrient extracting capacity of roots is reduced by the precipitated Fe on the root surface which acts as a mechanical barrier to the absorption of other nutrients. But here it can be seen that with increase in K and lime, the uptake of Fe decreased and it enhanced the uptake of Zn. Similarly the K and lime interaction in grain revealed that the Mn uptake was significantly decreased at K_2L_2 level at which the Fe uptake was also decreased. Kulkarni *et al.* (1991) reported that Fe content of all rice cultivars was positively associated with Mn content, which is in conformity with the present finding.

5.1.5 Soil available nutrients

During the cropping period available nutrient content of soil at various growth stages were analyzed and their changes to various levels of P, K and lime were evaluated which is discussed hereunder.

It is observed from the data at Koyalmannam that application of P at 35 kg ha^{-1} significantly increased the available P and Mg content of the soil and decreased the available Fe, Mn and Zn content of the soil (Table 2.1). This decrease might be attributed to the precipitation of corresponding insoluble Fe, Mn and Zn phosphates. Gupta and Singh (1989) observed a similar decrease in Fe and Mn concentration with increase in soil availabe P. Potassium application at higher level significantly increased the available N, K and decreased the exchangeable Ca and Fe content of soil. Mitra (1992) reported similar results. Reddy *et al.* (1978) observed an increase in the availability and uptake of N and K when the K dose was increased from 50 to 100 kg ha^{-1}, which is in conformity with the present findings.

Combined application of P and K significantly decreased the Fe content at P_2K_2 and increased the Mg (Table 2.2a). The decrease in Fe might be due to the increased level of P and K. Ismunadj and Ardjasa (1989) reported a decrease in Fe concentration with P, K and Ca application. Rosmini and Mukhlis (1989) have made similar reports.

In the control treatments considerable decrease in N, P, K, Ca and Mg and an increase in Fe content was observed in the farmer's practice (Table2.1). The farmer applied only organic manures and that too based on the availability which restricts the timely and balanced supply of sufficient nutrients.

At Ottappalam also P application at higher level significantly increased the available N and P and decreased the Fe and Zn content of the soil as that of Koyalmannam (Table2.3). Frageria *et al.* (1982) observed similar results of increase in the N, P, K content of the soil at higher level of P application. A positive response on the available N and K content and negative response on the Mg and Mn content of the soil was observed at higher level of K application.Similar results of increase in the available N and K with K application was observed by Alvarenga and Lopa (1988). Combined application of P at 35 kg ha^{-1} and K at 70 kg ha^{-1} showed significant increases in the available N and decrease in the available Fe content of the soil (Table 2.4). Datta and Gomez (1982) reported that the response to P was more when applied with K.

The response to P was not pronounced on the major nutrients of soil except P at panicle initiation stage (Table 2.5).The available phosphorus got increased at 35 kg ha^{-1} of P. The Fe and Mn significantly decreased at higher level of P. Precipitation of Fe and Mn as phosphates reduces the availability of these in the soil. However, the reversible reaction also can occur releasing soluble Fe and Mn and P. Hence the status of these nutrients is changeable; it may vary significantly in a relatively short time or within a limited distance. A significant decrease in the Fe content was observed at P_2K_2 while the Mn decreased significantly at P_2K_3 as observed from the table 2.6a. Similar findings were made by Ottow (1981) and according to him Fe toxicity is due to low supply of P and K. Here it is found that P and K at 35 and 70 kg ha^{-1} respectively could significantly decrease the Fe and Mn (Fig 13). This is in conformity with the findings of Gupta and Singh (1989) and Sahu (1993) also.

It is observed that the exchangeable Ca of the soil decreased with increase in K dose at P_1 level. But at higher level of P this decrease was not observed (Table 2.6a). Prabhakumari (1992) has reported similar synergistic relationship between P and Ca.

Among the control treatments the P, K and Ca content of the soil registered significantly lower quantity in the farmer's practice while POP registered the highest content of these nutrients (Table2.5).This is attributed to the lack of balanced fertilization in the farmer's practice.

The available P, K and Mn significantly increased and the Fe and Zn decreased with P at 35 kg ha^{-1} at PI stage at Ottappalm (Table 2.7) Antagonistic effect of Mn on the Zn was observed by Singh *et al.* (1978). Phosphorus at higher level decreased the Fe and Zn content, which might have enhanced the Mn content in soil.

Increasing levels of K increased available N, P, K and decreased Ca, Fe and Mn content of soil. Similar results were reported by Marykutty (1986), Alvarenga and Lopa (1988) and Sahu (1993). Application of lime at 600 kg ha^{-1} significantly increased almost all the nutrients of the soil except Fe and Mn at panicle initiation stage. A decrease in Fe and Mn content of the soil was observed at higher level of lime application. Ionic activities of Ca and Mg increased in soil solution in accordance with liming treatments and lead to decrease in Fe and Mn. According to Mathan and Raj (1975) in laterites lime application resulted in release of P and liming at the rate of 300 or 600 kg ha^{-1} even without the addition of any fertilizer was beneficial in releasing sufficient P.

A review of the data on the main effects at flowering stage at Koyalmannam (Table 2.9) revealed that the influence of P was pronounced on P, K, Mn and Zn at this stage .The Mn and Zn decreased and the available K content increased at 35 kg ha^{-1} of P application. Synergism between K and P (Lahar, 1972) and antagonism between P and Zn has already been reported. The Fe content of the soil was significantly decreased at 70 kg ha^{-1} of K and the Ca content decreased at 105 kg ha^{-1}.

The application of P and K at highest level significantly decreased the Fe content of the soil (Table 2.10). However, P_2K_3 was on par with P_1K_2 at flowering stage. Ismunandj and Ardjasa (1989) reported that Fe toxicity is decreased by the application of P and K. Lime application also decreased the Fe content of the soil and increased the P, Ca and Mg content (Table2.9). These observations were supported by the findings of Kamprath (1967) who envisaged the lime requirement to overcome the toxicities and deficiencies rather than raising the pH to neutrality.

A perusal of the data in the table 2.11 at Ottappalam showed almost similar pattern of variation in nutrient content of soil. A significant decrease in zinc content at higher level of P and decrease in the Fe, Mn and Ca content in soil with increasing K levels was observed.

Likewise lime applied @ 600 kg ha^{-1} also brought down the available Fe content of soil. Devi *et al.* (1996) observed similar results of decrease in available Fe content in soil with higher level of lime application. Among the control treatments the farmer's practice recorded the lowest content of almost all the nutrients. Combined application of K and lime respectively at 105 kg ha^{-1} and 600 kg ha^{-1} significantly reduced the Fe content. The low content in soil reduced the Fe toxicity problems (Table2.12b).

At Koyalmannam, at harvest stage an increase in the P and decrease in Fe and Zn content of soil was observed at higher level of P (Table 2.13). Patra (1981) reported significant decrease in DTPA extractable Fe and Zn content with P application, which is in conformity with the present finding. Increasing level of K increased K and decreased the Fe content of soil. But for Zn highest and lowest level of K produced no change while 70 kg ha^{-1} of K significantly increased the Zn content of soil. Mandal *et al.* (1996) reported an increase in Zn content in soil with K application, which is attributed to an increase in water soluble, exchangeable and organically complexed form of Zn in soil. Available P and exchangeable Ca content of the soil significantly increased at higher level of lime application while Potassium and lime applied together significantly decreased the Mg content of soil at K_3L_2 (table 2.13 and 2.14b). However at lower level of K this was not observed. It was observed that Mg and Ca reduction occurs from ion antagonism in soils with exchangeable K (Daliparthy, 1994).

At Ottappalam combined application of P and K at 35 and 70 kg ha^{-1} respectively significantly increased the available K and decreased the Mn content of the soil (Table 2.16a). P_1K_3 recorded the lowest value for Mn.This could be attributed to the antagonistic effect of monovalent and divalent ions. Phosphorus and lime at the highest level significantly decreased the Fe content of the soil (Table2.16b). Howeler (1985) reported similar results.

5.2 Second crop of rice

The second crop of rice was taken with the same treatments during the mundakan season. The results of the experiment are briefly discussed here. The influence of P, K and lime on yield and yield attributes were studied and their effect was evaluated with the same variety "Jyothi" for the second crop season also.

5.2.1 Yield and yield attributes of rice

Significant positive response to higher level of P on the productive tillers, grain yield and straw yield was observed at Ottappalam. (Table 4.1 and Table 4.2).. Response to P application by rice has been observed in all types of soils irrespective of the initial available P content (De datta, 1983; Bhaskar *et al.*, 1988). Lime application at higher level increased the thousand grain weight but no effect was observed on grain yield. However a slight increase in the straw yield was observed at 600 kg ha^{-1} of lime. This might be due to the ameliorating effect, which enhance the supply of nutrients.

Grain yield, grains per panicle and thousand grain weights were significantly increased by the combined application of P and K (Table 4.3a). A significant increase in thousand-grain weight was observed at P_1K_2. But the grains per panicle and the grain yield were significantly increased when the K dose was increased to 105 kg ha^{-1}. P_1K_3 was on par with P_2K_2. Earlier reports of Venkatasubbiah *et al.* (1982) revealed that effect of K was more on grain yield than straw yield and the application of K at 120 kg ha^{-1} significantly increased the grain yield compared to 60 kg ha^{-1}. Bridgit (1999) also reported similar results of increased yield up to 120 kg ha^{-1}. Combined application of K and lime at 70 and 600 kg ha^{-1} respectively significantly increased the grain yield and straw yield (Table 4.3b). Farmer's practice recorded the minimum value for thousand grain weight, grain yield and straw yield.

A review of the response obtained at Ottappalam showed no significant effect of P on growth and yield attributes except thousand grain weight (Table 4.4 and Table 4.5). Potassium applied at 70 kg ha^{-1} significantly increased thousand grain weight, straw and grain yield. Combined application of 35 kg ha^{-1} of P and lime at 300 kg ha^{-1} significantly increased the thousand grain weight and straw yield as evident from the table 4.6. Calcium stimulated the absorption of P and consequently the yield increased by the combined application of P and lime. Padmaja and Varghese (1972) and Prakash and Badrinath (1995) observed similar results.

Grain yield and straw yield were pooled for the two seasons and the two locations. Seasonal influence was not significant while the location effect was found to be significant. Effect of phosphorus showed that P application at 35 kg ha^{-1} significantly increased the grain and straw yield compared to lower level of P (17.5 kg ha^{-1}). Pooled analysis showed significant positive response up to 105 kg ha^{-1} of K for the straw yield which is in conformity with the findings of Bridgit (1999) (Table 4.6b). Effect of P, lime and location on yield showed that at Koyalmannam, response to higher level of P was obtained at both levels of lime application (Table 4.6c). But at Ottappalam response to higher level of P was observed only at lower level of lime application. The soil available P and exchangeable Ca content at Koyalmannam was low and the available Fe content was comparatively higher compared to Ottappalam which might be the reason for significant yield response at higher level of P and lime at Koyalmannam.

5.2.2 Elemental composition of rice

At maximum tillering stage Fe and Zn content significantly decreased with P application at higher level, which might be due to the precipitation as phosphates at higher level (Table 4.7). Potassium application at higher level significantly increased the content of most of the nutrients except Mn. Positive effect of K on nutrient content of rice was reported by Randhawa and Pasricha (1976). Combined application of P and lime at higher level increased the N and P content of the plant while the Mn and Zn content decreased significantly (Table 4.8a). Prakash and Badrinath (1995) observed similar results. Koshy (1960) reported that availability of P increased due to the application of lime and the combined effect enhanced the content and uptake of nutrients. Thus Phosphorus and lime produced a negative effect on the Mn and Zn content (Xavier and Holford, 1981). Lime application at higher level significantly increased the Ca content at lower level of K (Table 4.8b). At higher level of K, Ca content showed no significant variation but the Mg content was decreased. This may be probably due to the antagonistic effect of mono and divalent ions as reported by Mathew (1993). The Fe and Mn content of the plant decreased significantly at higher level of lime application, which is in conformity with the findings of Devi *et al.* (1996). Highest content of Fe and lowest content of Mn was recorded by the farmer's practice. This may be due to the antagonistic effect of Fe on Mn.

A perusal of the data (Table4.9) at Ottappalam at MT stage showed that P application at higher level significantly increased the P and K content. Sufficient supply of P promotes root growth, which enhances the absorption of nutrients. Potassium applied at 70 kg ha^{-1} significantly decreased the Fe and Mn content. The enhanced root oxidation capacity decreased the Fe and Mn uptake and thereby the content.

Similarly at PI stage at Koyalmannam the P and K applied together increased the N and K and decreased the Fe content of the plant (Table 4.12a). The N, P and Ca content was enhanced by the lime application at higher level while the K, Fe and Mn content was decreased (Table 4.11). Lime directly influences the content of Fe and Mn by its influence on pH, which is increased by lime application decreasing the content of Fe and Mn. The Ca content influences the root permeability also, which in turn moderates the absorption of nutrients. At panicle initiation stage the combined application of 35 kg ha^{-1} of P and 70 kg ha^{-1} of K in the presence of 300 kg ha^{-1} of lime significantly decreased the Fe and Mn content (Table 4.13). The conditions affecting Fe toxicity in rice plant are related to nutritional state of other nutrients such as P, K, Ca and Mg. Therefore a sufficient supply of these nutrients enhances the Fe excluding ability reducing the Fe uptake as observed in this experiment.

At Ottappalam also almost similar pattern of variation was observed where the Fe content was significantly decreased at $P_2K_2L_2$ and it was on par with $P_2K_3L_1$ (Table 4.16). The Mn content also decreased at higher level of P, K and lime, which is in conformity with the findings that Fe content of all cultivars, was positively associated with Mn content of plant tissue (Kulkarni *et al.*, 1991).

At flowering stage an increase in the N, P, K content was observed by the P and lime application (Table 4.17). But the higher level of K application decreased the Ca, Mg, Fe and Mn content. Phosphorus applied at 17.5 kg ha^{-1} in the presence of 70 kg ha^{-1} of K and 600 kg ha^{-1} of lime significantly decreased the Fe content of the plant (Table 4.19). Variation in the nutrient content as observed at Ottappalam revealed that P application together with K and lime at the highest level significantly decreased the Fe, Mn and Zn content of the plant. $P_2K_3L_2$ was on par with $P_2K_2L_2$ (Table 4.22). Ismunadj and Ardjasa (1989) observed similar effects on application of P, K and Ca.

The N, P, K content of the straw was significantly increased by the combined application of P and lime at Koyalmannam (Table 4.24a). Prakash and Badrinath (1995) have reported similar results of synergistic influence of P and lime on nutrient content of the straw. It is observed from the table 4.23 that potassium application at 70 kg ha^{-1} significantly increased the P, K, Zn and decreased the Fe and Mn content of the straw. Potassium along with lime significantly decreased the Fe content at K_2L_2 in both grain (Table 4.28b). Similarly the Ca also showed a decrease with increasing K dose at both levels of lime application. This shows the antagonistic effect of monovalent and divalent ions as reported by Mathew (1993). Significantly lower quantity of Fe, Mn and Zn was present at $P_1K_2L_2$ (Table 4.29). Lime is a key factor in deciding the pH and thereby the availability of other nutrients. Similarly potassium improves the oxidizing capacity of roots while phosphorus enhances the root growth which influences the nutrient removal by the plant.

The response for the various treatments at Ottappalam showed that Fe content of straw significantly decreased at 70 kg ha^{-1} of K while in the grain the Mn content was significantly decreased (Table 4.25 and 4.30). The grain content of Zn was significantly decreased at the highest level of K application. The K and Zn relationship in grain is in conformity with the findings of Singh and Kumar (1993). Similarly the P and K combination at the highest level as seen in the table (4.26a) significantly decreased the Zn content in straw indicating the antagonistic effect of P and K on Zn. It can be seen from the table (4.26b) that at the same level of lime application with increase in P the Zn decreased but Mn got increased which might be due to the antagonistic effect of Mn and Zn. Chavan and Banerjee (1980) observed a decrease. The P and K combination at the highest level increased the N, P and K content of the grain (Table 4.31a). Singh *et al.* (1989) observed similar results.

5.2.3 Nutrient uptake studies

The nutrient uptake studies at Koyalmannam showed positive response of P on the N, P, Mg, Mn, Zn and Si(table 4.32). Even though the Zn content in straw decreased at higher level of P, the uptake of Zn was significantly enhanced by P application. The synergistic influence of K was revealed by the enhanced uptake of most of the nutrients at 70 kg ha^{-1} of K viz., N, P, K, Ca, Mg, Zn and Si. Combined application of P,K and lime significantly enhanced the uptake of P and reduced the Fe uptake at $P_1K_2L_2$ (Table 4.34a). The Ca uptake was decreased at $P_2K_2L_1$. The response to P application was boosted when K was also applied (Datta and Gomez, 1982). Turner and Barkus (1983) observed that increased K supply increased the uptake of P while it reduced that of Ca and Mg. Increasing rate of each nutrient N, P, K and Ca increased the yield and uptake of N, P, K, Ca and Mg by rice (Singh *et al.*, 1989 and Prakash and Badrinath, 1995). It is observed that the P and K uptake of grain significantly increased at $P_1K_2L_2$ and Fe uptake was decreased.

At Ottappalam P application at higher level increased the uptake of only N ,K and Si by straw(Table 4.35). Response to K application was significantly reflected at 70 kg ha^{-1} for the uptake of most of the nutrients in grain and straw. According to Reddy *et al.* (1978) N uptake was significantly increased by the application of K from

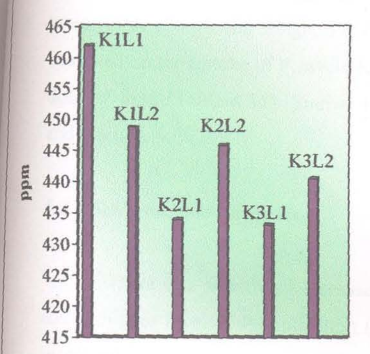

Fig. 11. Effect of K andl ime on Mn content of rice at PI stage (Ottappalam)

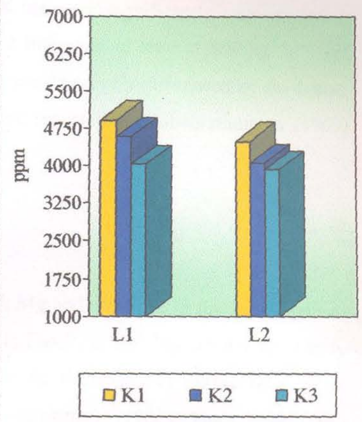

Fig. 12. Effect of K and Lime on Fe content of rice at PI stage (Ottappalam)

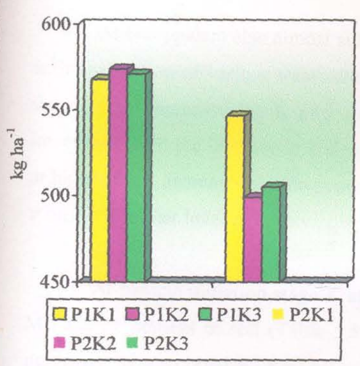

Fig. 13. Effect of P and K on Fe content of soil at PI stage (Koyalmannam)

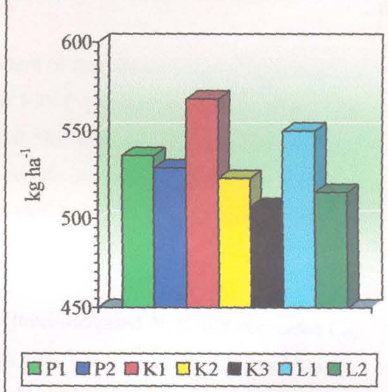

Fig. 14. Soil available Fe at PI stage (Koyalmannam)

50-100 kg ha^{-1}. The total uptake of N, P and K increased significantly with increasing levels of K (Singh and Singh, 1987). Positive influence of lime at 600 kg ha^{-1} was observed on the uptake of P, while K and Fe were negatively influenced by the higher dose of lime (Table 4.35). Similar results were reported by Kabeerathumma (1969) and Anilakumar (1980).

5.2.4 Soil available nutrients

There was significant increase in the P, Mg and decrease in the Zn content of soil at higher level of P application (Table 5.1).The P, K and Mg were significantly increased and Ca, Fe and Mn were found to be decreased at higher level of K application. Similar reports were made by Anilakumar (1980), Patra (1981) and Marykutty (1986).

The effect of combined application of P and K showed that Fe was significantly decreased at P_1K_3 and Zn content increased at P_1K_2 and P_1K_3 (Table 5.2a). The antagonistic interaction effects of Fe on Zn and Zn on Fe has already been observed.

At Ottappalam also almost similar pattern of nutrient availability was observed with application of various treatments (Table 5.3). Combined application of P and K significantly increased the K and decreased the Mg and Zn (Table 5.4a). At lower level of P the increase in K dose increased the available Zn content of soil but P at higher level decreased the Zn content. This may be due to the antagonistic effect of P on Zn at higher level of P.

At panicle initiation stage K at higher level increased N, K and decreased Ca, Mg and Fe content of soil (Table 5.5 and Fig 14). The Fe content was significantly decreased by the combined application of P and lime at the highest level (Table 5.6b). An earlier report of Devi *et al.* (1996) is in conformity with the present findings of negative influence of lime on the Fe content. Calcium content influenced the root permeability as well as the pH of the soil, both of which were responsible for the decline in Fe content of soil.

The oxidizing capacity of the root is enhanced by the applied K which in turn influenced the micro flora responsible for the reduction of ferric to ferrous ions. Similarly the P content of the soil often reacts with ferrous ions precipitating insoluble ferric phosphates by which the concentration of ferrous ions in the soil is decreased. Thus it is seen that it is not the concentration of Fe labeled as "toxic" that decides the yield but the balanced supply of other nutrients which can modulate the uptake of Fe by plants that decide the yield.

Phosphorus and K applied together at the highest level significantly increased the available K and decreased the Mn content of the soil (Table 5.10a). The Zn content of the soil also showed a decrease at 70 kg ha^{-1} of K.There are reports which support the role of K in decreasing the Fe and Mn content of the soil. As seen, response to K was more in the presence of P and hence the combined application influenced the nutrient availability of soil.

The Fe content was negatively influenced by P and K applied together at Ottappalam. Positive response of Zn to K was observed at lower level of P(Table 5.12a). At higher level no significant effect was noticed. Similar findings were observed by Patra (1981), Sahu (1993). Farmer's practice registered the lowest content of available N, P, K and highest Fe content. At harvest stage it was observed that increasing the K dose increased the P and K and decreased the Mn content (Table 5.13). Lime application increased the Ca and decreased the Fe content of the soil. Similarly phosphorus with lime decreased the Mn and Zn content of the soil (Table 5.14).

5.3 Correlation studies

From a review of correlation pattern of nutrient ratios with yield it can be observed that total yield was positively correlated with N/Fe, N/Mn, P/Fe, P/Mn, K/Fe and K/Mn ratios of the plant . This indicated that excess accumulation of Fe, Mn which limits the yield is the resultant of insufficient supply of P and K. A balanced supply of these nutrients decrease the Fe concentration in both plant and soil to certain extend thereby enhancing the yield. It was found that increasing the level of K from 35 to 70 kg ha^{-1} facilitated better internal nutritional environment by reducing the Fe and Mn content in the plant.

K/Fe ratio of plant was significantly and positively correlated with grain and straw yield at both locations indicating the dominant role of K in bringing down the Fe concentration in both plant and soil (Table6.12 and Table 6.14) From a review of K/Ca + Mg ratios of the plant it can be observed that yield was positively correlated with K/Ca + Mg ratio of the plant (Table 6.4 and Table6.5). It is evident that increasing the K dose positively influenced the K/Ca + Mg ratio thereby enhancing the yield. Marykutty *et al.* (1992) reported that yield governing factor in rice is the narrowing down of Ca + Mg/K ratio and not the individual components. These results support the present findings of positive correlation of K/Ca + Mg ratio with yield.

K/Fe ratio of the soil was significantly and positively correlated with both grain and straw yield at both locations (Table 3.6 and Table3.12). Hence it is clear that a sufficient supply of K fertilizer could check the available Fe content of the soil through its influence on oxidising capacity of roots and also through microbial activity responsible for Fe reduction.

5.4 Weather parameters and grain yield

Weather parameters at both locations during the first crop season showed that variation in sunshine hours 45 days prior to harvest influenced the grain yield. An increase in the sunshine hours 45 days prior to harvest at Ottappalam compared to Koyalmannam might have increased the grain yield (Table3.17). Pamplona *et al.* (1995) reported that grain yield was highly correlated with sunshine hours. However, a significant variation in yield with total sunshine hours was not observed, but the sunshine hours at the ripening phase and 45 days prior to harvest was correlated with yield. A perusal of the data on rainfall and sunshine hours for the first crop season over the three years at Koyalmannam (Table 3.18) showed grain yield increased in the year 1999 and 2001, when the increase of sunshine hours 45 days prior to harvest was more when compared to the year 2000. Similarly the rainfall at the ripening and reproductive phase was higher in the year 2000 compared to the preceding and succeeding years which might have negatively influenced the yield. Thus the study indicated that grain yield may be highly related with sunshine hours 45 days prior to harvest if the other environmental factors are homogeneous.

Salient findings

An overall review of the study indicates that grain yield at both locations was increased by higher level of K at 70 kg ha^{-1} along with P and lime at 35 and 600 kg ha^{-1} respectively.

Elemental composition of rice plant at earlier stages of growth had shown that P applied as such had no significant effects. However, when it is applied along with K or lime the content of N, P, K and Ca increased while that of Fe and Mn decreased with slight variation at certain critical stages. It is generalized that K and P have synergistic effects with respect to the absorption of these elements by plants.

Potassium and lime application reduced the Fe content of the plant at both the locations. The interaction effects of P, K and lime revealed that at Koyalmannam P, K and lime applied @ 35, 70 and 600 kg ha^{-1} respectively reduced the Fe content of the plant at panicle initiation stage. At Ottappalam the same dose of P and lime with 105 kg ha^{-1} registered the lowest content of Fe at panicle initiation stage. A balanced supply of P, K and Ca decreased the Fe toxicity problem in laterite soil (Ottow, 1981). Thus on comparing the results obtained with POP recommendations a higher level of K, double the dose than POP is required for a higher yield. Grain and straw content of nutrients like N, P, K also were increased and Fe and Mn decreased at higher level of K application with recommended levels of P and lime.

Nutrient uptake studies at Koyalmannam showed that the uptake of Fe and Zn decreased in straw with 35 kg ha^{-1} of P and 105 kg ha^{-1} of K. Similarly Mn and Zn in the grain also decreased at this level of nutrient application. At Ottappalam uptake of major nutrients increased at higher level of K application (70 kg ha^{-1}). The Fe content of straw and grain decreased when 600 kg ha^{-1} of lime applied with 70 kg ha^{-1} of K. In the grain and straw Ca uptake showed a significant decrease at highest level of K due to the antagonistic effect at higher level. With ample supply of K to the soil excess of K would be taken by the plant and that in turn reduce the uptake of other cations like Ca, Mg, Fe etc.

Available nutrients of the soil and nutrient content in the plant highly influenced the straw and grain yield. In general application of nitrogenous fertilizer along with higher level of P, K and lime created a suitable environment for the better uptake of major nutrients and reduced uptake of micronutrients like Fe and Mn.

Available nutrient content of the soil showed that P and K at the higher level increased the availability of major nutrients and decreased that of micronutrients especially Fe. Lime at 600 kg ha^{-1} with higher levels of P and K significantly decreased the available Fe content of the soil. With increase in lime dose the exchangeable Ca content of the soil increased but at higher level of K, the extent of increase was reduced, which might be due to the antagonistic effect of K and Ca.

Summary

6. SUMMARY

The project entitled "Critical analysis of the soil plant atmosphere continuum for increasing the productivity of rice in lateritic soils"consisting of four field experiments was carried out during 2000-2001 in the farmer's field at Koyalmannam and Ottappalam of Palakkad district. The salient research results obtained are presented here.

Salient results obtained from the first and second crop of rice at Koyalmannam and Ottappalam are separately listed here under.

A – Koyalmannam

1. Maximum grain yield was obtained by the application of 35 kg ha^{-1} of P and 70 kg ha^{-1} of K along with 600 kg ha^{-1} of lime or with 17.5 kg ha^{-1} of P with 105 kgha^{-1} of K and 600 kg ha^{-1} of lime .
2. The elemental composition of the plant varied with different levels of P, K and lime application.
3. The N, P and K contents of the plant increased with 70 kg ha^{-1} of K and 600 kg ha^{-1} of lime application at PI stage.
4. The Fe and Zn and Si contents of the plant significantly decreased at higher level of P and K dose.
5. Phosphorus and potassium contents of the grain increased at higher level of K while Ca, Mg, Fe, Mn and Zn decreased. The Fe and Mn registered the lowest value at 70 kg ha^{-1} of K.
6. The Ca, Fe and Zn uptake in the straw decreased at the highest level of P and K application.
7. In the grain Mn and Zn recorded the lowest uptake at the highest level of P and K application.
9. Soil available Fe, Mn and Zn content significantly decreased while the available N increased at the highest level of P and K application.

10. The exchangeable Ca content of the soil decreased at the highest level of K application.
11. Total yield was positively correlated with N/Fe, N/Mn, P/Fe, P/Mn, K/Fe and K/Mn ratios of the plant.
12. K/Fe ratio of the plant was significantly and positively correlated with grain and straw yield.
13. K/Ca+Mg ratio of the plant at PI stage was positively correlated with yield.
14. K/Fe ratio of the soil showed positive correlation with yield.
15. From a comparison of weather parameters at both locations, it was observed that grain yield at Koyalmannam increased when sunshine hours 45 days prior to harvest was increased.
16. At Koyalmannam for the second crop also grain yield was increased with increase in K dose to 70 kg ha^{-1}.
17. A review of the nutrient content at critical stages for the second crop showed that at PI stage a significant decrease in Fe and Mn content of the plant was observed with 35 kg ha^{-1} of P, 70 kg ha^{-1} of K and 600 kg ha^{-1} of lime.
18. Both grain and straw content of Fe decreased with K and lime application at 70 kg ha^{-1} and 600 kg ha^{-1} respectively.
19. Fe, Mn and Zn content of the grain and straw decreased with 70 kg ha^{-1} of K along with 600 kg ha^{-1} of lime and 17.5 kg ha^{-1} of P application.
20. The grain uptake of P and K increased while Fe, Mn and Zn decreased at the highest level of P and K application at 35 kg ha^{-1} and 105 kg ha^{-1} respectively.

B – Ottappalam

21. At Ottappalam maximum grain yield was obtained with 17.5 kg ha^{-1} of P, 70 kg ha^{-1} of K and 600 kg ha^{-1} of lime. For the second crop also the above level of nutrients gave the maximum yield but reducing the lime dose to 300 kg ha^{-1} from 600 kg ha^{-1} did not affect the yield. However significant response to both grain and straw yield were observed at 35 kg ha^{-1} of P on pooling the yield data. It also showed that straw yield significantly increased even up to 105 kg ha^{-1} of K.

22. Potassium application at higher level increased P and decreased the Ca, Mg and Fe content of the plant at PI stage.
23. Lime application at 600 kg ha^{-1} significantly increased the N, P and Ca content while it decreased the Fe and Mn content.
24. Potassium at 70 kg ha^{-1} and lime at 600 kg ha^{-1} significantly decreased the Fe and Mn content of the grain. The uptake of N, P, K, Mn, Zn and Si uptake significantly increased at 105 kg ha^{-1} of K application.
25. In both grain and straw, Ca and Fe uptake significantly decreased at 105 kg ha^{-1} of K application.
26. Soil available N and P increased significantly while Fe and Zn content decreased with 35 kg ha^{-1} of P compared to lower level of P.
27. Potassium at 70 kg ha^{-1} significantly increased the available N and K and decreased the Mg and Mn content of the soil at MT stage.
28. For the second crop, P at 35 kg ha^{-1}, K at 70 kg ha^{-1} and lime at 600 kg ha^{-1} recorded significantly lower content of Fe and Mn while the K content was significantly increased at PI stage. Similar decrease in Fe, Mn and Zn content was observed at the flowering stage also.
29. An increase in the N, P, K and Ca content was observed at 600 kg ha^{-1} of lime application.
30. Uptake of most of the nutrients was significantly increased at 70 kg ha^{-1} of K application.
31. Lime application at 600 kg ha^{-1} increased the uptake of P and decreased the uptake of Fe, Zn and Si in straw.
32. The grain uptake of P, Ca and Mg got increased and Fe uptake decreased in grain at higher level of lime application.
33. Higher level of P and K at 35 kg ha^{-1} and 70 kg ha^{-1} respectively decreased the uptake of Fe in the grain.
34. Soil available N increased while the Fe and Zn decreased at 35 kg ha^{-1} of P and 600 kg ha^{-1} of lime application.
35. Higher level of P as well as K increased the available P and K content of the soil.

36. Total yield was significantly and positively correlated with N/Fe, N/Mn, P/Fe and P/Mn ratios of the plant.
37. Significant positive correlation of the K/Fe and K/Mn ratios of the plant and soil with total yield was also observed. Both grain and straw yield were significantly and positively correlated with the above ratios of the plant.

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Appendices

Appendix 1

Weekly weather data from January -2000 to March -2001(Ottappalam)

standard week	temperature(^0C)		rainfall	solar radiation
	Max	Min	mm	h/day
1	33.00	23.00	_	7.80
2	32.00	23.20	_	7.00
3	33.50	24.30	_	9.00
4	34.20	22.90	_	8.40
5	34.00	22.20		8.30
6	34.80	21.60	_	8.00
7	34.40	21.60	_	9.00
8	34.40	21.90	_	8.90
9	35.50	22.90	9.50	7.30
10	35.80	23.40	_	8.40
11	36.40	23.00	_	8.40
12	36.50	24.50	_	8.70
13	34.40	24.40	14.40	5.30
14	35.20	25.00	23.60	7.30
15	34.40	28.70	10.80	5.30
16	34.60	25.30	7.60	7.10
17	34.90	25.30	0.70	7.80
18	36.70	25.00	3.80	7.90
19	34.60	24.50	24.90	9.90
20	33.90	24.70	15.90	8.60
21	32.40	24.00	27.60	7.90
22	29.00	22.70	299.70	7.00
23	30.10	23.00	96.70	1.40
24	29.90	23.10	92.70	4.20
25	29.10	22.70	131.34	3.00
26	28.90	22.70	210.10	4.40
27	29.20	22.00	31.60	2.40
28	30.00	22.70	1.70	4.20
29	30.90	22.90	33.60	7.50
30	31.00	23.70	97.40	9.70
31	29.00	22.40	83.20	7.70
32	22.90	26.80	204.20	3.70
33	21.90	25.10	106.00	5.00

Appendix 1 contd

standard	temperature(^{0}C)		rainfall	solar radiation
week	Max	Min	mm	h/day
34	25.50	22.50	30.70	1.10
35	26.00	23.00	0.70	3.60
36	25.90	22.80	18.80	3.20
37	28.00	27.00	88.60	2.80
38	27.30	25.80	104.30	3.00
39	28.40	24.90	104.30	3.10
40	30.50	21.90	47.80	3.00
41	30.50	22.90	14.80	6.90
42	31.90	21.90	27.20	5.00
43	31.80	22.50	17.00	6.20
44	33.40	24.80	_	8.60
45	32.80	22.00	_	8.50
46	30.60	21.70	16.00	8.20
47	31.00	20.00	84.30	3.40
48	31.50	20.80	_	6.80
49	30.80	18.50	_	8.80
50	31.20	19.10	_	10.00
51	30.20	18.60	109.00	8.60
52	32.70	20.30	_	7.10
53	32.20	20.90	_	8.70
54	32.60	20.70	_	9.00
55	33.40	22.00	_	9.10
56	33.90	23.00	34.30	7.80
57	33.00	20.90	17.30	4.90
58	33.70	21.30	_	8.70
60	34.20	22.70	_	9.40
61	35.30	23.00	_	8.90
62	35.00	22.50	_	8.90
63	35.40	22.50	_	8.50
64	34.90	22.50	_	8.90
65	34.40	24.20	_	8.30
66	33.50	24.00	_	8.50

Appendix II

Weekly weather data from January -2000 to March -2001(Koyalmannam)

standard week	rainfall mm	solar radiation h/day
1	_	9.60
2	_	7.60
3	_	9.50
4	_	9.90
5	_	7.20
6	_	9.30
7	7.00	8.70
8	_	8.00
9	_	9.50
10	_	9.60
11	_	9.90
12	3.50	9.20
13	14.00	5.50
14	_	7.60
15	63.00	8.40
16	_	6.90
17	7.00	8.40
18	_	9.30
19	3.50	9.10
20	_	7.20
21	_	5.60
22	21.00	2.00
23	140.00	3.30
24	157.50	3.10
25	17.50	4.10
26	62.30	1.50
27	105.00	3.50
28	210.00	5.70
29	28.00	8.40
30	17.50	2.50
31	9.10	4.10
32	1.40	0.30
33	98.00	4.60

Appendix II contd

Weekly weather data from January -2000 to March -2001(Koyalmannam)

standard week	rainfall mm	solar radiation h/day
34	78.40	7.10
35	207.20	7.50
36	42.00	3.90
37	42.00	4.60
38	2.10	7.10
39	_	7.50
40	66.50	3.90
41	70.00	4.60
42	_	3.20
43	5.60	7.10
44	43.40	3.70
45	_	7.40
46	_	8.30
47	15.40	7.70
48	59.50	3.10
49	_	6.20
50	_	8.50
51	_	9.70
52	_	7.30
53	_	8.40
54	_	9.00
55	_	8.80
56	_	8.10
57	_	7.70
58	_	9.10
60	_	8.70
61	_	8.70
62	_	8.10
63	_	8.60
64	_	7.20
65	_	8.00

CRITICAL ANALYSIS OF THE SOIL PLANT ATMOSPHERE CONTINUUM FOR INCREASING THE PRODUCTIVITY OF RICE IN LATERITIC SOILS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The project entitled Critical analysis of the soil plant atmosphere continuum for increasing the productivity of rice in lateritic soils was conducted at two locations of Palakkad district (Koyalmannam and Ottappalam) for two seasons during 1999-2001. Objective of the study was to identify the role of P, K and lime in influencing the nutrient content of soil and plant and hence rice yield in Fe toxic lateritic solils .The study included the evaluation of influence of P, K and lime on macro and micronutrient content of soil and plant at critical stages in addition to uptake studies, Correlation pattern of nutrient ratios with soil and plant was also studied.

Field evaluation of the crop performance at two locations revealed the following.

At Koyalmannam and Ottappalam P, K and lime significantly influenced the yield and yield contributing characters. Phosphorus, potassium and lime at 35 kg ha^{-1}, 70 kg ha^{-1} and 600 kg ha^{-1} respectively increased the grain yield. However for the second crop at Ottappalam significant yield reduction was not observed even with the 17.5 kg ha^{-1} of P.

Pooled analysis of yield data showed significant influence of higher level of P at 35 kg ha^{-1}. Potassium at higher level of 70 kg ha^{-1} significantly increased the yield. But higher level of lime application at 600 kg ha^{-1} significantly increased only the straw yield. However higher level of P, K and lime at 35, 70 and 600 kg ha^{-1}

respectively increased the major nutrient content of the plant and decreased the Fe and Mn contents.

There was significant increase in the uptake of N, P and K while the Fe uptake was reduced by the higher level of K application. Potassium and phosphorus applied together in general decreased the Fe uptake while it enhanced the uptake of P and K.

Soil available major nutrients also showed significant positive response to higher level of K and lime application. There was an increase in the N, P and K contents of the soil at higher level of P application at 35 kg ha^{-1}. The available Fe and Mn contents of the soil showed significant decrease at higher dose of K and lime.

Correlation studies showed significant positive correlation of N/Fe, P/Fe, K/Fe and K/Ca+Mg ratios of soil and plant with yield which indicated that an increase in P and K followed a decrease in the Fe content of soil which subsequently increased the yield.