EFFECT OF NUTRIENT INTER-RELATIONS ON PRODUCTIVITY OF RICE IN LATERITIC SOILS

By
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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Effect of nutrient inter-relations on productivity of rice in lateritic soils"** is a bonafide 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 **"Effect of nutrient inter-relations on productivity of rice in lateritic soils"** is a record of research work done independently by **Miss. Sindhu P.V.**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

chl. – Chlorophyll

DAT – Days after transplanting

MT – maximum tillering

MTL – leaf blade at maximum tillering

MTS – leaf sheath at maximum tillering

PI – panicle initiation

PIL – leaf blade at panicle initiation

PIS – leaf sheath at panicle initiation

Introduction

INTRODUCTION

Sustainability is the crux of any continuing enterprise. In production systems, sustainability is primarily decided by the efficiency of the inputs as well as their proper integration. Sustainability is basic to agriculture especially for food crops like rice, as it has to continue indefinitely. However recent trends show that it is being threatened, which calls for an in depth analysis and formulation of remedial measures to preserve the same.

Structural modification of the plant type to circumvent self inhibitory influences of production, like mutual shading, has wiped out the inherent limiting effects of the plant. Inculcation of photo and thermo periodic insensitivity into plant types have significantly foreclosed the possibility of weather influences limiting productivity. These two achievements in the preceding half century have narrowed down the causes of low productivity and wide yield variation from place to place exclusively to soil effects or otherwise to management lacunae. Thus measures to bridge the gap between realisable and realised yields as well as to ensure maximum expression of genetic potential and sustainability have become the bounden duty of crop managers.

Harvested yields of rice grain in acid kole soils and alkaline black soils work out to 8-9 MT ha^{-1} as against 3 MT ha^{-1} in lateritic soils. Thus poor average productivity of rice in this state is because of the inhibited yield expression of rice in the laterites. Super performance of rice in soils of different composition and chemical properties serves as ample proof that laterite soils also can be made to yield highly. Intensive investigations on the yield limiting influences of rice in laterite soils have revealed absence of response to major nutrients, lime and high accumulation of iron in the plant (Potty, 1965) and chlorophyll instability (Bridgit and Potty, 1992). Musthafa (1995) found that widening N/Fe ratio of the plant is conducive for higher realised yields. Marykutty *et al.* (1992) have reported that more than the individual contents of elements, it is a narrow Ca+Mg/K ratio which decides the yield in rice. Bridgit (1999) found that yield of rice could be increased without any addition of N and P beyond POP recommendations, if Fe and Mn absorption could be restricted and leaf sap pH maintained at around 6.2. She had suggested enhancement of K levels and inclusion of S in nutritional management for high yields and nitrogen use efficiency. In-depth analysis of nutritional effects by Sreekumaran (1998) and Bridgit (1999) showed that interrelation among nutrients decided the yield expression. Information on nutrient interactions affecting the nutrients themselves as well their influence on regulation of yield are meagre. Theoretically, interactions are governed by nature, valency, concentration and bonding strength of elements which are found to vary with plant specificities. As conventional fertility management includes only application of three elements but involves native elements, applied – native element characteristics are found to modify the net effects. The present study was undertaken to collect information on these aspects in rice crop management. The suspected deficiency in laterite soils from the twin angle of management and amelioration are the anions P and S, and the cations K and Ca. Hence the present study was taken up on the effects of these elements with the following objectives:

1. To elucidate interaction pattern between applied and native elements that influence productivity.
2. To find out the minimum level combination of applied elements that produce highest possible yield in laterite soils.
3. To arrive at the most sustainable management system, which brings about a balance between removal of nutrients and crop yield without depleting the soil.

Review of Literature

2. REVIEW OF LITERATURE

2.1 Significance of nutrition

Growth is defined as the progressive development of an organism. The plant is a product of both its genetic constitution and its environment. The genetic constitution is a fixed quantity for a given plant and determines its potential for growth in a favourable environment. Mineral nutrition is one of the most important environmental factors affecting growth and productivity of a crop. Where rice is concerned, the stage of growth is also important as it decides the physiological requirement of each element. In addition to the specific functions of each nutrient, the interacting influences of the different nutrients absorbed by the rice plant are also to be considered to determine nutritional influence on crop growth and productivity. Their balances in the plant system may be more important than the content of individual elements absorbed when soil contents of these elements are either at deficient or excess levels. Interaction refers to the response of one factor in the presence of another factor. In the case of nutrition, interactions are naturally to be expected as 16 elements are involved in the process of yield formation. Realised yield is the product of interaction and not the function of individual elements. In the present study the pattern of interacting influences of P, K, Ca and S at two levels, among themselves as well as on the native elements were investigated.

2.2 Nutrient function and plant behaviour

2.2.1 Phosphorus

Phosphorus (P) does not occur as abundantly in soils as N or K. Total concentration in surface soils varies between about 0.02 and 0.10%. In the case of rice, however, in general, the effect of phosphate fertilizer is not clearly recognised and the lack of phosphate is harder to observe.

The most essential function of P in plants is in energy storage and transfer. Adenosine di and tri phosphates (ADP and ATP) act as "energy currency" within plants (Tisdale *et al.*, 1997)

Phosphorus is associated with root development, early flowering and ripening and active tillering (De Geus, 1954). An adequate supply of P is associated with greater strength of cereal straw (Tisdale *et al.*, 1997). In rice, a plentiful supply of P in the early stages promotes early growth because such a high supply increases the content of nucleic acids and phospholipids. Nucleic acids can actually promote heading in rice as they control vegetative growth through protein biosynthesis and reproductive growth through flower initiation (Fujiwara, 1964). P manuring increases early tiller formation, the greater part of which ultimately provides more grains of heavier weight and also stimulates early and synchronous flowering (Bhattacharya and Chatterjee, 1978). Favourable influence of P application on tillering was also observed by Nair *et al.* (1972), Bhattacharya *et al.* (1974) and Choudhary *et al.* (1978). However Alexander *et al.* (1973), Kalyanikutty and Morachan (1974) and Suseelan *et al.* (1978) have reported lack of any response to P application on rice tillering.

Majumdar (1971) observed that there is significant increase in number of productive tillers and test weight due to P application. Contradictory reports are available on the effect of P on rice grain yields. Favourable responses have been reported by Mohanty and Patnaik (1974), Kalyanikutty and Morachan (1974), Ittiyavarah *et al.*, (1979) and Kalita and Baroova (1994). However, several workers have reported that mean grain yields were not significantly affected by P fertilizers (Dargan and Chillar, 1978, Dargan *et al.*, 1980 and Rao and Kumar, 1994).

2.2.2 Potassium

Potassium, unlike N, P and most other nutrients, does not form co-ordinated compounds in the plant. Instead, it exists solely as the K^+ ion, either in solution or bonded to negative charges such as organic radicals like the acid radical –R-COO-. As a result of its strictly ionic nature K^+ has functions particularly related to the ionic strength of solutions within plant cells (Tisdale *et al.*, 1997). Potassium (K^+) is actively taken up from the soil solution by plant roots. The concentration of K^+ in vegetative tissue usually ranges from 1 to 4% on dry matter basis. Thus plant requirements for available K are quite high. Potassium apparently does not form an integral part of any plant component and its function is catalytic in nature. It is essential for the physiological functions of carbohydrate metabolism and synthesis of proteins, control and regulation of activities of various essential mineral elements, neutralisation of physiologically important organic acids, activation of various enzymes, promotion of the growth of meristematic tissue and adjustment of stomatal movement and water relations (Tisdale *et al.*, 1997). It is also involved in imparting resistance to drought, frost, pests, diseases and physiological disorders (Balram *et al.*, 1977, Singh and Tripathi, 1979).

Potassium is indispensable to the growth and grain production of rice. Tanaka *et al.* (1977) reported that the rice plant was characterised by its high capacity of absorbing as well as exhausting K and thereby tended to maintain the K concentration in a plant at a constant level. When the K concentration in the rice plant was forced to be low, its relative growth increment decreased drastically. A positive response of rice to K application was observed by Su (1976).

Significant increase in rice plant height with increase in the levels of K was observed by Vijayan and Sreedharan (1972) and Venkatasubbaiah *et al.* (1982). A positive correlation between K application and leaf area index in rice was observed by Mandal and Dasmahapatra (1983). Increase in chlorophyll content in the flag leaf due to K application was observed by Ray and Choudhari (1960). Potassium checks the chlorophyll degradation and promotes the synthesis of both chlorophyll "a" and "b". Increase in the rate of translocation of amino acids to the grain and protein formation was reported by Mengel *et al.* (1981) and Ray and Choudhari (1960).

Potassium application positively influences yield attributes in rice. Potassium absorbed at the maximum tillering stage increases the number of panicles, spikelets per panicle and weight of grain (Su, 1976, Mandal and Dasmahapatra, 1983). Verma *et al.* (1979) observed longer panicles with increased K rates while Vijayan and Sreedharan (1972) reported greater number of spikelets per panicle. Higher grain and straw yields were reported by Gurumani *et al.* (1984). Similar results were reported by Gosh *et al.* (1994). Mikkelsen and Patrick (1968) indicated that 75 percent of the total amount of potassium is absorbed prior to the booting stage and no absorption takes place from grain forming to grain filling. Noguchi (1940) reported increase in the lignin content in the rice stem with increased application of K. Mitra *et al.* (1990) evaluated the effects of higher level of K (0 to 160 kg ha^{-1}) on rice in an iron toxic laterite soil and reported that Fe toxicity symptoms decreased with increasing K application.

2.2.3 Calcium

Calcium is an element required by all higher plants. It is seen as a constituent of the cementing material of plant cells. It is an important constituent of calcium pectate, which strengthens the cell wall. It maintains the turgidity of cell walls and promotes normal root growth and development. Calcium stimulated the absorption of P and K (Tanaka, 1961, Jacobsen *et al.* 1961, Erdei and Zsoldos, 1977), and accelerated more effectively the translocation of photosynthetic products compared to K and Mg. Application of lime increased rice yield by rectifying the ill effects of Fe and Al (Sahu, 1968, Dixit and Sharma, 1993, Laskar, 1990). Marykutty (1986) found that Ca application, though it raised the pH could not bring down Fe content below the critical level of 300 ppm in rice in laterite soil. Saharawat *et al.* (1999) reported that P in combination Ca and/ Mg significantly increased yield and agronomic and physiological P efficiencies and improved harvest index. Improvement in the quality of grain and straw as indicated by their protein content due to the application of calcium oxide was reported by Padmaja and Varghese (1972).

2.2.4 Sulphur

Sulphur is an important element for plants and is now recognised as the fourth major nutrient in addition to N, P and K. It is a constituent of the amino acids cysteine, cystine and methionine and the plant hormone thiamine and biotin. Sulphur is involved in the formation of chlorophyll, activation of enzymes and in the formation of glycosides and glucosinolates. Tandon (1986) and Nair (1995) reported that more that 80% of Indian soils are deficient in sulphur. Rice plant requires 1.67kg sulphur to produce one ton hulled grain (Suzuki, 1977). Application of S up to 60 kg ha^{-1} increased the growth attributes and yield of rice (Singh *et al.*, 1993, and Raju *et al.*, 1995). However Liu *et al.* (1989) reported that application of S retarded organic matter accumulation in paddy soil, increased available P and S and released K from the clay crystal lattice. Significant negative correlation between N:S ratio and yield was reported by Bansal (1991). A wide N:S ratio drastically reduces the yield.

Sulphur application is known to reduce plant content of iron by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970 and Pillai, 1972). Ramaswamy (1992) found that rice plant removes 37-42kg S ha^{-1} and that elemental S will not facilitate heavy absorption immediately, but Singh *et al.* (1990) was of the view that steady supply of S from elemental sulphur ensured better growth. Nanawati *et al.* (1973) showed that the content of chlorophyll, water-soluble protein and peroxidase in rice were significantly reduced under conditions of sulphur deficiency. These results are similar to those of Thomas *et al.* (1950) who found 40% less chlorophyll in the leaves of sulphur deficient *Medicago sativa* plants than in non-deficient plants.

2.3 Nutrient interaction basis

Two or more growth factors are said to interact when their individual influence is modified by the presence of one or more of the others. When factors in combination result in a growth response that is greater than the sum of their individual effects, interaction is positive and when the combined effect is less, the interaction is negative. In the former case the factors are synergistic, whereas in the latter they are antagonistic. Additivity indicates the absence of interaction. Because of the complex interdependence of growth factors in biological systems, numerous interactive effects have been identified (Summer and Farina, 1986). 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 where nutrient and other growth factors are in favourable state of balance. As one moves away from this state of balance, nutrient antagonisms are reflected in reduced yields (Summer and Farina, 1986).

Nutrient absorption by plants is usually referred to as ion uptake or ion absorption, because it is in the ionic form that nutrients are absorbed. Cations and anions may be absorbed independently and may not be absorbed in equal quantities. Electro neutrality must be maintained within reasonable limits in the plant and in the growth medium because ionic relationships achieve major importance in plant nutrition (Fageria, 1983).

Apart from the availability of adequate quantities of nutrients in soil, it is also important to have a proper balance between the nutrient constituents present both in the soil and in the plant. It is well known that all the essential and other beneficial elements are involved in mutual interaction among themselves. Interaction between nutrient elements can be synergistic or antagonistic and the type of interaction is usually characteristic of the plant species (Emmert, 1961).

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).

2.4 Nutrient interactions

2.4.1 P × K

Wahid *et al.* (1977) found positive significant correlation between P and K contents in the 14th leaf in coconut. Sindhu (1997) reported that in banana, with increased level of K, N content decreased, while P showed an increasing trend. Muthuswamy *et al.* (1974) indicated that potassium application was correlated with the uptake of N, P and K by rice. Similar findings were reported 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 Lahav (1972) in banana. Lakshmikanthan (2000) reported that at higher level of K uptake of P significantly increased at maximum tillering stage in rice. Bridgit (1999) also reported similarly.

2.4.2 P × S

Haque (1992) reported that P application increased S loss from flooded soil and resulted in a higher negative S balance for rice. Kumar and Singh (1994) observed that under sulphur deficient conditions, phosphorus in plants is not properly utilised and hence an increase in total phosphorus occurs. Aulakh and Dev (1978) indicated that higher application of phosphorus resulted in an increase in sulphur content in soil solution as a result of anion exchange, ultimately resulting in higher sulphur absorption. In black pepper synergistic interaction between P and S was reported by Mathew (1993).

2.4.3 P × Ca

Synergistic relationship between P and Ca in coconut was reported by Prabhakumari (1992). Deguchi and Ota (1957) reported that Ca stimulates the absorption of P and K under certain concentration ranges of ions in nutrient solutions. Padmaja and Varghese (1972) observed as increase in phosphorus content of the grain and straw by the application of calcium. According to Erdei and Zsoldos (1977) calcium stimulated the absorption of P and K and accelerated more effectively the translocation of photosynthetic products as compared to K and Mg. An increase in the available N and P content of the soils by the application of graded levels of lime has been observed by Marykutty (1986).

2.4.4 K × Ca

Marykutty (1986) reported that application of lime significantly decreased available potassium status of the soil from a mean value of 85 ppm to 39.7 ppm. Deguchi and Ota (1957) observed increase in absorption of K by the addition of Ca. Erdei and Zsoldos (1977) also observed the same stimulatory effect of Ca and uptake of K. According to Bridgit (1999) calcium application narrowed K/Ca, K/Mn, K/Fe, K/Zn and K/Cu ratios in plants. Prabhakumari (1992) observed antagonistic relationship between K and Ca in coconut. Jacobson *et al.* (1961) reported that Ca stimulates absorption of K and Rb while it inhibits the absorption of

Na and Li in plant roots. Bridgit (1999) observed that $\frac{Ca + Mg}{K}$ ratio in the plant showed a negative correlation with yield and total biomass. Applied K decreased Ca and Mg content in plants raised in alluvial soils (Chakaravorti, 1989). According to Bridgit (1999) though the application of Ca reduced Fe content, it failed to improve yield because it increased Ca content and increase in calcium alone tilted the $\frac{Ca + Mg}{K}$ balance. Sudhir *et al.* (1987) reported that absorption of K is stimulated by Ca ions at low concentrations and decreased at high concentrations. Daliparthy (1994) reported that magnesium (Mg) or calcium (Ca) deficiency occurs from ion antagonism in acid soils following K fertilization and in soils with high exchangeable K. Ho (1968) observed a decrease in leaf Ca content by potassium application in banana. According to Nair and George (1960), resistance to bunchy top may really be correlated to the ratio of $CaO+MgO/K_2O$ and not merely CaO/MgO ratio in the leaf. Fernandez *et al.* (1973) found that K was negatively correlated with Ca and Mg in all stages. Sindhu (1997) reported a decreasing trend of Ca and Mg contents in banana with increasing K.

2.4.5 K × S

Sulphur has been reported to increase K absorption and productivity of oil seed crops by Daliparthy (1994). Prabhakumari (1992) observed antagonistic relationship between K and S in coconut. Kumar and Singh (1994) observed an increase in total potassium in sulphur deficient plants, because of improper utilization of potassium. Jaggi *et al.* (1995) have reported an increase in potassium concentration in plants due to sulphur application.

2.4.6 Ca × S

Aulakh and Dev (1978) observed that when Ca content was increased in plants, sulphur uptake also increased, thus there was synergistic effect. Studies conducted by Bridgit (1999) on the effect of Ca and S on nutrient ratios showed that application of S widened K/Mn, K/Fe, K/Zn, K/Cu and K/Ca ratios and narrowed N based ratios at panicle initiation and flowering stages. Calcium on the other hand narrowed them. Prabhakumari (1992) observed synergism between S and Ca.

2.4.7 P × K × Ca

Deguchi and Ota (1957) reported that Ca stimulates the absorption of P and K under certain concentration ranges of ions in nutrient solutions. According to Erdei and Zsoldos (1977) calcium stimulated the absorption of P and K and accelerated more effectively the translocation of photosynthetic products compared to K and Mg.

2.4.8 P × K × S

Potassium interacts with many other plant constituents to affect crop yield and quality and the magnitude of this interaction is high in areas of high cropping intensity like the tropics. Ca deficiency occurs from ion antagonism following K fertilization and in soils with high exchangeable K. Sulphur has been reported to increase K absorption and productivity of crops. With increasing levels of applied or soil K the severity of phosphorus induced Zn deficiency has been observed to decrease (Daliparthy *et al.*, 1994).

2.5 Levels of elements and interaction

Mitra *et al.* (1990) reported that Fe toxicity symptoms decreased with increasing K applications. Vijayalakshmi and Mathan (1991) observed that grain and straw yields were highest with 40 kg Mg and 25 kg K_2O ha^{-1} in lowland soil at Coimbatore. Mitra *et al.* (1990) evaluated the effects of higher level of K (0 to 160 kg ha^{-1}) on rice in an iron toxic laterite soil and reported that Fe toxicity symptoms decreased with increasing K applications. Sarkunan *et al.* (1998) reported that increasing levels of P from 0 to 100 mg kg^{-1} soil progressively increased the grain yield from 16.9 to 42.5 g pot^{-1}. The interaction revealed that the grain yield increased significantly with S addition up to 25 mg kg^{-1} rate in absence of added P. Even with higher rates of P the yield declined at 50 mg S kg^{-1} indicating deleterious effect of higher levels of S. According to Choudhary and Bodiuzzaman (1992), a combination of 150 kg K + 30kg S gave the highest grain yield of 5.0 t ha^{-1} and 1000 grain weight of 17.10 g. Bridgit (1999) observed that increasing the levels of K significantly increased the height of the plant at PI, flowering and harvesting stages and increases were 1.2 and 6.2% at PI, 1.8 and 8% at flowering and 0.5 to 7.7% at harvest over 60 and 120 kg ha^{-1} respectively. Increasing levels of K beyond 120 kg ha^{-1} did not have any effect. Singh *et al.* (1989) reported that increasing rates of each nutrient viz., N, P, and K increased yield and uptake of N, P and K, in rice and wheat. Sahu *et al.* (1996) reported that rice produced maximum yield with application of 33 kg K and 30 kg S ha^{-1}. Upadhyay (1995) observed that grain yield increased significantly up to 100 kg N + 50 Kg P_2O_5. There were no significant effects of K application on grain yields. Bhargava *et al.* (1985) found that on soils of humid to semi arid western ghats and Karnataka plateau, application of 60 kg K_2O ha^{-1} over N and P gave 5.1-8.3 and 2.3-5.56 kg rice and wheat grains respectively per kg of applied K_2O. According to Subbaiah and Mitra (1997) the application of 4 tonnes of lime produced highest grain yields of 5.0 and 4.93 t ha^{-1}. Liming and P application increased the uptake of N and P. Raju *et al.* (1995) reported that application of S up to 60 kg ha^{-1} increased the growth attributes and yield. Bridgit (1999) reported that application of 200kg S ha^{-1} significantly reduced the chlorophyll "a" content over that of 100 kg S ha^{-1} at PI as well as in boot leaf and the decreases were 1.2 and 0.9%.

2.6 Form of the source and interaction

Bajpai and Joshi (1992) found that application of 120 kg P ha^{-1} as mono calcium phosphate gave the highest grain and straw yields and N, P and K concentrations. Mutanal *et al.* (1998) found that application of 75 kg P_2O_5 as 50:50 rock phosphate: diammonium phosphate produced highest mean grain yield of 5.21 t ha^{-1} which was not significantly different from 4.79 t obtained with diammonium phosphate applied alone. Gupta *et al.* (1997) reported that among different sources of S, sulphur powder produced highest mean yield (4.41 t ha^{-1}), which was significantly better than that with gypsum and iron pyrites. Yu *et al.* (1998) observed that number of effective panicles was higher with application of calcium magnesium phosphate than with calcium super phosphate. The number of green leaves/plant, the number of effective grains/panicle and 1000-grain weight were also higher with calcium magnesium phosphate than with calcium super phosphate. Singh *et al.* (1990) reported that steady supply of S from elemental sulphur ensured better growth. Clarson and Ramaswamy (1992) reported that elemental sulphur would not facilitate heavy absorption immediately. In Japan, Matsuda *et al.* (1954) reported that in pot experiments, rice plants suffered from sulphur deficiency when continuously supplied with sulphur-free fertilizers.

2.7 Interaction and soil

Mitra *et al.* (1990) found that in a Fe toxic lateritic soil the effects of 0-160 kg K_2O ha^{-1} on rice decreased the Fe toxicity symptoms and increased yields. Sarkunan *et al.* (1998) reported that on a P and S deficient sandy loam soil, rice plants which did not receive P were stunted in growth with limited number of tillers. Increasing levels of P from 0 to 100 mg kg^{-1} increased the grain yield and the interaction revealed that the grain yield increased significantly with S addition in absence of added P. Thakur *et al.* (1996) reported marginal improvements in grain yield under different treatments in a silty clay soil at Pusa. Liu *et al.* (1989) reported that sulphur application retarded organic matter accumulation in paddy soil, increased available P and S and released K from clay crystal lattice. Qadar (1989) reported that K application tended to increase yield in sodic soil by reducing the concentration of Na in the shoots, which resulted in a better ionic balance and increased growth and yield.

2.8 Interaction and phase of growth

Srivastava and Shanker (1989) reported that application of P or N+P increased P uptake. Of the total P uptake 30-35% was absorbed up to tillering and 65-70% before flowering. Raju (1999) observed that application of K_2O at 40 kg ha^{-1} did not influence the yield and yield attributes when applied either as basal or at active tillering or in 2 equal splits (basal and PI). However 40 kg K_2O applied at PI stage remarkably enhanced the yield over no K.

Palaniappan *et al.* (1992) observed that application of 60 kg K_2O ha^{-1} as splits at various growth stages increased uptake of N and K in grain and straw. Hayashi *et al.* (1951) showed that partial productive efficiency of phosphorus for rice grains was higher in the early period than in the late period. It was pointed out that the reason for this was that phosphorus being an easily translocated element, there was the possibility of supplying adequate P during the early growth period to promote tillering and retranslocating the nutrient to other organs later. Bridgit (1999) found that potassium affected Chl.'b' content at PI and Chl.'a' content at boot leaf. Highest contents were recorded at both stages at 120 kg K ha^{-1} and the same were significantly lower at 180 kg K ha^{-1}. Tanaka (1956) observed that until panicle formation stage, potassium continuously moved to and accumulated in the centrally active leaves at each of their developmental stages just like N and P. Mikkelsen and Patrick (1968) reported that 75% of the total amount of K is absorbed prior to booting stage and almost no absorption takes place in the growth stages from the grain forming to grain filling, while most of the potassium absorbed stays in the shoot and husk. Kiuchi (1952) reported that productive efficiency of K in rice reached a peak in 35-45 days before heading, lowered thereafter and then rose slightly again at the ripening stage. Vijayan and Sreedharan (1972) suggested that the best time of application of K was found to be half at planting and the other half at active tillering stage. Patra (1998) reported that application of fertilizer S or soil drying for 2 weeks during active tillering or panicle initiation stage and reflooding increased crop yield by eliminating S deficiency. Soil drying and reflooding influenced Mg, S, Fe, Mn, Zn and Cu nutrition of rice favourably which together accounted for 89% variability in rice grain yield.

2.9 Varietal variation and nutrient interaction

Sahrawat *et al.* (1999) reported that in a field experiment in 1994 near Man, Ivory coast on an Ultisol, acid tolerant upland rice cv WAB, was given P, Ca and Mg singly and in all possible combinations. P alone or in combination with Ca and / Mg significantly increased yield, agronomic and physiological P efficiencies and also improved the harvest index. Chen (1997) reported that K application increased the root growth, the number of roots, re growth capacity and uptake of N, P, K, Ca and Mg in rice. But the effect was dependent on the cultivars, with those cultivars with high affinity for K showing greatest increase.

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled 'Effect of nutrient inter-relations on productivity of rice in lateritic soils', was carried out at the Agricultural Research Station, Mannuthy during the first crop season of 2000-2001. The materials used and the methodology adopted for the study are described in this chapter.

3.1 Location

The Agricultural Research Station, Mannuthy, located at 10° 31' N latitude and 76° 13' E longitudes and at an altitude of 40.29 M above sea level, is situated about 6km East of Thrissur town to the right side of Thrissur-Palakkad NH-47.

3.2 Weather and Climate

The area enjoys a typical humid tropical climate. The mean weekly averages of the important meteorological parameters observed during the experimental periods are presented in Appendix 1 and fig.1

The mean maximum temperature experienced during the period of study was 29.74°C, while the mean minimum temperature was 22.66°C, with an average mean of 26.2°C.

3.3 Soil

Laterite Loamy sand of the Ultisol group is the soil type of the area. The soils are acidic in reaction with a pH of 5.3.

Fig. 1. 1 Weekly weather data during the crop period

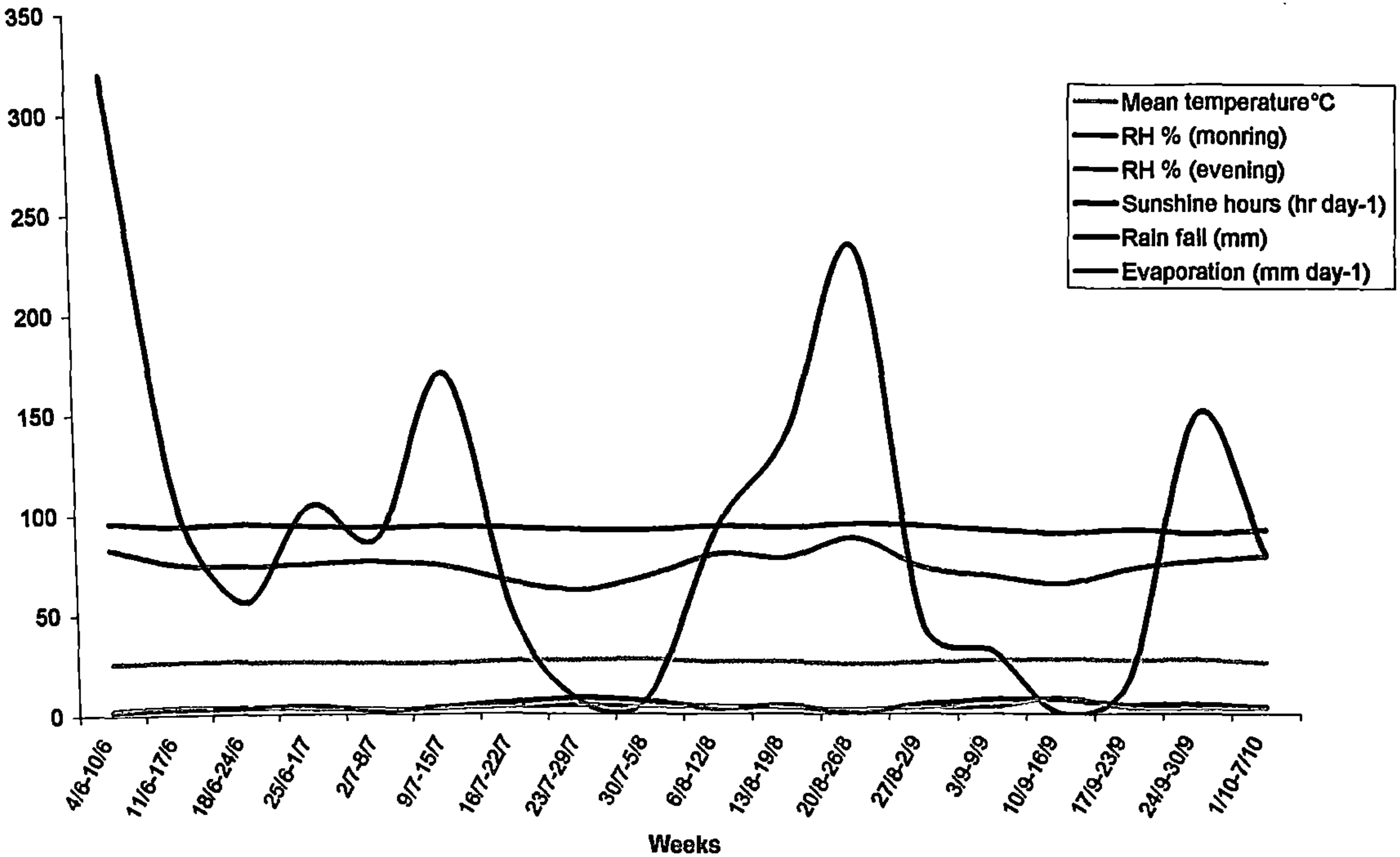

Fig.1.2 Layout of the experimental field

N↑

←5m→ ↕4m

	$p_1k_2ca_1s_1$	$p_2k_1ca_2s_2$	$p_1k_1ca_2s_1$	AC	$p_2k_1ca_1s_2$	$p_2k_2ca_2s_1$
R_1	$p_2k_2ca_2s_2$	$p_1k_1ca_1s_1$	$p_1k_2ca_2s_1$	$p_2k_2ca_1s_1$	$p_1k_2ca_2s_2$	POP
	$p_2k_1ca_1s_1$	$p_2k_2ca_1s_2$	$p_1k_1ca_2s_2$	$p_1k_1ca_1s_2$	$p_2k_1ca_2s_1$	$p_1k_2ca_1s_2$
	$p_1k_2ca_2s_2$	AC	$p_2k_2ca_1s_1$	POP	$p_2k_1ca_1$	$p_2k_2ca_1s_2$
R_2	$p_2k_2ca_2s_2$	$p_1k_1ca_1s_1$	$p_2k_1ca_2s_1$	$p_1k_1ca_2s_2$	$p_1k_2ca_2s_1$	$p_1k_2ca_1s_1$
	$p_1k_1ca_2s_1$	$p_2k_1ca_1s_1$	$p_2k_1ca_1s_2$	$p_1k_2ca_1s_2$	$p_2k_2ca_2s_1$	$p_2k_1ca_2s_2$
	$p_1k_2ca_1s_2$	$p_2k_2ca_1s_2$	$p_1k_1ca_2s_1$	$p_2k_1ca_1s_2$	$p_2k_2ca_2s_2$	$p_2k_1ca_1s_1$
R_3	$p_2k_1ca_2s_2$	POP	$p_2k_1ca_1$	$p_2k_2ca_1s_1$	$p_1k_1ca_2s_2$	$p_1k_2ca_1s_1$
	$p_1k_2ca_2s_1$	$p_1k_1ca_1s_2$	$p_2k_2ca_2s_1$	$p_1k_2ca_2s_2$	AC	$p_1k_1ca_1s_1$

P_1 & P_2 - P levels (17.5 kg ha^{-1} and 35 kg ha^{-1})
K_1 & K_2 - K levels (70 kg ha^{-1} and 105 kg ha^{-1})
Ca_1 & Ca_2 - Ca levels (150 kg ha^{-1} and 300 kg ha^{-1})
S_1 & S_2 - S levels (50 kg ha^{-1} and 100 kg ha^{-1})
POP - 70:35:35 kg NPK ha^{-1}
AC - Absolute control

Table 1. Physico-chemical characteristics of the soil of the experimental site

pH	5.3
Electrical conductivity (ds m^{-1})	0.12
Bulk density (g cm^{-3})	1.33
Particle density (g cm^{-3})	2.30
Porosity (%)	49.0
Water holding capacity(%)	49.15
Mechanical composition	
Sand %	76.25
Silt %	4.44
Clay %	18.35
Available Nutrients	
Organic carbon(%)	0.65
N (kg ha^{-1})	302.3
P (kg ha^{-1})	30.0
K (kg ha^{-1})	92.28
Ca (kg ha^{-1})	138.0
Mg (kg ha^{-1})	40.0
S (kg ha^{-1})	290.5
Na (kg ha^{-1})	103.2
Fe (kg ha^{-1})	780.85
Mn (kg ha^{-1})	125.28
Zn (kg ha^{-1})	2.1

The physico chemical characteristics of the soil of the experimental field are presented in table 1.

3.4 Crop and variety

The rice cv. Jyothi, a red kernelled, short duration variety of 110-120 days duration, was used for the experiment. The variety is suitable for direct seeding and transplanting during both first and second crop seasons, is tolerant to BPH and rice blast disease, moderately susceptible to sheath blight and capable of producing a yield of over 8 MT ha^{-1} under favourable situations and moderately good yields under adverse conditions.

3.5 Cropping history of the experimental site

The experimental area belongs to a typical double-cropped wetland. The field was under bulk cropping of rice in the previous season.

3.6 Experimental methods

The experiment was conducted during the first crop season (*Virippu*) of 2000-2001. The experimental design was 2^4+2 factorial RBD with 3 replications. The plot size was 5.0 m×4.0 m and the spacing adopted was 15 cm ×10 cm. The net plot size was 4.4 m×3.4 m. The treatment details for the crop are given below.

3.7 Treatments details

Treatments of the experiment consisted of 2 levels each of 4 elements namely phosphorus, potassium, calcium and sulphur plus two controls, all replicated thrice.

Levels of elements were

Nutrient element	Dose (kg ha^{-1})	
P	17.5	35.0
K	70.0	105.0
Lime	150.0	300.0
S	50.0	100.0

Controls

C_1 - Package of practices recommendations-70: 35:35 kg NPK ha^{-1}.

C_2 - Absolute control

Farmyard manure and nitrogen were applied uniformly as per package of practices recommendations.

Urea, Rajphos, muriate of potash, calcium oxide (burnt lime) and elemental sulphur were used as the sources of different nutrients. The nutrient content of the sources is given in table 2.

Table 2. Chemical composition of fertilizers

Fertilizer	Nutrient	Nutrient content (%)
Urea	Nitrogen (N)	46
Rajphos	Phosphorus (P_2O_5)	18-20
Muriate of potash	Potassium (K_2O)	60
Lime (CaO)	Calcium (Ca)	71.4%
Elemental sulphur	Sulphur	100

3.8 Crop culture

The cultural operations were carried out as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1996).

Seeds of the variety Jyothi were obtained from Agricultural Research Station, Mannuthy. Twenty two days old seedlings were transplanted from the nursery raised for the purpose into a well puddled and levelled field at a spacing of 15 cm×10 cm @ 2-3 seedlings per hill. Date of nursery sowing, transplanting and harvesting are given in table 3.

Table 3. sowing and harvesting dates of crop

Particulars	Date
Sowing (Nursery)	8.06.2000
Transplanting	30.06.2000
Harvesting	05.10.2000
Duration	119 days

Farmyard manure, calcium and sulphur were applied fully as basal along with third ploughing. The full quantity of phosphorus and half the quantity of nitrogen and potassium were applied at the time of planting and remaining quantity of nitrogen and potassium were applied as top dressing at panicle initiation stage (KAU, 1996). Fertilizers were applied as per the treatments.

Hand weeding was done twice at 20 and 40 days after transplanting.

Experimental plots were harvested when matured. Plants in the two border rows on all sides of each plot were harvested first and removed. Net plots were harvested by cutting at the base. Threshing was done on the same day and fresh yields were recorded. Dry weight of grain and straw were recorded at 12% moisture content.

3.9 Observations recorded

3.9.1 Biometric

1. Plant height at two weeks interval
2. No. of tillers at two weeks interval
3. No. of panicles per plant
4. Panicle characters

12 hills per plot selected at random served as the sampling unit for biometric observations

3.9.2 Physiological

1. Chlorophyll content at panicle initiation stage and at 50% flowering
2. Cell sap pH at panicle initiation stage and at 50% flowering

Chlorophyll content of index leaves was estimated colorimetrically (Yoshida *et al.*, 1972) in a Spectronic-20 Spectrophotometer.

Cell sap pH was estimated using a pH meter. A 1:2.5 leaf sample: water suspension was utilized (Jackson, 1958).

Table 4. Methods used for plant nutrient analysis

Sl. No.	Nutrient	Method	Reference
1	N	Microkjeldhal digestion and distillation method	Jackson, 1958
2	P	Vanadomolybdo phosphoric yellow colour method using Spectronic 20	Jackson, 1958
3	K	*Diacid extract using flame photometer	Cheng and Bray,1951
4	Ca	Diacid extract using atomic absorption spectrophotometer	Cheng and Bray,1951
5	Mg	Diacid extract using atomic absorption spectrophotometer	Cheng and Bray,1951
6	S	Turbidimetric method using spectronic 20	Williams and Steinbergs, 1959
7	Fe	Diacid extract using atomic absorption sepctro photometer	Sims and Johnson,1991
8	Mn	Diacid extract using atomic absorption sepctro photometer	Sims and Johnson,1991
9	Zn	Diacid extract using atomic absorption sepctro photometer	Sims and Johnson,1991
10	Si	Rapid micro determination of silicon	Nayar et al. 1975

*For the estimation of P, K, Ca, Mg, S, Mn, Fe and Zn the plant samples were digested with nitric-perchloric acid (9:4) mixture (Wilde *et al.* 1972).

Table 5. Methods used for soil chemical analysis

Sl. No.	Character	Method	Reference
1	Soil reaction (pH)	Soil water suspension of 1:2.5 and read in a pH meter	Jackson, 1958
2	Electrical conductivity	Soil water suspension of 1:2.5 and read in a pH meter	Jackson, 1958
3	Organic carbon	Walkely and Black method	Walkely and Black, 1934
4	Available Nitrogen	Alkaline permanganate method	Subbaiah and Asija 1956
5	Available P_2O_5	Ascorbic acid reduced molybdophosphoric blue colour method	Watanabe and Olsen, 1965
6	Available K_2O	NN NH_4 Ac extract using Flame photometer	Jackson, 1958
7	Exchangeable Ca	Neutral normal ammonium acetate extract(Page *et al.*1982) using Atomic Absorption Spectrophotometer	Hesse,1971
8	Exchangeable Mg	NN NH_4 Ac using Atomic Absorption Spectrophotometer	Hesse,1971
9	Available S	$CaCl_2$ extract-turbidimetry method	Chesnin and Yien, 1951
10	Available Fe	DTPA extract method using Atomic absorption spectro photometer	Lindsay and Norvell, 1978
11	Available Mn	DTPA extract method using Atomic absorption spectro photometer	Lindsay and Norvell,1978
12	Available Zn	DTPA extract method using Atomic absorption spectro photometer	Lindsay and Norvell

3.9.3 Chemical

For chemical analysis five hills were selected at random from each plot. Plant samples were collected at maximum tillering stage, 50% flowering stage and at harvest. After cleaning the samples, leaf blades and sheath were separated, dried in a hot air oven at 60±5°C, powdered well and analysed for different nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Zn and S_iO_2). The methods used for the analysis of different nutrients are given in table 4 & 5

3.10 Statistical analysis

Statistical analysis was done using the analysis of variance technique (Panse and Sukhatme, 1978). MSTATC and MS-Excel softwares were used for computation and analysis.

Results

4. RESULTS

4.1 Growth attributes

4.1.1a. Between controls

Comparative evaluation of rice growth under absolute control with recommended nutritional management is presented in table 6.1. The latter registered significant superiority over the former in improving the height at all stages of observation. The elongation phase also varied between the treatments. The highest rate of elongation under package of practices treatment (POP) was before the panicle initiation (PI) stage where as in absolute control it was between 50 and 75 days of growth.

A perusal of the data on tiller count also showed that active tillering phase preceded PI when the crop received the recommended dose, though a gradual and general decline in tiller count was noted thereafter. As against this, continued tiller production in control was evident up to 65 days after sowing. Control crops also showed a tendency to produce tillers in the maturity phase of the crop.

4.1.1b. Control Vs the rest

Data in table 6.2 showed that the mean treatment effect was significantly superior in affecting height at all stages of growth but tiller count was affected only at post panicle initiation and flowering phases. A scrutiny of the data showed that rate of elongation in pre PI stage was 75% due to mean treatment effect as against 25% in control.

Table 6. Effect of treatments on growth attributes

Table 6.1 Between controls

Treatments	Height (cm)					Tillers/hill (No.)				
	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT
C_1	31.21	51.71	60.34	68.71	68.63	5.67	6.88	6.00	6.04	5.75
C_2	25.17	34.55	48.96	53.03	53.88	4.84	5.09	5.29	4.50	4.88
CD (0.05)	2.62	4.38	4.59	6.03	5.68	NS	1.12	NS	0.90	NS

Table 6.2 Control Vs the rest

Treatments	Height (cm)					Tillers/hill (No.)				
	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Control	28.19	43.13	54.65	60.86	61.25	5.25	5.98	5.65	5.27	5.32
Rest	32.29	55.16	63.55	73.77	74.16	5.15	6.52	6.55	6.01	5.71
CD (0.05)	2.62	4.38	4.59	6.03	5.68	NS	NS	0.99	0.91	NS

Table 6. Effect of treatments on growth attributes

Table 6.1 Between controls

Treatments	Height (cm)					Tillers/hill (No.)				
	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT
C_1	31.21	51.71	60.34	68.71	68.63	5.67	6.88	6.00	6.04	5.75
C_2	25.17	34.55	48.96	53.03	53.88	4.84	5.09	5.29	4.50	4.88
CD (0.05)	2.62	4.38	4.59	6.03	5.68	NS	1.12	NS	0.90	NS

Table 6.2 Control Vs the rest

Treatments	Height (cm)					Tillers/hill (No.)				
	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT	18 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Control	28.19	43.13	54.65	60.86	61.25	5.25	5.98	5.65	5.27	5.32
Rest	32.29	55.16	63.55	73.77	74.16	5.15	6.52	6.55	6.01	5.71
CD (0.05)	2.62	4.38	4.59	6.03	5.68	NS	NS	0.99	0.91	NS

Observations on tiller count showed that rate of increase in tiller count in active tillering phase was low in controls, and the decline phase was longer. Mean treatment effect increased the rate of tiller production in active tillering phase and arrested tiller decline till flowering, which made variation in tiller counts at 45 and 65 days after transplanting significant.

4.1.1c. Mean main effects of treatments

Data on the mean main effects of treatments are presented in table 6.3. Results showed that height of plants was more responsive to input management than tiller count. Significant variation in height among treatments was apparent from 45^{th} day after transplanting onwards. Sulphur applied at 50 kg ha^{-1} recorded significantly greater height over C_1 in all the observations from 45^{th} day onwards, whereas effect of K applied at 105 kg was apparent only on 75^{th} DAT. Incremental level of Ca and S tended to reduce the height as against K, which tended to increase it. Treatment effect on tiller count showed significance only at 18 DAT and the effect was confined to absolute control.

4.1.2 Two factor interactions

Combined effect of P and Ca at higher levels of 35 and 300 kg ha^{-1} respectively manifested significant increase in height at 18 DAT (Table 7). Lower dose of P combined with higher level of Ca recorded the lowest height of 31.02 cm as against 33.18 cm in p_2ca_2. However this interaction effect was not sustained subsequently.

Table 7. Two factor interaction effects on growth attributes

Treatments	Height (cm)						Tillers/hill (No.)	
	18DAT		60 DAT		75 DAT		18DAT	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1ca_1	33.63	30.15	78.53	71.29	78.75	71.71	5.02	4.56
k_1ca_2	32.46	32.27	71.50	71.46	71.32	71.41	5.05	5.80
k_2ca_1	32.15	34.04	76.15	78.77	76.73	78.77	4.67	5.46
k_2ca_2	33.10	30.55	74.34	68.13	76.01	68.61	5.71	5.0
CD (0.05)	1.31		3.01		2.84		0.49	

Table 8. Interaction effect of P with Ca on height

Treatments	Height 18 DAT	
	ca_1	ca_2
p_1	32.65	31.02
p_2	32.34	33.17
CD (0.05)	0.65	

Table 9. Effect of treatments on physiological attributes

Table 9.1 Between controls

Treatments	Chlorophyll (mg g^{-1}) fresh weight of sample						Cell sap pH	
	PI stage			50% flowering stage			PI stage	50% flowering stage
	chl.'a'	chl.'b'	Total	chl.'a'	chl.'b'	Total		
C_1	2.37	2.33	3.34	2.26	0.83	3.19	6.8	6.60
C_2	1.60	1.35	2.25	1.10	0.53	2.21	5.73	5.40
CD(0.05)	0.48	0.15	0.46	0.30	NS	0.67	0.10	0.16

Table 9.2 Control Vs the rest

Treatments	Chlorophyll (mg g^{-1}) fresh weight of sample						Cell sap pH	
	PI stage			50% flowering stage			PI stage	50% flowering stage
	chl.'a'	chl.'b'	Total	chl.'a'	chl.'b'	Total		
Control	1.99	0.61	2.80	1.68	0.68	2.70	6.23	6.00
Rest	2.30	0.75	3.11	2.10	0.99	3.34	6.80	6.40
CD (0.05)	0.48	NS	NS	0.30	0.33	0.67	0.10	0.30

4.1.3 Three factor interactions

Data on the interaction effects of K, Ca and S (Table 8) showed that positive synergistic effect was manifested both at the lower levels of 70,150 and 50 kg ha^{-1} of all the three elements and also when higher levels of K and S were combined with lower level of Ca. This effect however was evident at 60 and 75th day also. The results also indicated that negative effect of 150 kg Ca could not be contained by an additional dose of S alone. The data further showed that if Ca level was increased to 300 kg, application of 105 kg K and 100 kg S together also would be inadequate to countercheck Ca.

4.2 Effect of treatments on physiological attributes

4.2.1a Between controls

Table 9.1 shows the main effect of treatments between controls. All physiological characters studied were seen to be higher in C_1 as compared to absolute control. Cell sap pH was also seen to be higher in this treatment.

4.2.1b Control Vs the rest

At PI stage chlorophyll content in the control plots was seen to be lower compared to other treatments and cell sap pH was also observed to be lower (Table 9.2).

4.2.1c Mean main effects of treatments

Main effects of treatments when compared showed that chlorophyll 'a' and 'b' contents were higher in the POP plots than in the other treatments. But chl. 'a' was lowest in absolute control, where chl. 'b' was seen to be highest at PI stage.

Table 9.3 Mean main effects of treatments

Treatments	Chlorophyll ($mg\ g^{-1}$) fresh weight of sample						Cell sap pH	
	PI stage			50% flowering stage			PI stage	50% flowering stage
	chl.'a'	chl.'b'	Total	chl.'a'	chl.'b'	Total		
P_1	2.28	0.79	3.11	2.11	1.01	3.29	6.79	6.42
P_2	2.32	0.72	3.12	2.02	0.97	3.39	6.75	6.37
K_1	2.29	0.75	3.20	2.07	0.94	3.40	6.77	6.44
K_2	2.31	0.76	3.03	2.07	1.04	3.27	6.77	6.35
Ca_1	2.31	0.72	3.12	2.03	1.07	3.28	6.77	6.37
Ca_2	2.28	0.78	3.11	2.10	0.91	3.40	6.77	6.42
S_1	2.25	0.79	3.13	2.15	0.98	3.54	6.77	6.43
S_2	2.34	0.71	3.10	1.98	1.00	3.14	6.79	6.36
C_1	2.37	1.03	3.34	2.26	0.83	3.19	6.8	6.60
C_2	1.60	1.35	2.25	1.10	0.53	2.21	5.73	5.40
CD(0.05)	0.48	0.15	NS	0.86	0.33	0.67	1.10	NS

Significant variation did not occur between treatments in chl. 'a' and 'b' contents (Table 9.3).

At 50 % flowering stage chl. 'a' was maximum in the POP plot while chl. 'a', 'b' and total were seen to be minimum in absolute control plots. Between treatments there was no significant difference in chlorophyll contents at 50% flowering stage.

Cell sap pH showed significant variation only at the PI stage. Absolute control was more acidic when compared to all other treatments which did not vary significantly.

4.2.2 Two factor interactions

4.2.2.1 Interaction of P with K, Ca and S

Table 10 showed that at PI stage highest total chlorophyll content was produced when P and Ca interacted at their higher levels. At 50% flowering stage P at 17.5 kg and Ca at 300 kg ha^{-1} resulted in highest chl. 'a' content of 2.24 mgg^{-1}.

Total chlorophyll and chl. 'b' content were significantly affected at the PI stage. Both were seen to be higher when 35 kg P was applied along with 50 kg ha^{-1} S.

Cell sap pH was significant at PI stage. pH towards neutrality resulted when P at lower level was combined with K at higher level.

4.2.2.2 Interaction effect of P with S

Data presented in table 11 showed that at 50 % flowering stage, total chlorophyll content was highest in p_2s_1 combination.

Table 10. Interaction effect of P with Ca, S and K on physiological attributes

Treatments	Chlorophyll (mg g^{-1}) PI stage (Total)		Chlorophyll (mg g^{-1}) 50% flowering chl. 'a'		Chlorophyll (mg g^{-1}) PI stage (Total)		Chlorophyll (mg g^{-1}) 50% flowering chl. 'a'		Cell sap pH PI stage	
	ca_1	ca_2	ca_1	ca_2	s_1	s_2	s_1	s_2	k_1	k_2
p_1	3.24	2.97	1.98	2.24	0.78	0.79	2.92	3.29	6.75	6.82
p_2	3.00	3.25	2.08	1.96	0.81	0.64	3.33	2.92	6.78	6.72
CD(0.05)	0.12		0.08		0.04		0.18		0.03	

Table 11. Interaction effect of P with Ca and S on physiological attributes

Treatments	Chlorophyll (Total), mg g^{-1} 50% flowering		Cell sap pH (PI stage)	
	s_1	s_2	s_1	s_2
p_1	3.39	3.42	6.73	6.80
p_2	3.69	2.85	6.80	6.75
CD(0.05)	0.17		0.03	

Table 12. Interaction effect of K with S

Chlorophyll (Total) 50% flowering (mg g^{-1})		
Treatments	s_1	s_2
k_1	3.18	3.62
k_2	3.37	3.17
CD(0.05)	0.17	

Table 13. Interaction effect of P and K with S and Ca on physiological attributes of rice

Treatments	Chlorophyll (Total) (mg g^{-1}) PI stage		Chlorophyll (Total) (mg g^{-1}) PI stage	
	ca_1	ca_2	s_1	s_2
p_1k_1	3.09	3.20	3.00	3.29
p_1k_2	3.38	2.75	2.85	3.29
p_2k_1	3.24	3.25	3.22	3.27
p_2k_2	2.76	3.24	3.44	2.56
CD(0.05)	0.23		0.23	

4.2.2.3 Interaction effect of K with S

Table 12 is a record of interaction effect of K with S. Total chlorophyll at 50% flowering stage was found highest when higher levels of both elements were combined.

4.2.3 Three factor interactions

4.2.3.1 Interaction between P, K and Ca

At PI stage, highest total chlorophyll content of 3.38 mg g^{-1} was recorded when P at 17.5 kg ha^{-1} combined with K at higher level and Ca at lower level (Table 13). P at lower level combined with K and Ca at higher levels and P and K at higher levels with Ca at lower level resulted in significantly lower total chlorophyll content.

4.2.3.2 Interaction between P, K and S

Table 13 showed that P, K and S interacted significantly on total chlorophyll content at PI stage. P, K and S at lower levels and P, K and S at higher levels as also P and S at lower levels in combination with K at higher level resulted in significantly lower total chlorophyll content.

4.2.3.3 Interaction between P, Ca and S

At PI stage higher contents of S in combination with lower levels of P and Ca significantly influenced chl. 'a' content except in the case of $p_2ca_2s_2$, where the content decreased. Lower content was also recorded when P and S at 17.5 and 50 kg ha^{-1} interacted with 300 kg Ca ha^{-1}. Highest chl. 'a' content was recorded in $p_2ca_2s_1$.

Table 14. Interaction effect of P, Ca and S on physiological attributes

Treatments	Chlorophyll 'a' (PI stage), mg g^{-1}		Cell sap pH (PI stage)	
	s_1	s_2	s_1	s_2
p_1ca_1	2.27	2.35	6.83	6.74
p_1ca_2	2.06	2.45	6.68	6.88
p_2ca_1	2.21	2.43	6.70	6.78
p_2ca_2	2.47	2.15	6.79	6.74
CD(0.05)	0.17		0.05	

Table 15. Interaction effect of K and Ca with S on physiological attributes

Treatments	Chlorophyll 'b' (50% flowering stage) mg g^{-1}	
	s_1	s_2
k_1ca_1	0.89	1.09
k_1ca_2	0.87	0.09
k_2ca_1	1.33	0.97
k_2ca_2	0.82	1.04
CD(0.05)	0.16	

Table 16. Interaction effect of P, K and Ca with S on physiological attributes

Treatments	Chlorophyll 'b' (mg g^{-1}) PI stage	
	s_1	s_2
$p_1k_1ca_1$	0.68	0.77
$p_1k_1ca_2$	0.89	0.77
$p_1k_2ca_1$	0.88	0.80
$p_1k_2ca_2$	0.66	0.83
$p_2k_1ca_1$	0.68	0.58
$p_2k_1ca_2$	0.90	0.73
$p_2k_2ca_1$	0.76	0.64
$p_2k_2ca_2$	0.88	0.59
CD(0.05)	0.15	

Cell sap pH at PI stage had also been significantly affected by treatment interactions. Highest pH value of 6.88 was recorded in the combination $p_1ca_2s_2$, while the lowest of 6.7 was recorded when P at higher level interacted with Ca and S at lower level (Table 14).

4.2.3.4 Interaction between K, Ca and S

Table 15 showed that at 50% flowering stage significantly higher chl. 'b' content was obtained when K at 105 kg ha^{-1} interacted with Ca and S at 150 and 50 kg ha^{-1} respectively. All other combinations were significantly inferior.

4.2.4 Four factor interactions

4.2.4.1 Interaction between P, K, Ca and S

Table 16 depicts interaction of P, K, Ca and S on chl. 'b' content at PI stage. Highest content of 0.9 mg g^{-1} was recorded when P and Ca at higher levels interacted with K and S at lower levels. Significantly lower values of chl. 'b' was produced when higher levels of P and S interacted with higher and lower levels of K and Ca.

4.3 Yield and yield attributes

4.3.1a Between controls

A perusal of the data in table 17.1 showed that POP treatment manifested significant superiority over absolute control in all the attributes studied and the increases were 36, 12.84, 65, 126, 25, 89 and 90% respectively.

Table 17. Effects of treatments on yield and yield attributes of rice

Table 17.1 Between controls

Treatments	Productive tillers/hill (No.)	Panicle length (cm)	Total grains (No.)	Unfilled grains (No.)	Filled grains (No.)	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Dry matter (kg ha^{-1})
C_1	5.83	19.33	77.0	7.67	69.33	27.6	4303.05	3346.86	7650
C_2	4.3	17.13	46.67	16.0	30.67	22.05	2276.31	1757.94	4034
CD (0.05)	0.78	1.69	8.82	2.38	8.68	1.95	399	350.8	740

Table 17.2 Control Vs the rest

Treatments	Productive tillers/hill (No.)	Panicle length (cm)	Total grains (No.)	Unfilled grains (No.)	Filled grains (No.)	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Dry matter (kg ha^{-1})
Control	5.08	18.23	61.83	11.83	50.0	25.05	3289.68	2552.40	5842
Rest	5.52	19.19	86.73	8.43	78.30	28.26	4637.14	3558.16	8195
CD (0.05)	NS	NS	8.82	2.38	8.68	1.95	399	350	740

Table 17.3 Mean main effects

Treatments	Productive tillers/hill (No.)	Panicle length (cm)	Total grains (No.)	Unfilled grains (No.)	Filled grains (No.)	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Dry matter (kg ha^{-1})
P_1	5.53	18.89	83.33	8.12	75.21	28.18	4648.41	3610.27	8258
P_2	5.51	19.49	90.13	8.75	81.38	28.38	4625.87	3506.05	8131
K_1	5.45	19.93	87.83	8.27	75.56	28.16	4634.32	3432.78	8067
K_2	5.59	18.46	85.63	8.60	77.03	28.35	4639.96	3683.54	8323
Ca_1	5.53	18.94	86.92	8.70	78.22	28.15	4673.77	3711.69	8385
Ca_2	5.51	19.44	86.54	8.17	78.38	28.37	4600.52	3404.63	8005
S_1	5.47	19.03	90.75	9.03	81.72	28.44	4637.14	3669.45	8306
S_2	5.57	19.35	82.71	7.84	74.87	28.07	4303.05	3446.87	8084
C_1	5.83	19.33	77.00	7.67	69.33	27.6	4303.05	3346.86	7649
C_2	4.3	17.13	46.67	16.00	30.67	22.05	2276	1757.94	4034
CD (0.05)	NS	1.68	8.82	2.38	8.68	NS	399	350	740

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4.3.1b Control Vs the rest

Comparison between controls mean and average inputs mean of P, K, Ca and S showed significant differences in respect of number of grains, unfilled grains as well as in thousand grain weight. Mean input effect recorded 40, 57 and 12 percent higher no. of total grains, filled grains and thousand grain weight over that of controls. Unfilled grains were significantly higher in control (40%) over mean main effect

Yield of grain and straw were higher over controls in main effect.

4.3.1c Mean main effects of treatments

Productive tillers and 1000-grain weight alone were not significantly affected by mean main effect of treatments. Length of panicle, total number of grains and filled grains significantly increased whereas unfilled grains decreased over control. K, Ca and S at 70, 300 and 100 kg ha^{-1} recorded the maximum panicle length in the order named. Sulphur applied at 50 kg and P applied at 35 kg produced 90.75 and 90.13 grains per panicle respectively, as against 60 grains in control. Highest number of unfilled grains viz., 16 per panicle was recorded by control as against 8 due to sulphur at 100 kg (Table 17.3).

The data further showed that yields of grain and straw were significantly affected.

4.3.2 Interaction effect of P with K, Ca and S

Interaction effect of P with K significantly affected number of unfilled grains, P with Ca affected yield and with S affected total number of grains, filled

Table 18. Two factor Interaction effects on yield and yield attributes

Table 18.1 Interaction effect of P with K, Ca and S

Treatments	Unfilled grains (No.)		Grain yield (kg ha^{-1})		Total grains (No.)		Filled grains (No.)		Grain yield (kg ha^{-1})	
	k_1	k_2	ca_1	ca_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	8.75	7.49	4597.70	4699.10	90.42	76.25	81.20	69.20	4518.80	4778.00
p_2	7.79	9.70	4749.8	4501.90	91.08	89.17	82.20	80.5	4755.5	4496.30
CD (0.05)	0.06		99.98		2.21		2.17		99.98	

Table 18.2 Interaction effect of K with Ca and S

Treatments	Panicle length (cm)		Total grains (No.)		Filled grains (No.)		Grain yield (kg ha^{-1})	
	ca_1	ca_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	19.30	20.56	87.33	88.33	78.69	80.43	4546.99	4721.66
k_2	18.58	18.33	94.17	77.08	84.75	69.31	4727.29	4552.63
CD (0.05)	0.42		2.20		2.17		99.98	

grains and yield. The results showed that higher level of 35 kg P with lower level of 70 kg K recorded minimum number of unfilled grains and with lower levels of Ca gave highest grain yield. Higher level of P with lower level of S gave maximum number of total grains as well as filled grains. However grain yield in the treatment was 2215 kg less than p_1s_2, which had recorded 4778 kg grain ha^{-1} (Table 18.1).

4.3.3 Interaction effect of K with Ca and S

Data in table 18.2 showed synergistic influence of combined effect of higher dose of 105 kg K with 50 kg S, which turned antagonistic when S was increased to 100 kg. This significant synergistic effect was observed in total number of grains, filled grains and grain yield and worked out to 22,22 and 4% respectively over k_2s_2. However, the synergistic effect of K with Ca was observed only in panicle length when 300 kg Ca was combined with 70 kg K. The increase was 10% over k_2ca_1.

4.3.4 Interaction effect of P and K with S

Data in table 19 will show that synergistic combined effect of K and S at 105 and 50 kg ha^{-1} respectively had been supplemented further when P was applied at 17.5kg ha^{1}. This treatment combination produced mean number of 94.67 grains per panicle, of which 86.18 were filled. This treatment was significantly superior to $p_1k_2s_2$ and $p_2k_2s_2$ and the differences worked out to 40.6 and 42% and 9 and 11% respectively.

Combined effect of P, K and S changed its pattern of influence in panicle length. $p_2k_1s_1$ gave the significantly highest length of 20.83cm followed by 20.18 cm in $p_1k_1s_2$ and was significantly superior to $p_1k_2s_1$ by 10%.

Table 19. Interaction effect of P and K with S

Treatments	Panicle length (cm)		Total grains (No.)		Filled grains (No.)	
	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	18.82	20.18	86.17	85.17	76.23	77.60
p_1k_2	18.88	17.66	94.67	67.33	86.18	60.83
p_2k_1	20.83	19.87	88.50	91.50	81.15	83.27
p_2k_2	17.58	19.70	93.67	86.83	83.32	77.78
CD (0.05)	0.84		4.41		4.34	

Table 20. Interaction effect of P and Ca with S

Treatments	Filled grains (No.)	
	s_1	s_2
p_1ca_1	77.85	72.27
p_1ca_2	84.57	66.17
p_2ca_1	83.05	79.70
p_2ca_2	81.42	81.35
CD (0.05)	4.34	

Table 21. Four factor interaction effects on yield and yield attributes

Treatments	Panicle length (cm)		Unfilled grains (No.)		Grain yield (kg ha^{-1})	
	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	19.08	19.03	11.0	8.47	4394.86	4958.30
$p_1k_1ca_2$	18.57	21.33	8.87	6.67	4462.47	4732.93
$p_1k_2ca_1$	18.10	18.14	8.97	5.33	4485.01	4552.62
$p_1k_2ca_2$	19.67	17.18	8.00	7.67	4732.93	4868.16
$p_2k_1ca_1$	19.33	19.73	7.80	7.50	4935.77	4462.47
$p_2k_1ca_2$	22.33	20.00	6.90	8.97	4394.86	4732.93
$p_2k_2ca_1$	17.42	20.67	10.10	10.43	4980.84	4620.24
$p_2k_2ca_2$	17.73	18.73	10.60	7.70	4710.39	4169.48
CD (0.05)	1.69		2.38		399.90	

4.3.5 Interaction effect of P, Ca and S

Modification of interaction effect among P, K and S when K was substituted with Ca is presented in table 20. $p_1ca_2s_1$ also had recorded the highest number of filled grains among the different calcium combinations, but substitution reduced the number of filled grains by 1.71 grains.

4.3.4 Four factor interaction

4.3.4.1 Interactions between P, K, Ca and S

Data presented in table 21 showed that addition of Ca to P, K, S effect on yield attributes had been significant. Maximum panicle length of 22.33 cm was recorded when $p_2k_1s_1$ was fortified with Ca application at 300 kg ha^{-1}. However this was on par with $p_1k_1ca_2s_2$, which implied that either of the anionic components should be at the higher level. This is further noted in the effect of treatment combinations in regulating lowest number of unfilled grains. However, these effects were not carried forward to the yield. Highest yield of 4980 kg ha^{-1} was recorded at $p_2k_2ca_1s_1$ followed by $p_1k_1ca_1s_2$ and $p_2k_1ca_1s_1$ with 4958 and 4933 kg ha^{-1} respectively. The data also showed that the treatment combinations which gave the maximum panicle length and minimum unfilled grains failed to give maximum yield. The grain yield in the treatment $p_2k_1ca_2s_1$ was significantly lower to $p_2k_2ca_1s_1$ and was also significantly inferior in panicle length and unfilled grains.

4.4.1 Elemental composition of leaf blade at maximum tillering

4.4.1a Between controls

Data presented in table 22.1 showed that absolute control recorded significantly higher contents of Mg, Mn and Zn over POP and lower contents N, P,

Table 22 Effect of treatments on nutrient content of Leaf blade at maximum tillering

Table 22.1 Between controls

Treatments	Leaf blade at maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	S_iO_2 (%)
C_1	5.57	0.19	1.55	0.12	0.02	3110.00	616.67	1502.67	53.33	1.77
C_2	2.63	0.10	0.63	0.03	0.17	1533.33	801.67	1153.67	101.67	1.53
CD (0.05)	0.10	0.06	0.13	0.009	0.02	12.58	NS	17.68	21.92	NS

Table 22.2 Control Vs the rest

Treatments	Leaf blade at maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	$Si O_2$ (%)
Control	4.10	0.15	1.09	0.07	0.10	2325.00	709.17	1238.00	77.50	1.65
Rest	4.67	0.18	1.56	0.25	0.10	2215.48	584.90	1245.98	65.48	2.42
CD (0.05)	0.10	NS	0.13	0.01	NS	12.58	177.35	17.68	NS	0.42

Table 22.3 Mean main effects

Treatments	Leaf blade at maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Si O_2 (%)
P_1	4.70	0.17	1.59	0.24	0.08	2181.75	577.71	1448.79	62.88	2.43
P_2	4.65	0.18	1.54	0.26	0.12	2249.21	592.08	1043.17	68.08	2.41
K_1	3.91	0.17	1.82	0.29	0.10	2245.96	658.12	1524.42	69.38	2.54
K_2	5.44	0.19	1.30	0.21	0.10	2185.00	511.67	967.54	61.58	2.30
Ca_1	4.21	0.17	1.69	0.23	0.11	2094.92	538.54	1238.17	56.83	2.61
Ca_2	5.13	0.18	1.44	0.27	0.09	2336.04	631.25	1253.79	74.13	2.23
S_1	4.60	0.18	1.39	0.27	0.12	2351.96	586.46	1736.29	68.29	2.65
S_2	4.74	0.17	1.73	0.23	0.08	2079.00	583.33	755.67	62.67	2.19
C_1	5.57	0.19	1.55	0.12	0.02	3110.00	616.67	1502.67	53.33	1.77
C_2	2.63	0.10	0.63	0.03	0.17	1533.33	801.67	1153.67	101.67	1.53
CD (0.05)	0.10	NS	0.13	0.01	0.02	12.58	17.68	177.68	NS	0.42

K, Ca, S, Fe and Si. The increment over POP worked out to 750, 3, 91% and decreases were 112, 90, 146, 300, 103, 30 and 16 % respectively.

4.4.1b Control Vs the rest

A comparison between means of control and treatments (Table 22.2) showed that N, P, K, Ca, Fe and Si were higher in the latter and the increases were 14, 20, 43, 257 and 47% respectively. Control plots showed an increase of 5, 21 and 18% S, Mn and Zn over treatment effect.

4.4.1c Mean main effects of treatments

Data on the mean main effects of treatments showed that foliar contents of all the elements except P and Zn were significantly affected. Though all the treatments increased N and S content over absolute control, they were significantly inferior to POP in affecting foliar contents of N and S at maximum tillering stage. Contrary to this, treatment main effects showed significant superiority in the foliar contents of K, Ca, Mg and Si. K applied at 70 kg gave the highest content 1.82% K, 0.29% Ca and 658 mg kg^{-1} Mn. S_1 recorded the highest content of Mg, S, Fe and Si of 0.12%, 2351 mg kg^{-1}, 1736 mg kg^{-1} and 2.65% respectively (Table 22.3).

4.4.2 Two factor interactions

4.4.2.1 Interaction effect between P and K

It can be seen that interacting influences of P and K significantly affected the contents of all elements studied. Increasing the level of K in the presence of 17.5 kg P increased N and P and decreased K, Ca, Mg, S, Mn, Fe, Zn and Si. However, when the level of P was raised to 35 kg ha^{-1}, magnitude of effect varied. It is also to

Table 23. Two factor interaction effect of treatments on elemental composition of leaf blade at MT

Table 23.1 P× K

Treatments	Leaf blade at maximum tillering															
	N(%)		P (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Si O_2 (%)	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
p_1	3.89	5.51	0.15	0.20	0.08	0.08	2186	2177.00	707.92	447.50	1850.66	1046.92	71.75	54.00	3.03	1.83
p_2	3.93	5.37	0.19	0.17	0.12	0.11	2305	2192.50	608.33	575.83	1198.17	888.17	67.00	69.17	2.05	2.77
CD (0.05)	0.02		0.02		0.01		12.58		44.34		17.67		5.48		0.10	

Table 23.2 P×Ca

Treatments	Leaf blade at maximum tillering													
	N(%)		P (%)		K (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1	4.20	5.19	0.15	0.20	1.75	1.42	0.08	0.08	1842.75	2520.75	488.75	666.67	1400.67	1496.92
p_2	4.22	5.08	0.20	0.17	1.62	1.46	0.12	0.11	2347.08	2151.33	588.33	595.83	1075.67	1010.67
CD (0.05)	0.02		0.02		0.03		0.01		12.58		44.34		17.67	

Table 23.3 P × S

Treatments	Leaf blade at maximum tillering													
	N(%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Si O_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	5.00	4.39	1.56	1.61	0.26	0.22	0.08	0.08	2366.92	1996.58	2171.92	725.67	2.94	1.93
p_2	4.21	5.09	1.22	1.86	0.28	0.24	0.15	0.09	2337.00	2161.42	1300.67	785.67	2.36	2.46
CD (0.05)	0.02		0.03		0.005		0.01		12.58		17.67		0.10	

Table 23.4 K ×Ca

Treatments	Leaf blade at maximum tillering																	
	N (%)		P (%)		K (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Si O_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
k_1	3.19	4.63	0.13	0.21	1.87	1.78	0.08	0.12	2409.91	2082.00	541.25	77.00	1463.17	1585.67	49.25	89.50	2.84	2.237
k_2	5.24	5.64	0.22	0.16	1.50	1.01	0.13	0.07	1779.92	2590.08	535.83	487.50	1013.17	921.92	64.42	58.75	2.38	2.218
CD (0.05)	0.02		0.02		0.03		0.01		12.58		44.34		17.67		5.48		0.10	

be noted that at 70 kg K, increasing the level of P to 35 kg from 17.5 kg ha^{-1} increased N and P but decreased K, Ca, Mn, Fe, Zn and Si (Table 23.1).

4.2.2 Interaction between P and Ca

Application of 300 kg Ca in the presence of 17.5 kg P increased N, P, S, Mn and Fe significantly over p_1ca_1 by 24, 33, 37, 36 and 7 per cent respectively (Table 23.2). Increasing the level of P to 35 kg ha^{-1} in the presence of 150 kg Ca gave the lowest content of N and highest content of K, Mg and S and the increases worked out as 11, 9 and 9 % over p_2ca_2 and higher contents of K and Mg over p_1ca_2 and p_1ca_2 (14 and 50% respectively).

4.4.2.3 Interaction between P and S

Data presented in table 23.3 showed that higher levels of P and S, viz. 35 and 100 kg ha^{-1} recorded the highest contents of N and K. Combining 50 kg S with 17.5 kg P registered highest blade content of S, Fe and Si. Increasing the level of P reduced N and K and increased Ca and Mg contents over p_1s_1.

4.4.2.4 Interaction between K and Ca

Combined application of 105 kg K and 300 kg Ca gave the highest blade contents of N and S (77 and 7% respectively) and lowest contents of K, Mg, Mn, Fe and Si (Table 23.4) and the variations were 70, 14, 11, 59 and 28% over k_1ca_1. Increasing the level of K to 105 kg with 150 kg Ca reduced the N and S contents by 7.6 and 45.5 % over k_2ca_2 but increased P, K, Mg, Mn, Fe, Zn and Si by 37.5, 36, 85.7, 10, 10, 10 and 7% respectively over k_2ca_2.

Table 23.5 K×S

Treatments	Leaf blade at maximum tillering													
	N (%)		P (%)		K (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	3.67	4.15	0.19	0.15	1.68	1.96	2754.92	1737.00	707.92	608.33	2313.17	735.67	86.75	52.00
k_2	5.54	5.34	0.17	0.20	1.01	1.50	1949.00	2421.00	465.00	558.33	1159.42	775.67	49.83	73.33
CD (0.05)	0.02		0.02		0.03		12.58		44.34		17.67		5.48	

Table 23.6 Ca ×S

Treatments	Leaf bladeat maximum tillering																			
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Si O_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
ca_1	3.97	4.46	0.20	0.14	1.48	1.89	0.24	0.21	0.12	0.09	2418.92	1770.92	618.75	458.33	1838.17	638.17	51.17	62.50	2.37	2.85
ca_2	5.24	5.02	0.17	0.20	1.30	1.57	0.30	0.25	0.11	0.08	2285.00	2387.08	554.17	708.33	1634.42	873.17	85.42	62.83	2.92	1.53
CD (0.05)	0.02		0.02		0.03		0.005		0.01		3.14		44.34		4.42		5.48		0.10	

If Ca level was raised to 300 kg and K was maintained in the lower level of 70 kg ha^{-1} (Table 23.4) N, P, K and Si decreased and K, S, Mn, Fe and Zn increased significantly over k_2ca_1.

4.4.2.5 Interaction between K and S

Interaction effect between K and S (Table 23.5) showed that highest plant contents of S, Mn, Fe and Zn were recorded in the leaf blade when 70 kg K was applied along with 50 kg S. When levels of both elements were raised to 105 kg and 100 kg ha^{-1} respectively, nitrogen content increased by 4.5% and S, Fe and Mn decreased by 14, 198 and 27% respectively over k_1s_1. Combining lower dose of S with higher level of K increased N and Fe and decreased K, S, Mn and Zn over k_2s_2.

4.4.2.6 Interaction between Ca and S

Combined application of Ca and S at lower levels of 150 and 50 kg ha^{-1} respectively gave the highest contents of P, Mg, S and Fe and the lowest contents of N and Zn.

Doubling the dose of Ca increased N, Ca, Mn, Zn and Si in the leaf blade by 31, 25, 12, 68 and 23% respectively over ca_1s_1. On the other hand, increasing the dose of S to 100 kg ha^{-1} gave the lowest contents of P, Ca, Mn and Fe (reduced by 43, 14, 35 and 188% over ca_1s_1). Mg content was also reduced significantly by 33%. N, K, S, Zn and Si were increased (Table 23.6).

Table 24. Three factor interaction effects of treatments on elemental composition of leaf blade at MT

Table 24.1 P × K × Ca

Treatments	Leaf blade at maximum tillering											
	K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Si O_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1k_1	2.11	1.63	0.17	0.42	0.08	0.08	1733.00	2639.00	599.17	816.67	3.94	2.12
p_1k_2	1.39	1.21	0.09	0.29	0.10	0.06	1952.50	2402.50	378.33	516.67	1.31	2.36
p_2k_1	1.62	1.93	0.31	0.26	0.08	0.16	3086.83	1525.00	483.33	733.33	1.75	2.36
p_2k_2	1.62	0.99	0.34	0.13	0.16	0.06	1607.33	2777.67	693.33	458.33	3.46	2.08
CD (0.05)	0.07		0.01		0.02		25.16		88.68		0.21	

Table 24.2 P × K × S

Treatments	Leaf blade at maximum tillering													
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	4.54	3.23	0.16	0.13	1.95	1.80	0.25	0.35	0.06	0.10	2993.00	1379	2925.67	775.00
p_1k_2	5.46	5.55	0.22	0.19	1.18	1.42	0.28	0.09	0.11	0.05	1740.80	2614.17	1418.00	675.00
p_2k_1	2.79	5.06	0.22	0.16	1.42	2.13	0.29	0.26	0.18	0.06	2516.83	2095.00	1700.00	695.00
p_2k_2	5.62	5.12	0.13	0.21	1.02	1.59	0.27	0.20	0.11	0.12	2157.17	2227.83	900.00	875.00
CD (0:05)	0.05		0.03		0.07		0.01		0.02		21.56		35.34	

4.4.3 Three factor interactions

4.4.3.1 Three factor interaction between P and K with Ca

Data on the interaction effects among P,K and Ca are presented in table 24.1. Data showed that increase in the level of P or K or Ca tended to decrease K and Si content of the blade. Highest content of 2.11% K and 3.94% Si was recorded at $p_1k_1ca_1$. Increase in P increased S content (78%) and increase in P and Ca increased Mg contents by 100% over $p_1k_1ca_1$.

4.4.3.2 Interaction between P and K with S

Data on the interaction effects among P, K and S are given in table 24.2. Highest contents of 2993 mg kg^{-1} of S and 2926 mg kg^{-1} of Fe were recorded in $p_1k_1s_1$. Increasing the level of S to 100 kg ha^{-1} increased Ca and Mg by 40 and 67% and reduced N, P, K, S and Fe.

Increasing the level of K increased N, P, Ca and Mg by 20, 37.5, 12 and 100% and reduced S and Fe by 72 and 106% over $p_1k_1s_1$.

Increasing the levels of K and S from 70 to 105 kg and 50 to 100 kg ha^{-1} respectively increased N by 22 % and reduced K, Ca, Mg, S and Fe over $p_1k_1s_1$ by 37, 20, 14.5 and 300 %.

Increasing the level of P increased Ca and Mg contents by 16 and 22 % and decreased N, K, S and Fe over $p_1k_1s_1$.

Increasing the level of P and K increased N content by 100% and decreased P, K, Ca, Mg, S and Fe by 69, 39, 7, 64, 17 and 89 % over $p_2k_1s_1$.

Table 24.3 P × Ca × S

Treatments	Leaf blade at maximum tillering													
	N (%)		P (%)		Ca (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Si O_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1ca_1	4.63	3.78	0.17	0.13	0.12	0.13	1880.50	1805.00	2100	700	40.50	66.67	2.90	2.35
p_1ca_2	5.38	5.00	0.21	0.19	0.41	0.30	2853.30	2188.17	2243	750	91.67	52.67	2.98	1.50
p_2ca_1	3.31	5.14	0.23	0.16	0.36	0.29	2957.30	1736.80	1575	575	61.83	58.30	1.85	3.36
p_2ca_2	5.16	5.05	0.12	0.2	0.20	0.19	1716.67	2586.00	1025	995	79.17	73.00	2.87	1.57
CD (0.05)	0.05		0.03		0.01		21.56		35.34		10.96		0.21	

Table 24.4 K × Ca × S

Treatments	Leaf blade at maximum tillering											
	N (%)		K (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Si O_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1ca_1	2.52	3.86	1.96	1.77	3529.83	1290.00	2375	550	48.50	50.00	2.84	2.85
k_1ca_2	4.81	4.44	1.41	2.15	1980.00	2184.00	2250	920	125.00	54.00	2.79	1.69
k_2ca_1	5.41	5.06	1.00	2.01	1308.00	2251.80	1300	725	53.80	75.00	1.90	2.86
k_2ca_2	5.67	5.61	1.20	1.00	2590.00	2590.17	1018	825	45.80	71.67	3.06	1.38
CD (0.05)	0.05		0.07		21.56		35.34		10.96		0.21	

Increasing the level of P over $p_1k_1s_1$ increased N and K by 11.5 and 9.2% and decreased S and Fe by 43 and 321%.

Application of P, K and S at their higher levels of 35, 105 and 100 kg ha^{-1} respectively increased N, P and Mg and decreased K, Ca, S and Fe over $p_1k_1s_1$. The variation worked out to 13, 31 and 100% and 23, 25, 34 and 234% respectively.

$p_2k_2s_2$ registered an increase in the contents of N, P Mg, S and Fe by 2, 31, 100, 6 and 26% and decreased K and Ca by 34 and 40% over $p_2k_1s_2$.

4.4.3.3. Interaction effect among P, Ca and S

Data presented in table 24.3 showed that at the lowest level of P, Ca and S, none of the elements were highest or lowest in the blade at maximum tillering stage.

Increasing the level of S from 50 to 100 kg ha^{-1} reduced the N, P, S and Fe and increased Ca, Zn and S.

Increasing the level of Ca application to 300 kg ha^{-1} increased the blade contents of N, P, Ca S, Fe, Zn and S.

Increasing the levels of Ca and S together significantly decreased the contents of all the above elements over $p_1ca_2s_1$. Compared to $p_1ca_1s_1$, N, P, Ca and Zn increased and Fe and Si were decreased.

Increasing the level of P from 17.5 to 35 kg ha^{-1} decreased N, Fe and Si and increased P, Ca, S and Zn over $p_1ca_1s_2$. Compared to $p_1ca_1s_2$, in this treatment, N, Zn and Si decreased and P, Ca, S and Fe increased.

Combining higher levels of application of P and Ca with lower doses of S had been found to increase N, Ca, and Zn and to decrease P, S, Fe and Si.

When the higher levels of all the three factors were combined all the elements except Fe and Si increased over $p_1ca_1s_1$.

$p_2ca_2s_2$ increased P and S and decreased N, Ca, Fe, Zn and Si.

4.4.3.4 Interaction effect among K, Ca and S

Data on the interaction effect among K, Ca and S on the elemental composition are presented in table 24.4. At the lowest levels of K, Ca and S viz., 70 kg K, 150 kg Ca and 50 kg S, leaf blade at maximum tillering stage recorded the lowest content of N and the highest contents of S and Fe. Increasing the level of S to 100 kg ha^{-1} significantly increased N by 53 % and reduced K, S and Fe by 10, 174 and 332% respectively. Zn and Si were not affected significantly.

When Ca was increased to 300kg ha^{-1} keeping K and S constant at 70 and 50 kg ha^{-1}, N and Zn contents were found to increase significantly by 91 and 158 %. K, S and Fe contents in the blade were reduced.

The results showed that when K level was raised to 105 kg ha^{-1} keeping the other two at 150 and 50 kg ha^{-1}, N and Zn contents of the blade increased by 115 and 11 %. The level of all the other elements reduced significantly.

Application of 300 kg Ca ha^{-1} and 100 kg S ha^{-1} along with 70 kg K ha^{-1} gave significantly higher content of K and lower contents of Fe and Si over $k_1ca_1s_1$ and $k_1ca_2s_1$. Compared to $k_1ca_2s_1$, in $k_1ca_2s_2$ leaf blade contents of N and Zn reduced and S content increased significantly.

Table 25. Four factor interaction effect of treatments on elemental composition of leaf blade at MT (P×K×Ca×S)

Treatments	Leaf blade at maximum tillering															
	N (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Si O_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	4.03	2.25	2.48	1.75	0.17	0.17	0.06	0.09	3032	433	2850	650	48.00	50.00	4.53	3.43
$p_1k_1ca_2$	5.06	4.22	1.41	1.85	0.32	0.52	0.05	0.11	2953	2324	3000	900	133.00	55.00	2.50	1.73
$p_1k_2ca_1$	5.22	5.31	0.90	1.88	0.07	0.10	0.12	0.07	728	3176	1350	750	32.67	83.00	1.26	1.36
$p_1k_2ca_2$	5.70	5.78	1.46	0.96	0.49	0.09	0.09	0.03	2753	2051	1485	600	50.00	50.00	3.45	1.27
$p_2k_1ca_1$	1.02	5.47	1.44	1.79	0.35	0.26	0.13	0.04	4027	2146	1900	450	48.67	50.00	1.14	2.35
$p_2k_1ca_2$	4.57	4.66	1.40	2.46	0.23	0.29	0.24	0.09	1006	2043	1500	940	116.67	52.67	3.07	1.65
$p_2k_2ca_1$	5.60	4.81	1.09	2.15	0.37	0.31	0.17	0.15	1887	1327	1250	700	75.00	66.67	2.5	4.37
$p_2k_2ca_2$	5.64	5.43	0.94	1.03	0.17	0.08	0.05	0.09	2426	3128	550	1050	41.67	93.00	2.67	1.48
CD (0.05)	0.096		0.13		0.02		0.02		43.12		70.68		21.92		0.52	

The data further showed that combining higher doses of K and Ca with lower level of S significantly increased N and decreased Fe. Combining K and Ca significantly neutralised the effect of both on reducing S.

4.4.4 Four factor interactions

4.4.4.1 Interaction between P,K,Ca and S

Data on four factor interaction are presented in table 25. Increasing the level of S to 100kg ha^{-1} over the basal dose of 17.5, 70, 150 and 50 kg ha^{-1} reduced N, K, S, Fe and Si by 79, 42, 600, 338 and 32%. Mg tended to increase, while Ca and Zn remained unaffected.

Increasing the level of Ca to 300 kg ha^{-1} increased N, Ca, Fe and Zn and reduced K, S and Si.

A comparison of the incremental effects of Ca and S over the basal level of P, K, Ca, and S showed that S application significantly produced higher contents of N, Ca, S and Fe and the effect on reducing K content was significantly less.

Combining higher level of 105 kg K with lower levels of P, Ca and S gave the lowest contents of S and Zn. It raised the N content to 5.22% and gave the lowest contents of K and Ca in the plant. Higher level of K increased Mg and reduced Si and significantly neutralised the influence of S in reducing Fe.

Higher dose of K and S (105 and 100 kg ha^{-1}) along with lower levels of P and Ca increased N, K, Ca, S and Zn over $p_1k_1ca_1s_2$ and $p_1k_1ca_2s_2$.

Combination of higher levels of K and Ca with lower levels of P and S increased N and Ca significantly.

Higher levels of K, Ca and S at the base level of P increased N and reduced K, Ca, Mg, S, Fe and Si significantly. Increasing the level of P reduced N and Si and increased Ca, Mg and S over the lowest combination.

When levels of P and S were raised, N and Ca increased over $p_1k_1ca_1s_1$, while Mg, S and Fe contents decreased significantly. When levels of P and Ca were raised, Ca, Mg and Zn contents increased significantly and K, S and Fe were reduced over $p_1k_1ca_1s_1$.

When levels of P, Ca and S were raised, Ca and Mg contents were increased and Si was reduced significantly. Raising of P and K levels to 35 and 105 kg increased N, Ca, Mg and Zn contents, while K, S and Fe were significantly lower than in $p_1k_1ca_1s_1$.

Increasing the levels of P, K, S while keeping Ca at 150 kg increased N, Ca, Mg and Zn and decreased K, S, Fe and Si over controls.

It could also be seen from the results that when the levels of all the elements in the combinations were raised, K and Si contents could not be raised to that in the lowest level combination. In addition, Ca, Mg and S contents in the highest and lowest level combinations were the same.

4.5 Elemental composition of culm at maximum tillering

4.5.1a.Between controls

Data presented in table 26.1 showed that N and P contents in POP were significantly higher than in absolute control. While K, Ca and S contents did not differ significantly, Mg, Mn, Fe, Zn and Si were significantly higher in absolute control.

Table 26. Effect of treatments on nutrient content of culm at maximum tillering

Table 26.1 Between controls

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	SiO_2 (%)
C_1	1.95	0.21	1.12	0.04	0.02	526.67	1550.00	1712.00	53.30	1.97
C_2	1.42	0.04	1.13	0.02	0.11	468.00	2255.00	2211.67	102.00	6.50
CD(0.05)	0.11	0.01	0.09	0.02	0.05	NS	317.88	192.60	26.62	0.05

Table 26.2 Control Vs the rest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	SiO_2 (%)
Control	1.68	0.12	0.75	0.03	0.06	497.67	634.17	1961.67	77.50	2.07
Rest	2.32	0.21	1.08	0.06	0.09	2183.58	732.83	1499.54	65.00	2.19
CD(0.05)	0.11	0.01	0.09	0.02	0.05	234.70	NS	192.60	NS	0.05

Table 26.3 Mean main effects

Treatments	Culm at maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Si O_2 (%)
P_1	2.34	0.20	0.85	0.53	0.10	2071.71	760.38	1854.67	65.42	2.17
P_2	2.30	0.22	1.32	0.07	0.07	2295.46	705.29	1144.42	64.58	2.21
K_1	2.14	0.23	0.97	0.06	0.06	2470.17	777.92	1400.67	65.63	2.58
K_2	2.49	0.19	1.20	0.06	0.11	1897.00	687.75	1598.42	64.38	1.79
Ca_1	2.28	0.19	1.22	0.05	0.10	3004.96	683.38	1573.42	68.13	2.49
Ca_2	2.35	0.23	0.95	0.08	0.07	1362.21	782.92	1425.67	61.88	1.89
S_1	2.41	0.21	0.96	0.05	0.13	1466.25	681.292	1260.92	56.04	1.50
S_2	2.22	0.21	1.20	0.07	0.05	2920.92	784.38	1738.17	73.96	2.88
C_1	1.95	0.21	1.12	0.04	0.020	526.67	1550.00	1711.67	53.30	1.97
C_2	1.42	0.04	1.13	0.01	0.11	468.00	2255.00	2211.67	101.67	6.50
CD (0.05)	0.11	0.01	0.09	0.02	0.01	2347.0	317.88	192.60	26.62	0.05

4.5.1b. Control Vs the rest

Table 26.2 showed that except for Fe, all elements were higher in treatment means when compared to control means. However in the case of Fe, the reverse was true and control plots showed an increase over the rest.

4.5.1.3 Mean main effects of treatments

Comparing the culm contents of N, P, Ca and S, absolute control was significantly inferior to all other treatments (Table 26.3). However, Mn, Fe and Si contents were significantly higher than in all other treatments. Mg and S contents in POP was significantly superior to all other treatments, while the Mn content was inferior only to absolute control.

K applied at 105 kg ha^{-1} recorded highest N content (2.49%) in the culm, while Ca at 300 kg ha^{-1} recorded highest P content (0.23%) and Ca at 150 kg ha^{-1} recorded highest S content of 3004.96 mg kg^{-1}.

4.5.2 Two factor interactions

4.5.2.1 Interaction between P and K

Table 27.1 showed that P and K interacted significantly with regard to N, P, K, Mg, Fe, Zn and Si contents. K at 105 kg ha^{-1} in the presence of P at 17.5 kg ha^{-1} significantly increased the contents of N, Mg and Fe. However the lower levels of the both elements was best in recording higher contents of P, Mn and Si. K at lower level of 70 kg ha^{-1} interacted significantly with 35 kg P ha^{-1} only in the case of Zn. The same was true in the reverse i.e., p_1k_2. Higher levels of both elements recorded significant increase in the K content of the culm.

Table 27 Two factor interaction effects of treatments on elemental composition of culm at MT

Table 27.1 P × K

Treatments	Culm at maximum tillering													
	N(%)		P (%)		K (%)		Mg (%)		Fe (mg kg^{-1})		Zn(mg kg^{-1})		S_1O_2 (%)	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
p_1	1.91	2.76	0.24	0.15	0.87	0.83	0.07	0.14	1725	1983	60.00	70.83	2.79	1.54
p_2	2.36	2.22	0.21	0.23	1.07	1.57	0.05	0.09	1075	1213	71.25	57.90	2.37	2.05
CD (0.05)	0.03		0.01		0.02		0.001		44.2		6.66		0.01	

Table 27.2 P×Ca

Treatments	Culm at maximum tillering											
	N(%)		K (%)		Mg (%)		Mn (mg kg^{-1})		Fe (mg kg^{-1})		S_1O_2(%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1	1.91	2.76	0.83	0.86	0.13	0.07	637.42	883.33	1971.17	1738.00	2.26	2.07
p_2	2.38	2.22	1.60	1.04	0.07	0.07	729.30	681.25	1175.70	1113.20	2.71	1.71
CD (0.05)	0.03		0.02		0.001		79.47		44.2		0.01	

4.5.2.2 Interaction between P and Ca

Ca at 300 kg ha^{-1} interacted significantly with P at 17.5 kg ha^{-1} in the case of N and Mn, which was superior to all the other combinations. Lower levels of P and Ca recorded higher Mg content of 0.13% and Fe content of 1971.17 mg kg^{-1}. Highest contents of K and Si were recorded in p_2ca_1, which was 54 and 58.5 % greater than in p_2ca_2 respectively (Table 27.2).

4.5.2.3 Interaction between P and S

Data present in table 27.3 showed that highest contents of N, Ca, Fe and Si were obtained when P at 17.5 kg ha^{-1} interacted with S at higher level of 100 kg ha^{-1}. This treatment was superior to all other combinations with regard to N, Fe and Si contents, while in the case of S it was on par with p_2s_2. Highest culm content of Mg (0.16%) was obtained by combining P at 17.5 kg ha^{-1} with S at 50 kg ha^{-1}.

4.5.2.4 Interaction between K and Ca

Data presented in table 27.4 showed that K and Ca interacted significantly with regard to culm contents of K, Mg, S, Fe and Si at maximum tillering. K at 105 kg ha^{-1} and Ca at lower level of 150 kg ha^{-1} recorded highest K content of 1.23% which was 2.5% higher than in k_1ca_1 and 3.5% higher than in k_2ca_2. k_2ca_1 recorded highest contents of Mg (0.17%), S (1984.5 mg kg^{-1}) and Fe (1733.70 mg kg^{-1}). K at 70 kg combined with Ca at 150 ha^{-1} and 300 kg ha^{-1} increased the Si content by 8.8 and 116 % over k_2ca_1 and k_2ca_2 respectively.

Table 27.3 P×S

Treatments	Culm at maximum tillering									
	N(%)		Ca (%)		Mg (%)		Fe (mg kg^{-1})		S_1O_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	2.31	2.37	0.03	0.08	0.16	0.05	1671.00	2038	1.12	3.21
p_2	2.52	2.07	0.07	0.07	0.10	0.05	850.70	1438	1.88	2.54
CD (0.05)	0.03		0.004		0.001		44.2		0.01	

Table 27.4 K × Ca

Treatment	Culm at maximum tillering									
	K (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2(%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
k_1	1.20	0.74	0.04	0.08	4025.00	914.90	1413.00	1388	2.59	2.58
k_2	1.23	1.16	0.17	0.06	1984.50	1809.50	1733.70	1463	2.38	1.20
CD (0.05)	0.02		0.001		586.85		44.2		0.01	

Table 27.5 K × S

Treatments	Culm at maximum tillering											
	N(%)		K (%)		Mg (%)		Mn (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	2.30	1.99	0.91	1.02	0.07	0.06	878.75	677.00	1263	1538	1.84	3.33
k_2	2.53	2.44	1.01	1.38	0.19	0.04	483.80	891.70	1258.70	1938	1.16	2.42
CD (0.05)	0.03		0.2		0.001		79.47		44.2		0.01	

Table 27.6 Ca × S

Treatments	Culm at maximum tillering													
	N(%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		S_1O_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
ca_1	2.49	2.07	1.05	1.38	0.04	0.05	0.16	0.04	1510.80	4499.08	1096	2050.70	1.91	3.06
ca_2	2.34	2.37	0.88	1.02	0.05	0.10	0.09	0.05	1381.70	1342.75	1425.70	1425.70	1.08	2.70
CD (0.05)	0.03		0.02		0.004		0.001		586.85		44.20		0.02	

4.5.2.5 Interaction between Ca and S

Ca at 150 kg ha^{-1} when combined with S at 50 kg ha^{-1} gave highest contents of N and Mg and lowest contents of Ca, Mn and Fe. Doubling the dose of S increased K, S, Fe and Si contents in the culm by 31,198,87 and 60 %. Highest Ca content of 0.05% was obtained when level of Ca application was raised to 300 kg ha^{-1} keeping S at 50 kg ha^{-1} (Table 27.6).

4.5.3.1 Three factor interactions

4.5.3.1 Interaction between P, K and Ca

Table 28.1 depicts interaction effect between P, K and Ca. As in the case of leaf blade, increasing the Ca level was seen to increase the Ca content of the culm. Highest content of 0.10 % Ca was recorded in $p_2k_1ca_2$. When P was applied at 17.5 kg ha^{-1} along with K at 105 kg ha^{-1}, increasing the Ca level to 300 kg ha^{-1} was found to increase N content by 22 % over $p_1k_2ca_1$. However when Ca was applied at lower level of 150 kg, highest Mg content of 0.23 % was recorded. Higher levels of P and K combined with 150 kg Ca ha^{-1} was seen to record highest contents of K(1.65%) and Si (2.93%) and lowest content of Mn (563 mg kg^{-1}). Highest Mn content of 966 mg kg^{-1} was obtained in $p_1k_1ca_2$ which was 66 % higher than in $p_2k_2ca_1$.

4.5.3.2 Interaction between P, K and S

Data on interaction of P and K with S on elemental composition of culm are presented in table 28.2. It was seen that P at 17.5 kg ha^{-1} and K at 105 kg ha^{-1} interacted significantly with S at 100 kg ha^{-1} to produce highest contents of N, Ca and Fe and lowest content of P. When S application was reduced to 50 kg, Mg content was found to be highest but K, Ca and Si were lowest in this combination. K content was increased by 100 % when P, K and S were combined in highest levels

Table 28. Three factor interaction effect of treatments on elemental composition of culm at MT
Table 28.1 P × K × Ca

Treatments	Culm at maximum tillering											
	N(%)		K (%)		Ca (%)		Mg (%)		Mn (mg kg^{-1})		SiO_2(%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1k_1	2.12	1.70	0.85	0.88	0.04	0.06	0.04	0.09	624	966	2.68	2.91
p_1k_2	2.49	3.03	0.81	0.84	0.03	0.07	0.23	0.05	650	800	1.84	1.23
p_2k_1	2.47	2.28	1.55	0.59	0.05	0.10	0.03	0.07	875	645	2.49	2.25
p_2k_2	3.58	1.86	1.65	1.48	0.06	0.08	0.11	0.07	583	716	2.93	1.16
CD (0.05)	0.06		0.26		0.01		0.003		158.4		0.02	

Table 28.2. P×K×S

Treatments	Culm at maximum tillering											
	N(%)		K (%)		Ca (%)		Mg (%)		Fe (mg kg^{-1})		S_1O_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	2.12	1.70	0.84	0.89	0.04	0.07	0.06	0.07	1900.70	1550.70	1.58	4.02
p_1k_2	2.49	3.03	0.61	1.05	0.02	0.09	0.26	0.02	1441.00	2525.00	0.66	2.41
p_2k_1	2.47	2.28	0.99	1.15	0.06	0.08	0.07	0.04	625.00	1525.00	2.09	2.65
p_2k_2	2.58	1.86	1.42	1.71	0.07	0.07	0.12	0.05	1075.00	1350.00	1.66	2.43
CD (0.05)	0.06		0.26		0.01		0.003		83.8		0.02	

Table 28.3. P×Ca×S

Treatments	Culm at maximum tillering									
	N(%)		Ca (%)		Mg (%)		Fe (mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1ca_1	2.33	2.07	0.03	0.04	0.23	0.04	1441	2500	1.53	3.00
p_1ca_2	2.28	2.66	0.03	0.11	0.09	0.05	1900	1575	0.71	3.43
p_2ca_1	2.66	2.07	0.05	0.05	0.10	0.04	750	1600	2.30	3.12
p_2ca_2	2.39	2.07	0.08	0.10	0.09	0.05	900	1275	1.46	1.96
CD (0.05)	0.06		0.01		0.003		83.8		0.02	

Table 28.4. K × Ca × S

Treatments	Culm at maximum tillering													
	N(%)		K (%)		Mg (%)		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
K_1ca_1	2.60	1.64	1.17	1.23	0.04	0.04	799	700	1325	1500	66.00	68.00	2.17	3.00
K_1ca_2	2.00	2.34	0.65	0.82	0.09	0.07	958	654	1200	1575	50.00	77.50	1.50	3.66
K_2ca_1	2.39	2.49	0.92	1.54	0.29	0.05	501	733	866	2600	45.80	91.60	1.66	3.11
K_2ca_2	2.67	2.39	1.11	1.22	0.09	0.03	466	1050	1650	1275	61.60	58.00	0.67	1.73
CD (0.05)	0.06		0.26		0.003		158.94		83.8		13.31		0.02	

of 35 kg ha^{-1}, 105 kg ha^{-1} and 100 kg ha^{-1} respectively. Highest Si content was obtained when P and K were reduced to 17.5 and 70 kg ha^{-1} respectively.

4.5.3.3 Interaction between P, Ca and S

Data presented in table 28.3 showed that highest Mg content of 0.23% was obtained when P, Ca and S interacted at their lowest levels. However this combination produced lowest Mn content of 574 mg kg^{-1}. Increasing the S dose to 100 kg ha^{-1} increased the Fe content by 73% over $p_1ca_1s_1$. Further increase of Ca to 300 kg ha^{-1} was found to increase Ca content of the culm which was 175% higher than in $p_1ca_1s_2$. P at higher levels was found to increase Ca content when compared to lower levels.

Increasing the levels of both P and S while keeping the Ca dose at 150 kg ha^{-1} recorded highest Si content of 3.12% which was significantly superior to all other combinations. Highest N content was obtained when P application was at the higher level of 35 kg ha^{-1}, and Ca and S were kept at lower levels of 150 and 50 kg ha^{-1} respectively. When higher levels of all the three factors were combined, lowest N content was found to be obtained.

4.5.3.4 Interaction between K, Ca and S

Data on interaction between K, Ca and S are presented in table 28.4. Lowest levels of K and Ca along with 100 kg S ha^{-1} produced the highest K content of 1.13% and lowest content of N. Increasing Ca to 300 kg gave the highest Si content of 3.66 % which was 22 and 69 % higher than $k_1ca_1s_2$ and $k_1ca_1s_1$ respectively. Si showed an increasing content with increasing levels of S application.

Table 29. Four factor interaction effect of treatments on elemental composition of culm at MT (P×K×Ca×S)

Treatments	Culm at maximum tillering													
	N(%)		P (%)		K (%)		Ca (%)		Mg (%)		Fe (mg kg^{-1})		S_1O_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	2.08	1.28	0.27	0.18	0.91	0.79	0.04	0.04	0.03	0.05	1900	1650	1.81	3.56
$p_1k_1ca_2$	2.16	2.12	0.28	0.24	0.76	1.00	0.04	0.09	0.09	0.09	1900	1750	1.35	4047
$p_1k_2ca_1$	2.58	2.86	0.22	0.09	0.42	1.20	0.02	0.04	0.42	0.03	982	3650	1.25	2.44
$p_1k_2ca_2$	2.40	3.20	0.16	0.15	0.79	0.90	0.01	0.13	0.09	0.01	1900	1400	0.08	2.39
$p_2k_1ca_1$	3.11	2.01	0.06	0.25	1.44	1.67	0.05	0.04	0.05	0.02	750	1650	2.53	2.45
$p_2k_1ca_2$	1.83	2.56	0.28	0.26	0.55	0.64	0.08	0.13	0.09	0.05	500	1400	1.65	2.85
$p_2k_2ca_1$	2.20	2.13	0.21	0.26	1.41	1.88	0.05	0.06	0.15	0.06	750	1550	2.07	3.79
$p_2k_2ca_2$	2.95	1.58	0.21	0.25	1.42	1.54	0.08	0.07	0.09	0.04	1400	1150	1.26	1.07
CD (0.05)	0.11		0.01		0.09		0.02		0.005		117.68		0.05	

Highest Mg content was obtained when K at higher level interacted with Ca and S at lower levels. Increasing the S level reduced Mg content by 480 % while increasing the Ca content reduced it by 867%. Mg content was lowest when K, Ca and S at the higher levels were combined. However this combination produced highest Mn content of 1050 mg kg^{-1}.

K at 105 kg ha^{-1} and Ca at 300 kg ha^{-1} interacted significantly with S at 50 kg ha^{-1} to produce highest N content. Further increase in S level reduced N content by 12 %.

Fe and Zn contents were maximum when K and S at higher levels were combined with 150 kg ha^{-1} Ca. Decreasing the S level to 50 kg ha^{-1} reduced Fe content by 200 % and Zn content by 100 %.

4.5.4 Four factor interactions

4.5.4.1 Interaction between P, K, Ca and S

Interaction effects among P, K, Ca and S are presented in table 29. P, K and Ca at lower levels combined with lower level of 50 kg ha^{-1} S produced higher contents of N, P and K when compared to higher S dose. Increasing the level of S to 100 kg increased Mg and Si contents by 67 and 97%. S at higher level with $p_1k_1ca_1$ recorded the lowest N content.

P, K and S at lower levels combined with Ca at 300 kg ha^{-1} recorded highest P content. Increasing S level to 100 kg ha^{-1} reduced the P content by 2 % but resulted in highest Si content of 4.47 %. A similar increasing trend was seen in all elements except Fe.

K at 105 kg ha^{-1} in combination with P, Ca and S at 17.5, 150 and 50 kg ha^{-1} respectively resulted in highest Mg content. N was also found to increase but K decreased significantly to 0.42%. Increasing the S dose to 100 kg ha^{-1} significantly increased the Fe content.

P at 17.5 kg ha^{-1} with higher doses of K, Ca and S recorded highest N content which was 33 % higher than $p_1k_2ca_2s_1$. However P and Mg were minimum in this treatment combination. Reducing S to 50 kg significantly reduced Ca and Si contents. Reduction was seen in K also.

Higher levels of P and S with lower levels of K and Ca produced highest K content in the culm. An increase was also seen in P and Fe.

Increasing the levels of P and Ca over the combination of lowest levels was found to decrease N,K, Fe and Si and increase P, Ca and Mg. When the level of S was increased to 100 kg, N, Ca, Mg and Si were found to increase while P, K and Fe decreased.

Increased levels of P and K with lower levels of Ca and S increased N, K, Ca, Mg and Si contents over $p_1k_1ca_1s_1$, while P and Fe were reduced. Increasing S levels to 100 kg ha^{-1} led to an increase in N,K, Ca, Mg and Si.

Higher levels of P, K and Ca combined with lower levels of S increased the N, K, Ca and Mg contents over $p_1k_1ca_1s_1$. Further application of 50 kg ha^{-1} of S reduced the N, P, Fe and Si contents and increased the K, Ca and Mg contents over the lowest dose.

Table 30. Elemental composition of leaf blade at PI stage

Table 30.1 Between controls

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
C_1	1.18	0.08	0.71	0.23	0.01	1577	650	1636	37	7.06
C_2	1.34	0.10	1.00	0.14	0.02	514	851.67	1521	102	0.78
CD (0.05)	0.06	0.01	0.09	0.008	0.05	70	NS	NS	34	0.11

Table 30.2 Control Vs the rest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
Control	1.26	0.09	0.85	0.18	0.03	1046	750.80	1579	69.50	3.92
Rest	1.59	0.10	1.47	0.26	0.15	1747	479.00	1132	88.00	3.36
CD (0.05)	0.06	NS	0.09	0.008	0.05	70	219	77	NS	0.11

Table 31. Mean main effects

Treatments	Leaf blade at panicle initiation									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	$Si\ O_2$ (%)
P_1	1.41	0.10	1.48	0.32	0.11	1776	492.71	1250.60	91.79	2.41
P_2	1.76	0.10	1.46	0.21	0.19	1717	464.58	1013.00	84.38	4.30
K_1	1.61	0.10	1.37	0.30	0.12	1704	403.96	1144.00	83.00	3.86
K_2	1.16	0.10	1.57	0.23	0.18	1789	553.30	1119	93.13	2.86
Ca_1	1.45	0.10	1.52	0.24	0.10	1932	461.88	1075.00	88.25	4.70
Ca_2	1.72	0.10	1.42	0.29	0.19	1561.50	495.42	1188.00	87.90	2.02
S_1	1.71	0.10	1.63	0.30	0.14	1926	463.54	1450	77.63	3.75
S_2	1.46	0.10	1.31	0.23	0.16	1567.50	493.75	818.00	98.54	2.96
C_1	1.18	0.08	0.71	0.31	0.03	1577.00	650	1636	37.00	7.06
C_2	1.34	0.10	1.00	0.14	0.02	514	851.67	1521	102	0.78
CD (0.05)	0.06	0.01	0.09	0.008	0.05	70.00	219.43	77.34	34.22	0.11

4.6 Elemental composition of leaf blade at PI

4.6.1.1 Between controls

Analysis of the data presented in table 31.1 showed that absolute control registered significantly higher contents of N, P, K and Zn and the increases worked out to 14,25,41 and 176 % over POP. Ca, Mg and S contents were higher in POP by 64,100 and 207 %. In the case of Si the increase worked out to 805 %.

4.6.1.2 Control Vs the rest

Comparing with other treatments, control recorded higher contents of Mn, Fe and Si to the tune of 57,40 and 17%. However in the case of N, K, Ca, Mg and S control was significantly inferior by 26,73,44,400 and 67 % (Table 31.2).

4.6.1c. Mean main effects of treatments

Data on mean main effects of treatments are presented in table 31.3. Leaf blade contents of all elements were seen to be influenced by treatments. Treatments were found to significantly reduce N, P, K and Zn contents as compared to POP, while they significantly increased Mg, Fe and Si contents. Leaf blade contents of P, Mn, Fe and Zn were maximum in absolute control, while it recorded lowest values with regard to S and Si. Treatment mean effects registered significant superiority in N,K,Ca, Mg, S and Si contents when compared to absolute control.

P at 35 kg ha^{-1} recorded highest N content of 1.76%. Highest contents of K and Fe were recorded when S was applied at 50 kg ha^{-1} while S at 100 kg ha^{-1} recorded the highest Zn content. P at 17.5 kg ha^{-1} recorded highest Ca content of 0.32 % while K at 105 kg ha^{-1} had the maximum Mn content of 533 mg kg^{-1}. Ca at 150 and 300 kg ha^{-1} recorded the highest contents of S, Si and Mg respectively. Still

Table 32. Two factor interaction effect of treatments on elemental composition of leaf blade at PI

Table 32.1 P × K

Treatments	Leaf blade at panicle initiation																	
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
p_1	1.47	1.34	0.10	0.09	1.30	1.65	0.41	0.24	0.07	0.15	1657	1895	1200	1300	78.58	105.00	3.84	0.99
p_2	1.76	1.77	0.09	0.10	1.45	1.48	0.20	0.21	0.17	0.20	1751	1684	1088	938	87.50	81.25	3.88	4.73
CD (0.05)	0.01		0.001		0.07		0.002		0.004		25		193.3		8.55		0.03	

Table 32.2 P × Ca

Treatments	Leaf blade at panicle initiation																			
	N(%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		S_iO_2(%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1	1.16	1.66	0.09	0.11	1.60	1.35	0.26	0.39	0.09	0.12	1832	1719	561	424	1213	1288	103.58	80.00	3.30	1.52
p_2	1.75	1.78	0.11	0.09	1.44	1.49	0.22	0.20	0.11	0.26	2031	1403	362.50	566.60	938.00	1088.00	72.90	95.80	6.10	2.51
CD (0.05)	0.01		0.001		0.07		0.002		0.004		25		54.86		193		8.55		0.03	

higher contents of K and Fe were obtained when 50 kg ha^{-1} of S was applied. When S dose was increased to 100 kg ha^{-1}, Zn content was maximum.

4.6.2 Two factor interactions

4.6.2.1 Interaction between P and K

Significant interaction between P and K was seen in all the elements studied except Mn (Table 32.1). In the presence of higher levels of P and K, N, Mg and Si increased significantly. Lower levels of the two elements recorded higher contents of P and Ca. Increasing the K dose to 105 kg ha^{-1} increased K, S, Fe and Zn contents over p_1k_1.

4.6.2.2 Interaction between P and Ca

P $\times$ Ca interactions were significant in all elements studied in the leaf blade at PI stage (Table 32.2). Combining P at 35 kg ha^{-1} with Ca at 300 kg ha^{-1} resulted in higher contents of N, Mg and Mn. Lower levels of both elements recorded significant increases only in Zn content. P at 17.5 kg ha^{-1} in combination with Ca at 300 kg ha^{-1} recorded significant increases in the contents of P, Ca and Fe, while Ca at lower dose with P at higher level recorded highest S and Si contents.

4.6.2.3 Interactions between P and S

Data presented in table 32.4 showed that higher leaf blade contents of P, K, Ca, S and Fe were recorded when lower levels of P and S were applied i.e., 17.5 kg ha^{-1} and 50 kg ha^{-1} respectively. When S dose was increased to 100 kg ha^{-1}, N content was highest. Increase of P along with this resulted in higher Mg content. But S recorded a decline. P at 35 kg ha^{-1} combined with S at 50 kg ha^{-1} reduced the leaf blade contents of P and Ca.

Table 32.3 K × Ca

Treatments	Leaf blade at panicle initiation											
	N(%)		P (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		SiO_2(%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
k_1	1.40	1.83	0.10	0.10	0.29	0.31	0.07	0.17	2244.50	1163.70	6.11	1.61
k_2	1.50	1.62	0.10	0.01	0.18	0.27	0.14	0.21	1620	1959	3.28	2.43
CD (0.05)	0.01		0.001		0.002		0.004		25		0.03	

Table 32.4 P × S

Treatments	Leaf blade at panicle initiation													
	N(%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	1.63	1.18	0.11	0.09	1.70	1.25	0.41	0.23	0.11	0.11	1973	1578	1763	738
p_2	1.79	1.74	0.09	0.11	1.56	1.37	0.18	0.23	0.17	0.21	1879	1556	1138	888
CD (0.05)	0.01		0.001		0.07		0.002		0.004		25		193	

Table 32.5 Ca×S

Treatments	Leaf blade at panicle initiation																	
	N(%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
ca_1	1.44	1.47	0.12	0.07	1.76	1.28	0.26	0.21	0.07	0.14	2477.50	1387	1525.70	625.70	66.90	109.58	4.47	4.92
ca_2	1.99	1.46	0.07	0.12	1.50	1.34	0.33	0.25	0.21	0.18	1375	1747.0	1375.70	1000.70	88.30	87.50	3.03	1.01
CD (0.05)	0.01		0.001		0.07		0.002		0.004		25		193		8.55		0.03	

Table 32.6 K×S

Treatments	Leaf blade at panicle interaction															
	N(%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	1.77	1.46	0.12	0.08	1.60	0.15	0.31	0.30	0.17	0.07	2233	1174	1525.70	763	3.61	4.11
k_2	1.65	1.46	0.08	0.11	1.66	1.48	0.29	0.17	0.11	0.24	1619	1960	1375.70	863	3.89	1.82
CD (0.05)	0.01		0.001		0.07		0.002		0.004		25		193		0.03	

4.6.2.4 Interaction between K and Ca

K and Ca at lower levels of 70 kg ha^{-1} and 150 kg ha^{-1} recorded significantly higher contents of S and Ca. Further increase of Ca dose to 300 kg ha^{-1} resulted in higher contents of N, P, Ca and Mg though the content of K and Si declined.

Highest content of Mg was recorded when higher doses of K and Ca were combined, though this interaction resulted in lowest leaf blade content of P (Table 32.3).

4.6.2.5 Interaction between K and S

K and S interacted significantly at lower levels to produce significantly higher contents of N, P, Ca, S and Fe (Table 32.6). Increasing the S dose to 100 kg ha^{-1} significantly increased the Si content. K at higher level when applied with lower level of S significantly raised the K content. However this resulted in minimum content of P. Further increase in the S dose to 100 kg ha^{-1} gave the highest Mg content though the Ca and Si contents were minimum at this combination.

4.6.2.6 Interaction between Ca and S

Ca $\times$ S interaction effects are presented in table 32.5. Ca at 150 kg ha^{-1} interacted with S at 50 kg ha^{-1} producing significantly higher levels of P, K, S and Fe in the leaf blade at PI stage. However Mg and Zn were minimum in this combination. Increasing the S level to 100 kg ha^{-1} significantly increased the contents of N, Mg, Zn and Si but decreased the P, K, Ca, S and Fe contents.

Table 33. Three factor interaction effect of treatments on elemental composition of leaf blade at PI

Table 33.1 P × K × Ca

Treatments	Leaf blade at panicle initiation													
	N(%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1k_1	1.00	1.94	0.10	0.11	1.40	1.19	0.34	0.47	0.06	0.08	2263	1051	5.61	2.07
p_1k_2	1.31	1.38	0.08	0.11	1.80	1.51	0.18	0.30	0.13	0.17	1402.80	2387	0.99	0.98
p_2k_1	1.80	1.71	0.09	0.09	1.45	1.45	0.25	0.15	0.08	0.27	2226	1276	6.61	1.15
p_2k_2	1.69	1.86	0.12	0.08	1.43	1.53	0.18	0.24	0.15	0.26	1837.7	1531	5.58	3.88
CD (0.05)	0.03		0.003		0.05		0.004		0.01		50		0.06	

Table 33.2 P × K × S

Treatments	Leaf blade at panicle initiation																	
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		S_iO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	1.89	1.06	0.13	0.18	1.72	0.08	0.44	0.37	0.07	0.07	2114	1199	1150	550	73.8	83.00	4.75	2.92
p_1k_2	1.38	1.31	0.09	0.10	1.69	1.62	0.38	0.10	0.15	0.15	1832	1957	1675	925	83.00	126.70	0.90	1.08
p_2k_1	1.65	1.86	1.10	0.08	1.49	1.41	0.18	0.23	0.27	0.07	2352	1150	1200	975	66.70	108.00	2.47	5.29
p_2k_2	1.93	1.62	0.07	0.13	1.63	1.33	0.19	0.23	0.07	0.34	1406	1962	1075	800	86.70	75.80	6.89	2.57
CD (0.05)	0.03		0.003		0.05		0.004		0.01		50		386.70		17.11		0.06	

Application of Ca at 300 kg ha^{-1} along with 50 kg ha^{-1} S resulted in highest contents of N, Ca and Mg but the contents of P, K, S and Si were significantly reduced.

4.6.3. Three factor interactions

4.6.3.1 Interaction between P, K and Ca

Interaction effects of P, K and Ca are given in table 33.1. The effects were significant with regard to the contents of N, P, K, Ca, Mg, S and Si. P at 17.5 kg ha^{-1} and K at 70 kg ha^{-1} interacted with Ca at 150 kg ha^{-1} to produce higher contents of Ca and Si in the leaf blade at PI stage. Increasing the Ca level to 300 kg ha^{-1} significantly increased the contents of N, P, Ca and Mg but decreased K, S and Si contents. Application of K at 100 kg ha^{-1} in combination with P and Ca at lower levels increased the contents of N, P and Mg in comparison with $p_1k_1ca_1$ but reduced the Ca content.

Increasing Ca level to 300 kg ha^{-1} further increased the content of Mg, but all other elements decreased. P and K at higher levels in combination with 150 kg Ca resulted in the highest P content of 0.12%.

4.6.3.2 Interaction between P, K and S

P, K and S interacted significantly in almost all the elements studied (Table 33.2). P at 17.5 kg ha^{-1}, K at 70 kg ha^{-1} and S at 50 kg ha^{-1} interacted to give the highest leaf blade contents of P, K, Ca and Fe. Increasing the S dose to 100 kg ha^{-1} reduced the contents of all elements except Zn which increased by 12.5 %.

P and S in their lower levels in combination with K at its higher level reduced the contents of all elements except Mg and Zn. Increasing the S level to 100 kg succeeded in increasing the contents of S, Zn and Si, but all other elements decreased in content.

$p_2k_1s_1$ recorded higher Mg and S contents in comparison with $p_1k_1s_1$ but P, K, Ca, Fe and Si contents were significantly reduced. Increasing the S application by 50 kg ha^{-1} increased Zn and Si contents in comparison with $p_1k_1s_1$ but increased the contents of N and Ca compared to $p_2k_1s_1$.

P and K at 35 kg ha^{-1} and 105 kg ha^{-1} in combination with S at 50 kg ha^{-1} resulted in highest contents of N and Si. Increasing the S dose to 100 kg ha^{-1} significantly increased the contents of P, Ca, Mg and S but reduced the contents of N, K, Fe, Zn and Si.

4.6.3.3 Interaction between P, Ca and S

Table 33.3 depicts interaction effects of P,Ca and S on leaf blade contents of elements at PI stage. Combination of lower levels of three elements resulted in highest contents of P and K. Contents of N, Ca, S, Fe and Si were also higher when compared to contents when S was applied at 100 kg ha^{-1}.

Increasing the Ca dose with lower doses of P and S significantly increased the contents of N, Ca, Mg and Fe in comparison with $p_1ca_1s_1$. Increasing S dose to 100 kg ha^{-1} decreased the contents of N, K, Ca, Mg, S, Fe and Si, while P content alone was increased. P at 35 kg ha^{-1} interacted with Ca at 300 kg ha^{-1} and S at 50 kg ha^{-1} giving higher contents of N, S and Si content in the blade as compared to $p_1ca_1s_1$, but reduced the contents of P, K, Ca, Mg and Fe. Increasing the level to 100 kg could increase the contents of N, P, Ca, Mg and Si.

Table 33.3 P × Ca × S

Treatments	Leaf blade at panicle initiation															
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1ca_1	1.18	1.13	0.14	0.03	2.0	1.20	0.33	0.18	0.08	0.10	2213	1452.50	1700	725	3.30	3.29
p_1ca_2	2.09	1.23	0.08	0.14	1.40	1.30	0.49	0.29	0.13	0.11	1734	1704	1825	750	2.34	0.71
p_2ca_1	1.70	1.80	0.10	0.11	1.52	1.37	0.19	0.25	0.05	0.17	2741	1321	1350	525	5.64	6.55
p_2ca_2	1.88	1.68	0.07	0.11	1.60	1.38	0.18	0.21	0.29	0.24	1016	1791	925	1250	3.72	1.30
CD (0.05)	0.03		0.003		0.05		0.004		0.01		50		386.70		0.06	

Table 33.4 K × Ca × S

Treatments	Leaf blade at panicle initiation															
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1ca_1	1.54	1.27	0.13	0.06	1.78	1.08	0.28	0.31	0.05	0.08	3364	1124	1675	500	5.43	6.78
k_1ca_2	2.00	1.65	0.11	0.09	1.42	1.22	0.34	0.29	0.28	0.06	1102	1225	1375	1025	1.78	1.43
k_2ca_1	1.34	1.66	0.12	0.08	1.74	1.49	0.24	0.12	0.08	0.19	1590.80	1649	1375	750	3.51	3.06
k_2ca_2	1.97	1.26	0.04	0.15	1.58	1.46	0.33	0.21	0.13	0.29	1647.80	2270.80	1375	975	4.28	0.58
CD (0.05)	0.03		0.003		0.05		0.004		0.01		50		386.7		0.06	

P and Ca at higher levels along with S at 50 kg increased the N, Mg and Si contents but reduced the P, K, Ca, S, Fe and Zn contents in comparison with $p_1ca_1s_1$. Increasing the S dose to 100 kg resulted in decreased contents of P, Ca, S and Fe.

4.6.3.4 Interaction between K, Ca and S

Data on K, Ca and S interaction effect are presented in Table 33.4. K at 35 kg ha^{-1}, Ca at 150 kg ha^{-1} and S at 50 kg ha^{-1} interacted to produce highest contents of P, K, S and Fe in the leaf blade. Increasing the S dose to 100 kg ha^{-1} reduced elemental composition except in the case at Ca, Mg and Si, which increased by 10, 60 and 25 % respectively.

K and S at lower levels in combination with 300 kg ha^{-1} of Ca resulted in highest contents of N and Ca but comparing with $k_1ca_1s_1$ the contents of P, K, S, Fe and Si were reduced considerably. Further decreases in contents of P, K, Fe and Si were observed when S dose was increased to 50 kg ha^{-1}.

Increasing the K dose while keeping Ca and S at lower levels decreased contents of N, Ca, S, Fe and Si while P and Mg were decreased in comparison with $k_2ca_1s_1$. S at 100 kg ha^{-1} could increase the contents of N, Mg, S and Si to some extent.

K and Ca at higher levels interacted with 50 kg ha^{-1} S beneficially in comparison with lowest levels in the case of N, Ca and Mg. Increasing the S application to 100 kg ha^{-1} gave similar results with respect to P and Mg.

Table 34. Four factor interaction effect of treatments on elemental composition of leaf blade at PI (P×K×Ca× S)

Treatments	Leaf blade at panicle initiation																			
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		S_1O_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	1.14	0.87	0.15	0.05	2.10	0.72	0.36	0.31	0.08	0.03	3001	1524	581	413	1850	450	77	116	6.33	4.88
$p_1k_1ca_2$	2.64	1.24	0.12	0.10	1.33	1.05	0.52	0.43	0.05	0.11	1227	874	366	213	1850	650	70	50	3.17	0.96
$p_1k_2ca_1$	1.22	1.40	0.14	0.02	1.90	1.69	0.30	0.05	0.08	0.17	1425	1380	666	583	1550	1000	83	136	0.275	1.70
$p_1k_2ca_2$	1.54	1.21	0.04	0.17	1.47	1.56	0.46	0.14	0.21	0.12	2240	2535	466	650	1800	850	83	116	1.52	0.45
$p_2k_1ca_1$	1.93	1.67	0.11	0.08	1.46	1.44	0.19	0.31	0.03	0.12	3727	725	250	300	1500	550	66	100	4.53	8.68
$p_2k_1ca_2$	1.37	2,05	0.10	0.09	1.51	1.39	0.16	0.14	0.52	0.02	977	1575	483	623	900	1400	66	116	0.40	1.89
$p_2k_2ca_1$	1.46	1.92	0.10	0.14	1.57	1.29	0.18	0.18	0.08	0.21	1756	1918	450	450	1200	500	40	85	6.74	4.42
$p_2k_2ca_2$	2.39	1.31	0.04	0.13	1.68	1.37	0.19	0.28	0.05	0.47	1055	2006	443	716	950	1100	133	66	7.04	0.72
CD (0.05)	0.06		0.01		0.09		0.008		0.049		70		NS		235		34.22		0.11	

4.6.4 Four factor interactions

4.6.4.1 Interaction between P, K, Ca and S

Data on interaction of applied levels of P, K, Ca and S on elemental composition of leaf blade at PI stage are presented in table 34.

P, K, Ca and S at lower levels of 17.5, 70, 150 and 50 kg ha^{-1} interacted to produce significantly higher contents of K, S and Fe. Raising the S dose to 100 kg ha^{-1} increased only the Zn content by 51 %. Contents of all other elements were decreased and K and Fe recorded lowest values. Ca application at 300 kg ha^{-1}, keeping the other nutrients at lower levels, resulted in highest contents of P, S, Mg, S and Si which were significantly reduced in comparison with $p_1k_1ca_1s_1$. Increasing S dose to 100 kg ha^{-1} decreased the contents of N, P, K, Ca, Mg, S, Fe, Zn and Si significantly.

Increasing the K dose to 105 kg ha^{-1} with P, Ca and S at lower levels decreased the contents of K, Ca, S, Fe and Si as compared to lowest levels. Further increases were noted in P,K, Ca, Mg, S and Fe, when S application was increased by 50 kg ha^{-1}. However highest content of 136 mg kg^{-1} Zn was obtained by this combination.

Combination of P and S at lower levels along with K and Ca at 105 and 300 kg ha^{-1} respectively increased the contents of N, Ca and Mg over $p_1k_1ca_1s_1$, while P, K and Si decreased significantly. Increasing the S dose to 100 kg ha^{-1} further decreased the content of Si. However P content was significantly increased.

Highest leaf blade content of Si (8.68%) was obtained when P and S at higher levels were combined with K and Ca at lower levels. But this treatment

Table 35. Elemental composition of culm at PI stage

Table 35.1. Between controls

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	SiO_2(%)	Zn(mg kg^{-1})
C_1	1.267	0.139	1.87	0.06	0.169	1235	717	1701.67	1.208	100
C_2	1.596	0.097	1.017	0.03	0.032	723	1627	2550	1.492	120
CD (0.05)	0.06	0.01	0.09	0.09	0.049	70	258	235	0.11	NS

Table 35.2 Control Vs the rest

Treatments	N (%)	P (%)	K (%)	Ca (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
Control	0.899	0.118	1.443	0.281	9790	1171.67	2126	110	1.35
Rest	0.969	0.101	1.128	0.17	1312.52	607	1245.67	62.24	3.084
CD (0.05)	0.06	0.01	0.09	0.09	70	258	235	34.22	0.11

resulted in lowest S content in the leaf blade. Reducing the S dose by 50 kg ha^{-1} beneficially affected the contents of N, P, Ca, S and Fe.

P and Ca at 35 kg ha^{-1} and 300 kg ha^{-1} interacted with K and S at 70 and 50 kg ha^{-1} and increased the contents of N and Mg as compared to lowest levels. Increasing the S dose to 50 kg ha^{-1} further increased the content of N. In comparison with lower S dose, contents of S, Fe, Zn and Si were also increased, but K, Ca and Mg were reduced.

P and K at higher levels along with Ca and S at lower levels raised the contents of N and Si, while all other elements were reduced when compared to $p_1k_1ca_1s_1$. S at 100 kg ha^{-1} could increase the contents of N, P, Mg, S and Zn comparatively.

P, K and Ca at higher levels and S at lower level raised the contents of N, Zn and Si and reduced P, K, Ca, Mg, S and Fe in comparison with lowest levels. Contents of P, Ca, Mg, S and Si could be increased significantly by the addition of a further 50 kg of S.

4.7 Elemental composition of culm at PI

4.7.1a Between controls

Data presented in table 35.1 showed that absolute control recorded significantly higher contents of N, Mn, Fe and Si over POP and the increases worked out to 23,127,50, and 23 %. With respect to P, K, Ca, Mg and S, package of practices treatment was superior and the increases were 40,83,100,466 and 71 %.

Table 35.3 Mean main effects

Treatments	Culm at panicle initiation									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
P_1	0.90	0.11	1.37	0.21	0.11	1366	555.46	1190	62.58	2.98
P_2	1.04	0.10	0.88	0.13	0.08	1259	69	1300	61.90	3.19
K_1	0.99	0.10	1.12	0.21	0.14	1340.50	474.88	1268	58.94	3.71
K_2	0.95	0.10	0.14	0.13	0.06	1284.50	739.58	1223	65.54	2.46
Ca_1	0.85	0.12	1.31	0.12	0.09	1235	604.38	1178	58.85	3.04
Ca_2	1.09	0.09	0.94	0.22	0.10	1390	610.08	1313	65.63	3.13
S_1	1.11	0.09	1.18	0.21	0.06	1203	571.13	1179	51.98	3.67
S_2	0.82	0.12	1.08	0.13	0.13	1422	643.33	1311.92	72.50	2.50
C_1	1.27	0.14	1.87	0.06	0.17	1235	717	1701.67	100	1.21
C_2	1.60	0.01	1.02	0.03	0.03	723	1627	2550	120	1.49
CD (0.05)	0.06	0.01	0.09	0.008	0.049	70	258	235	34.22	0.11

4.7.1b Control Vs the rest

N, S and Si in the rest of treatments were seen to be superior to control (Table 35.2). But the reverse was true in the case of P, K, Ca, Mn, Fe and Zn and the increases were 20, 8, 65, 93, 71 and 77 %.

4.7.1c Mean main effects of treatments

Effect of treatments was seen to be significant on elemental composition of all elements studied in the culm at PI stage (Table 35.3). N content in the control plots was found to be significantly higher than other treatments. Package of practices treatment recorded higher Mg, Fe and Zn contents, while Si was lower than in all other treatments. Mg, S and Si were significantly lower in absolute control, while Mn, Fe and Zn were higher.

Comparing the treatment applications, K at 70 kg ha^{-1} gave the highest contents of Ca, Mg and Si, and increasing the dose to 150 kg ha^{-1} significantly increased the Mn content. Application of lime at 300 kg ha^{-1} raised the Fe and Zn contents and similar results were obtained in N and K contents when 50 kg S was applied. Further increase of S by 50 kg produced highest contents of P and S.

4.7.2 Two factor interactions

4.7.2.1 Interaction between P and K

Table 36.1 depicts interaction effects of P and K. Lower levels of P and K at 17.5 kg ha^{-1} and 70 kg ha^{-1} significantly increased the P, K, Ca, Mg and S contents. Increasing the dose of P to 35 kg ha^{-1} significantly raised the Fe content by 36 % and the Si content by 45 % over p_1k_1. Raising the levels of both P and K had significant effect in raising only Mn content which was however on par with the content in p_1k_2.

Table 36. Two factor interaction effect of treatments on elemental composition of culm at PI

Table 36.1 P × K

Treatments	Culm at panicle initiation															
	P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2(%)	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
p_1	0.11	0.10	1.43	1.32	0.22	0.20	0.17	0.05	1441	1290	400	710	1073	1308	3.03	2.92
p_2	0.09	0.10	0.82	0.95	0.20	0.06	0.11	0.06	1239	1278	549	768	1463	1138	4.39	2.00
CD (0.05)	0.004		0.02		0.02		0.01		41		64		58.73		0.08	

Table 36.2 P × Ca

Treatments	Culm at panicle initiation																	
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1	0.72	1.08	0.11	0.10	1.45	1.30	0.16	0.26	0.12	0.10	1020	1711	596	514	1068	1313	3.46	2.49
p_2	0.98	1.10	0.12	0.07	1.18	0.59	0.09	0.17	0.06	0.11	1450	1068	612	705	1288	1313	2.61	3.78
CD (0.05)	0.02		0.004		0.02		0.02		0.01		41		64		58.73		0.08	

Table 36.3 P × S

Treatments	Culm at panicle initiation																	
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	1.09	0.71	0.10	0.11	1.52	1.22	0.30	0.12	0.06	0.16	1418	1313	1070	1310	49	75.80	3.88	2.07
p_2	1.14	0.94	0.07	0.12	0.83	0.94	0.11	0.15	0.07	0.10	987	1530	1288	1313	54.60	69.00	3.46	2.92
CD (0.05)	0.02		0.004		0.02		0.02		0.01		41		58.73		4.4		0.08	

Table 36.4 K ×Ca

Treatments	Culm at panicle initiation															
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		SiO_2(%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
k_1	0.80	1.18	0.12	0.09	1.29	0.95	0.12	0.30	0.12	0.16	1609.8	1071	527.90	421.80	3.68	3.74
k_2	0.90	1.00	0.11	0.09	1.34	0.93	0.13	0.13	0.06	0.05	860	1708.8	680.8	798	2.40	2.53
CD (0.05)	0.02		0.004		0.02		0.02		0.01		41		64		0.08	

4.7.2.2 Interaction between P and Ca

Data presented in table 36.2 showed that lower levels of P and Ca could produce highest contents of K and Mg in the culm, and by increasing the Ca dose by 150 kg ha^{-1}, Ca, S and Fe contents were maximum. P at 35 kg ha^{-1} along with Ca at 150 kg ha^{-1} resulted in highest content of P, but by further increase of 150 kg Ca the contents of N, Mn, Fe and Si could be increased by 52,18,22 and 9 % over p_1ca_1.

4.7.2.3 Interaction between P and S

P and S interacted significantly in almost all elements studied (Table 36.3). K, Ca and Si contents were highest when P at 17.5 kg ha^{-1} interacted with S at 50 kg ha^{-1}. Raising the S dose to 100 kg ha^{-1} increased the Mg and Zn contents by 166 and 55 %. N content increased by 5 % when P at 35 kg was combined with S at 50 kg ha^{-1}. p_2s_2 gave highest contents of P, S and Fe and the increases were 20,8 and 22 % over p_1s_1.

4.7.2.4 Interaction between K and Ca

Higher level of Ca combined with lower level of K gave highest contents of Ca, Mg and Si but P content was 150 % higher when Ca was applied at 150 kg ha^{-1}. Ca at lower level interacted with K at 105 kg ha^{-1} to give 1.34% K which was 8 % higher than in k_1ca_1. Increment of 150 kg of Ca produced a similar effect in N, S and Mn contents which were increased by 25,6 and 51 % over k_1ca_1 (Table 36.4).

4.7.2.5 Interaction between K and S

Table 36.5 showed that K and S interacted significantly in respect of all the elements studied except Fe. Highest contents of K and Ca were recorded when 70 kg

Table 36.5 K × S

Treatments	Culm at panicle initiation																	
	N(%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	1.06	0.92	0.08	0.12	1.15	1.09	0.26	0.16	0.05	0.23	1193	1487	538	411	43	74	4.39	3.03
k_2	1.17	0.73	0.09	0.11	1.20	1.07	0.16	0.11	0.07	0.04	1212	1357	604	875	60	70.80	2.95	1.97
CD (0.05)	0.02		0.004		0.02		0.02		0.01		41		64		4.4		0.08	

Table 36.6 Ca × S

Treatments	Culm at panicle initiation																	
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
ca_1	0.89	0.81	0.11	0.12	1.51	1.12	0.15	0.10	0.06	0.12	1084	1385	958	1398	30	87.5	4.20	1.87
ca_2	1.34	0.84	0.06	0.11	0.84	1.04	0.27	0.17	0.06	0.15	1321	1458	1400	1225	73.75	57.50	3.14	3.12
CD (0.05)	0.02		0.004		0.02		0.02		0.01		41		58.73		4.4		0.08	

ha^{-1} K was applied along with 50 kg ha^{-1} S. Increasing the S dose to 100 kg ha^{-1} increased the contents of P, Mg, S and Zn by 50,360,25 and 72 % over k_1s_1. N content was maximum when K at 105 kg ha^{-1} was applied along with S at 50 kg ha^{-1}, while to get highest content of Mn, S had to be increased to 100 kg ha^{-1}.

4.7.2.6 Interaction between Ca and S

Lower levels of Ca and S interacted significantly to increase the contents of K and Si but for highest contents of P and Zn, S application had to be increased by 50 kg ha^{-1}. N, Ca and Fe contents increased by 50,80 and 46 % over ca_1s_1 when Ca dose was increased to 300 kg ha^{-1}. Further increase in S application to 100 kg ha^{-1} increased the Mg and S contents by 150 and 10 % over the former (Table 36.6).

4.7.3 Three factor interactions

4.7.3.1 Interaction between P, K and Ca

P at 17.5 kg ha^{-1}, K at 70 kg ha^{-1} and Ca at 150 kg ha^{-1} was seen to significantly increase the contents of P and Mg. Increasing the Ca dose by 150 kg resulted in highest Ca content but significantly reduced the contents of P and Si. Increasing the K dose with lower levels of P and Ca was seen to decrease the contents of P, Mg, S and Si and increase the contents of Ca and Mn over $p_1k_1ca_1$. Increasing the Ca dose to 300 kg ha^{-1} increased the contents of N, Ca, S, Mn and Zn but reduced P, Mg and Si significantly (Table 37.1).

Highest content of S was obtained by P at higher level combined with K and Ca at lower levels. An increase was also noted in the contents of N, Ca and Mn when compared to $p_1k_1ca_1$. Increasing Ca application to 300 kg ha^{-1} produced significant increases in the contents of N and Si as well as Ca and Mn.

Table 37. Three factor interaction effect of treatments on elemental composition of culm at PI

Table 37.1 P × K × Ca

Treatments	Culm at panicle initiation															
	N (%)		P (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2(%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1k_1	0.73	1.14	0.13	0.10	0.09	0.35	0.17	0.16	1334	1547	389	412	59	53	4.19	1.87
p_1k_2	0.71	1.02	0.09	0.11	0.23	0.17	0.06	0.04	705.5	1876	804	616	63	75	2.74	3.10
p_2k_1	0.88	1.22	0.11	0.07	0.15	0.26	0.07	0.15	1885	594.80	666	431	55.9	67.5	3.17	5.61
p_2k_2	1.08	0.98	0.13	0.07	0.03	0.09	0.05	0.07	1015	1541	557	980	57.5	66.67	2.05	1.95
CD (0.05)	0.03		0.01		0.03		0.02		82		129		8.8		0.16	

Table 37.2 P × K × S

Treatments	Culm at panicle initiation																	
	N(%)		P (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	1.14	0.73	0.10	0.13	0.34	0.10	0.05	0.29	.1546	1336	386	415	700	1445	35	76	4.46	1.60
p_1k_2	1.04	0.70	0.10	0.10	0.27	0.13	0.07	0.03	1291	1290	729	691	1440	1175	63	75	3.30	2.55
p_2k_1	0.98	1.12	0.06	0.12	0.19	0.22	0.05	0.17	841	1638	690	408	1650	1275	51	71	4.32	4.45
p_2k_2	1.30	0.76	0.08	0.15	0.04	0.08	0.08	0.04	1132	1423	479	1058	925	1350	57	66	2.61	1.39
CD (0.05)	0.03		0.01		0.05		0.02		82		129		117.46		8.8		0.16	

P and K at higher levels along with Ca at lower levels increased the contents of N and Mn. A similar effect was obtained in these two elements as well as in S and Zn when Ca application was increased to 300 kg ha^{-1}.

4.7.3.2 Interaction between P, K and S

P, K and S interacted in their lower levels to produce significantly higher contents of N, Ca and Si in the culm at PI stage (Table 37.2). Increasing the S dose by 50 kg increased the contents of P, Mn, Fe and Zn. Comparing with $p_1k_1s_1$, P and S at 17.5 kg ha^{-1} and 50 kg ha^{-1} interacted with K at 105 kg ha^{-1} to produce lower contents of Mg and Mn. A similar effect was obtained with respect to Mn, Fe and Zn when S dose was increased by 50 kg. However all elements except P recorded a decrease. Application of 35 kg ha^{-1} of P in combination with 105 kg ha^{-1} of K and 50 kg ha^{-1} of S again had significant incremental effect only in these three elements.

Increasing S dose succeeded in increasing the contents of all elements except N, P and Ca in comparison with $p_1k_1s_1$. Similar effect was obtained in the contents of Mg, Mn, Fe and Zn, when P and K at higher levels were combined with S at 50 kg ha^{-1}.

Application of an incremental dose of 50 kg S could significantly increase the contents of P, Ca, Mn, Fe and Zn while, N, S and Si remained significantly inferior to $p_1k_1s_1$.

4.7.3.3 Interaction between P, Ca and S

Data presented in table 37.3 showed that lowest levels of P, Ca and S could produce highest contents of K and Si in the culm while Fe content was minimum.

Table 37.3 P × Ca × S

Treatments	Culm at panicle initiation																			
	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1ca_1	0.78	0.66	0.15	0.08	1.65	1.24	0.18	0.14	0.08	0.15	1042	997	628	565	740	1395	38	83	4.83	2.12
p_2ca_1	1.39	0.77	0.06	0.15	1.39	1.21	0.43	0.09	0.03	0.17	1794	1629	487	541	1400	1225	60	68	2.95	2.03
p_1ca_2	0.99	0.97	0.07	0.16	1.37	1.00	0.12	0.06	0.04	0.08	1126	1773	607	616	1175	1400	21.75	91.67	3.59	1.63
p_2ca_2	1.29	0.90	0.07	0.08	0.29	0.88	0.11	0.24	0.09	0.13	847	1288	561	850	1400	1225	87.50	46.70	3.33	4.22
CD (0.05)	0.03		0.01		0.04		0.05		0.02		82		129		117.46		8.8		0.16	

Table 37.4. K × Ca × S

Treatments	Culm at panicle initiation																	
	N (%)		P (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		S_1O_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1ca_1	0.87	0.73	0.10	0.14	0.13	0.10	0.06	0.19	1506	1713	682	373	1075	1395	39	75	5.86	1.49
k_1ca_2	1.25	1.11	0.06	0.11	0.39	0.22	0.05	0.26	881	1261	393	450	1275	1325	47	73	2.92	4.56
k_2ca_1	0.90	0.89	0.12	0.10	0.17	0.09	0.07	0.05	663	1057	555	808	840	1400	20.50	100	2.54	2.25
k_2ca_2	1.44	0.56	0.07	0.12	0.14	0.12	0.08	0.03	1761	1656	655	941	1525	1125	100	42	3.36	1.68
CD (0.05)	0.03		0.01		0.05		0.02		82		129		117.46		8.8		0.16	

Increasing the S dose to 100 kg ha^{-1} significantly increased the contents of Mg, Fe, Zn and Si, while all other elements were significantly reduced.

P and S at lower doses along with Ca at 300 kg ha^{-1} gave significantly higher contents of N, Ca, S, Fe and Zn while P, K, Mg, Mn and Si were significantly reduced in comparison with $p_1ca_1s_1$. Addition of 50 kg ha^{-1} S could increase the content of Mg, S, Fe and Zn but K, Ca, Mn and Si were significantly reduced. In comparison with $p_1ca_1s_1$, increasing the P level by 17.5 kg increased the contents of N, S and Fe, but a similar effect could be obtained in P and Zn only when the S dose was increased by 50 kg.

N, Fe and Zn contents were highest when P and Ca at higher levels interacted with S at 50 kg ha^{-1}. Increasing the S dose by 50 kg ha^{-1} produced a similar effect in Ca, S, Mn and Si, while P and K were found to decrease.

4.7.3.4 Interaction between K, Ca and S

Data on interaction effects at K, Ca and S are presented in table 37.4. K, Ca and S at lower levels gave higher contents of Mn and Si in comparison with S applied at 100 kg ha^{-1}. Increasing the Ca dose to 300 kg ha^{-1} increased N, Ca and Fe contents, while P, S, Mn and Si contents were significantly reduced. Applying an additional 50 kg S had a similar effect with regard to Mg and Si. But S and Mn were significantly reduced. K at 70 kg ha^{-1} along with Ca and S at 300 and 100 kg ha^{-1} gave significantly higher content of P in comparison with $k_1ca_1s_1$. An increase in S dose to 100 kg increased the content of Mn, Fe and Zn over the lower doses.

Highest contents of N, S, Fe and Zn were obtained when 105 kg ha^{-1} K, 300 kg ha^{-1} Ca and 50 kg ha^{-1} S were combined. Contents of P and Mn were also

Table 38. Four factor interaction effect of treatments on elemental composition of culm at PI (P×K×Ca×S)

Treatments	Culm at panicle initiation															
	P (%)		K (%)		Ca (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2(%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	0.14	0.12	1.61	1.34	0.06	0.11	1513	1156	565	213	600	1440	51	66	6.46	1.92
$p_1k_1ca_2$	0.06	0.14	1.49	1.27	0.62	0.08	1579	1515	207	616	800	1450	20	86	2.47	1.28
$p_1k_2ca_1$	0.15	0.04	1.70	1.14	0.30	0.16	572	838	691	916	880	1350	26	100	3.16	2.32
$p_1k_2ca_2$	0.06	0.16	1.30	1.14	0.24	0.11	2010	1742	766	466	2000	1000	100	50	3.43	2.78
$p_2k_1ca_1$	0.06	0.16	1.34	0.87	0.21	0.09	1500	2270	800	533	1550	1350	28.5	83	5.27	1.07
$p_2k_1ca_2$	0.06	0.08	0.16	0.89	0.16	0.36	183	1006	580	283	1750	1200	75	60	3.37	7.84
$p_2k_2ca_1$	0.08	0.17	1.39	1.12	0.03	0.03	753	1276	415	700	800	1450	15	100	1.91	2.19
$p_2k_2ca_2$	0.08	0.07	0.42	0.86	0.05	0.12	1512	1570	543	1416	1050	1250	100	33	3.3	0.59
CD (0.05)	0.02		0.07		0.09		165		258		234.93		17.65		0.32	

increased over lowest doses when S application was done at 100 kg ha^{-1} but contents of N, Mg and Si were significantly reduced when compared with $k_1 ca_1 s_1$.

4.7.4 Four factor interactions

4.7.4.1 Interaction between P, K, Ca and S

Table 38 depicts interaction between P, K, Ca and S. When P, K, Ca and S were applied at lowest levels, higher contents of P, K, S, Mn and Si were obtained, when compared with application of S at 100 kg ha^{-1}. When Ca level was increased to 300 kg ha^{-1} content of Ca alone was found to increase, but when S was also increased by 50 kg, Fe and Zn were also found to be increased significantly while K and Si contents were significantly reduced.

Increasing the K level to 105 kg ha^{-1} was found to raise the contents of K, Ca and Fe while S, Si and Zn contents were significantly reduced. Further increase of S to 50 kg ha^{-1} decreased the contents of P, K, S and Si while the Ca, Mn, Fe and Zn contents were found to increase.

When K and Ca levels were increased to 105 and 300 kg ha^{-1} P,K and Si contents were found to decrease significantly while Ca, S, Fe and Zn contents were significantly increased.

Applying another 50 kg S could increase P, S and Fe contents. But K and Si contents were adversely affected.

P at higher level in combination with lower levels of K, Ca and S reduced the P, K, Zn and Si contents. Increasing the S dose to 100 kg ha^{-1} counteracted this effect with regard to K and Zn. S and Fe contents were also found to be significantly increased.

Table 39. Effect of treatments on elemental composition of straw

Table 39.1 Between controls

Treatments	N (%)	P (%)	K %)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
C_1	1.03	0.11	0.24	0.10	0.02	1219.00	100.67	1353.67	52	1.23
C_2	0.81	0.06	1.12	0.05	0.05	78.00	800.00	2154.00	128	3.20
CD(0.05)	0.06	0.01	0.06	0.01	0.01	68.80	149.00	163.12	35	0.08

Table 39.2 Control Vs the rest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
Control	0.92	0.08	0.68	0.07	0.04	648.33	450.50	1753.83	90.00	2.22
Rest	1.11	0.08	0.22	0.09	0.06	774.21	419.50	1238.54	79.29	2.82
CD(0.05)	0.06	NS	0.06	0.01	0.01	68.80	NS	163	NS	0.08

Lower levels of K and S in combination with higher levels of P and Ca produced a similar effect with regard to P and S. The contents of Ca, Fe and Zn were found to significantly increase. Application of an incremental dose of 50 kg ha^{-1} S reduced the contents of P, K, S and Mn in comparison with lowest levels. But the Ca, Fe and Si contents were significantly increased.

When 17.5 kg ha^{-1} P and 105 kg ha^{-1} K were combined with 150 kg ha^{-1} Ca and 50 kg ha^{-1} S, a decrease was noted in the contents of P, K, Ca, S, Zn and Si, but when S level was increased, highest content at P was recorded along with increase in the contents of Fe and Zn.

Application of P, K and Ca at higher levels with S at 50 kg ha^{-1} was also inferior with regard to contents of P, K and Si. But by increasing the S dose, content of Ca could be significantly increased. Si content, however, decreased still further.

4.8 Elemental composition of straw

4.8.1a Between controls

Table 39.1 is a record of difference in elemental composition of straw between controls. N, P, Ca and S contents in POP were found to be significantly superior to absolute control. However the latter recorded higher values with regard to contents of K, Mg, Mn, Fe, Zn and Si to the tune of 366,150,690,59,146 and 160 %.

4.8.1b Control Vs the rest

Remaining treatments were compared with control (Table 39.2) and it was seen that control plots had higher K and Fe contents and the increases were 209 and 42 %. N, Ca, Mg, S and Si content was seen to be higher in the straw of treatment plots in comparison with control.

Table 39.3 Mean main effects

Treatments	Straw									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	SiO_2 (%)
P_1	1.56	0.08	0.18	0.097	0.06	1006.46	415.63	1185.42	78.29	2.67
P_2	1.06	0.09	0.27	0.091	0.07	541.96	423.38	1291.67	80.29	2.97
K_1	1.07	0.07	0.28	0.099	0.04	778.63	358.54	1285.42	71.92	3.54
K_2	1.15	0.09	0.17	0.089	0.09	769.79	480.46	1191.67	86.67	2.10
Ca_1	1.16	0.09	0.18	0.077	0.03	628.63	417.5	1285.42	72.75	2.44
Ca_2	1.05	0.07	0.27	0.11	0.09	919.79	421.5	1191.67	85.83	3.19
S_1	1.11	0.10	0.27	0.112	0.08	701.71	471.46	1176.42	80.46	3.74
S_2	1.11	0.06	0.18	0.076	0.04	846.71	365.54	1300.67	78.13	1.90
C_1	1.03	0.11	0.24	0.10	0.021	1219	100.67	1353.67	52	1.23
C_2	0.81	0.01	1.12	0.049	0.050	78	800	2154	128	3.2
CD (0.05)	0.06	0.01	0.06	0.01	0.01	68.80	149	163.12	34.79	0.08

4.8.1c Mean main effects of treatments

Main effects of treatments were significant in all elements. Data tabulated in table 39.3 showed that N and Si contents in POP were inferior to the other treatments. N, P and Ca in absolute control was significantly lower, while K was seen to be higher. Mn and Zn content in straw followed a similar pattern in both control plots with Mn being higher in POP and lower in absolute control than other treatments. Fe content was higher in control. S was seen to be higher in POP and lower in absolute control.

Comparing the other treatments, application of P at 17.5 kg ha^{-1} significantly increased the S content in straw. A similar effect was seen in contents of Mg, Mn and Zn when K was applied at 105 kg ha^{-1}. However K content was higher when lower dose of K i.e., 70 kg ha^{-1} was applied. Ca at 150 kg ha^{-1} significantly increased the N content and application of a further 150 kg of Ca resulted in highest contents of Ca and Mg. Significant increases in P, Ca and Si contents were obtained when S was applied at 50 kg ha^{-1}. Higher dose of S resulted in highest content of Fe i.e., 1300 mg kg^{-1}.

4.8.2 Two factor interactions

4.8.2.1 Interaction between P and K

Data on interaction between P and K are presented in table 40.1. P and K at lower levels interacted significantly to give higher contents of N, Ca and S. Increasing the K dose to 105 kg ha^{-1} raised the Zn content by 77 %. P at 35 kg along with K at 70 kg ha^{-1} gave the highest K and Si contents. Significant increases in Mg and Mn contents were obtained when P and K were combined at higher levels over p_2k_1.

Table 40. Two factor interaction effects of treatments on elemental composition of straw

Table 40.1 P × K

Treatments	N (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
p_1	1.18	1.13	0.17	0.20	0.13	0.07	0.04	0.07	1229	783	425.42	405.83	56.58	100	4.03	2.36
p_2	0.95	1.16	0.38	0.15	0.07	0.11	0.03	0.11	328.12	755.75	291.67	555.08	87.25	73.33	4.46	2.66
CD (0.05)	0.01		0.02		0.002		0.002		18		27.26		8.69		0.02	

Table 40.2 P × Ca

Treatments	N (%)		P (%)		K (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1	1.24	1.07	0.09	0.06	0.16	0.21	0.03	0.08	908.8	1104.08	397.08	434.17	84.08	72.5	3.19	2.14
p_2	1.09	1.03	0.10	0.08	0.20	0.33	0.03	0.11	348.42	735.5	437.92	408.8	61.42	99.17	1.69	4.24
CD (0.05)	0.01		0.002		0.02		0.002		18		37.26		8.69		0.02	

Table 40.3 P × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	1.24	1.07	0.11	0.05	0.19	0.17	0.13	0.07	0.06	0.05	960	1052.92	3.68	1.66
p_2	0.98	1.14	0.1	0.08	0.35	0.18	0.10	0.09	0.11	0.03	443.42	640.5	2.80	2.12
CD (0.05)	0.01		0.002		0.02		0.002		0.002		18		0.02	

Table 40.4 K × Ca

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
k_1	1.16	0.97	0.08	0.07	0.21	0.34	0.07	0.13	0.01	0.06	697	859.8	245.42	471.67	62.58	81.25	3.12	3.96
k_2	1.17	1.13	0.12	0.07	0.15	0.19	0.08	0.10	0.05	0.13	559.8	979.75	589.58	371.33	82.92	90.42	1.76	2.45
CD (0.05)	0.01		0.002		0.02		0.002		0.002		18		37.26		8.69		0.02	

4.8.2.2 Interaction between P and Ca

Table 40.2 depicts interaction effects between P and Ca. P at 17.5 kg ha^{-1} in combination with Ca at 150 kg ha^{-1} gave the highest N content of 1.24 %. Application of Ca at 300 kg ha^{-1} significantly increased the S content by 21.6 % over the lower levels. P at higher level interacted with Ca at 150 kg resulting in higher P and Mn contents. Ca at 150 kg resulted in higher P and Mn contents. An increment of 150 kg ha^{-1} of Ca could increase the contents of K, Mg, Zn and Si and the increases were 6.5,267,61.5 and 151 % over p_2ca_1.

4.8.2.3 Interaction between P and S

Data presented in table 40.3 showed that lower levels of P and S interacted to gave highest contents of N, P, Ca and Si. S content however was increased by 10 % when the level of S was increased to 100 kg ha^{-1}. P at 35 kg ha^{-1} along with S at 50 kg ha^{-1} resulted in highest K and Mg contents which were significantly superior.

4.8.2.4 Interaction between K and Ca

Lower level of K in combination with higher level of Ca resulted in 62,86 and 27 % higher contents of K, Ca and Si in comparison with k_1ca_1. However highest contents of 1.17 % N and 0.12 % P and 589.58 mg kg^{-1} Mn were obtained when K dose was increased, keeping Ca at lower level. Increasing both K and Ca levels significantly increased the contents of Mg, S and Zn which were 1000, 40 and 45 % higher than k_1ca_1 (Table 40.4).

Table 40.5 K × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	0.96	1.17	0.08	0.06	0.36	0.19	0.11	0.09	0.04	0.03	608	949.25	479.17	237.92	80.92	62.92	4.82	2.25
k_2	1.26	1.04	0.13	0.06	0.18	0.16	0.12	0.06	0.13	0.05	795.42	744.17	463.75	497.17	80	93.3	2.65	1.54
CD (0.05)	0.01		0.002		0.02		0.002		0.002		18		37.26		9.0		0.02	

Table 40.6 Ca × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe(mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
ca_1	1.19	1.14	0.13	0.07	0.19	0.17	0.09	0.07	0.03	0.03	648.42	608.8	1270.17	1300.67	3.25	1.63
ca_2	1.03	1.07	0.08	0.06	0.35	0.19	0.14	0.09	0.14	0.05	755	1084.58	1082.67	1300.67	4.22	2.16
CD (0.05)	0.01		0.002		0.02		0.002		0.002		18		40.78		0.02	

4.8.2.5 Interaction between K and S

Table 40.5 showed that P, K and Si contents in straw were highest when K and S were applied at 70 and 50 kg ha^{-1} respectively. When S application was increased to 100 kg ha^{-1}, S content was seen to increase by 56 %. K at higher level interacted with lower dose of S to significantly increase N, Ca and Mg contents by 31,9 and 225 % over k_1s_1. Mn and Zn contents, however, were seen to be significantly higher when K and S were applied at higher levels.

4.8.2.6 Interaction between Ca and S

Highest contents of N (1.19%) and P (0.13%) in straw were observed when 150 kg ha^{-1} Ca was applied along with 50 kg ha^{-1} S. When Ca level was increased to 300 kg ha^{-1}, K, Ca, Mg and Si contents was seen to be highest. Ca and S both at higher levels interacted to give significantly higher contents of S and Fe but in the case of the latter a similar effect was observed when lower level of Ca was combined with higher level of S (Table 40.6).

4.8.3 Three factor interactions

4.8.3.1 Interaction between P, K and Ca

Data on interaction effects between P, K and Ca are presented in table 41.1. The data showed that P, K and Ca at lower levels gave the highest content of N. Increasing the Ca level by 150 kg ha^{-1} significantly increased the contents of P, Ca, Mg and S, while when K application was increased to 105 kg ha^{-1} keeping P and Ca at lower levels, P, Mg and Zn were seen to be higher by 57,100 and 90%. A further increase in 150 kg Ca significantly lowered the contents of N, P, Ca, S and Si, while that of K, Mg and Zn were increased significantly.

Table 41. Three factor interaction effects of treatments on elemental composition of straw

Table 41.1 P × K × Ca

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1k_1	1.29	1.07	0.07	0.08	0.17	0.17	0.10	0.15	0.02	0.06	1026	1431	58.17	55	4.18	2.54
p_1k_2	1.20	1.07	0.11	0.05	0.15	0.24	0.05	0.09	0.04	0.10	791	776.7	110	90	2.2	1.75
p_2k_1	1.03	0.88	0.08	0.06	0.25	0.51	0.04	0.10	0.01	0.05	368	288	67	107.5	2.06	5.37
p_2k_2	1.14	1.19	0.13	0.09	0.15	0.15	0.11	0.11	0.05	0.18	328.67	1182.8	55.83	90.8	1.33	3.12
CD (0.05)	0.028		0.004		0.03		0.004		0.004		35		17.39		0.04	

Table 41.2 P × K × S

Treatments	N (%)		P (%).		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	1.05	1.31	0.09	0.05	0.16	0.18	0.18	0.07	0.03	0.05	978.8	1479	67	45.8	4.94	1.78
p_1k_2	1.43	0.84	0.13	0.04	0.23	0.17	0.08	0.06	0.08	0.06	941	626.5	90	110	2.41	1.54
p_2k_1	0.87	1.03	0.07	0.07	0.56	0.20	0.04	0.11	0.05	0.02	237	419	94.5	80	4.7	2.73
p_2k_2	1.08	1.25	0.13	0.09	0.14	0.16	0.16	0.06	0.18	0.04	649.7	861.8	70	76.67	2.89	1.55
CD (0.05)	0.03		0.004		0.03		0.004		0.004		35		17.39		0.04	

P at 35 kg ha^{-1} in combination with K at 70 kg ha^{-1} and Ca at 150 kg ha^{-1} could increase the contents of P and K and raising the Ca level to 300 kg ha^{-1} significantly increased the K, Mg and Si contents in comparison with $p_1k_1ca_1$.

Significantly higher contents of P, Ca and Mg and lower contents of N, K, S and Zn were obtained when higher levels of P and K interacted with lower level of Ca. A similar effect was obtained when Ca dose was also raised to its higher level except in the case of S and Zn which were significantly increased by 15.3 and 56 % over $p_1k_1ca_1$.

4.8.3.2 Interaction between P, K and S

Table 41.2 showed that when P, K and S were applied at lower doses highest contents of Ca and Si were obtained and the contents of P and Zn were also significantly higher. Increasing S application by 50 kg ha^{-1} significantly increased the contents of N, Mg and S in the straw and when K was similarly increased by 35 kg, N and P contents was seen to be highest. K and Mg were also increased. Combining a S increase of 50 kg ha^{-1} resulted in lower contents of N, P, Ca, S and Si but Mg was beneficially affected.

P at higher level interacted with K and S at lower doses and significantly increased K, Mg and Zn contents over $p_1k_1s_1$. When S was also increased to higher level significant increase was seen in K, but P, Ca, Mg, S and Si were reduced to significantly lower levels compared to $p_1k_1s_1$.

Highest content of P and Mg but lower Ca, S and Si contents were obtained when 50 kg ha^{-1} S was applied along with 17.5 kg ha^{-1} and 105 kg ha^{-1} of P and K respectively. Raising the S level to 100 kg ha^{-1} raised the contents of N and Mg in comparison with $p_1k_1s_1$ but P and K remained on par.

Table 41.3 P × Ca × S

Treatments	P (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe(mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1ca_1	0.12	0.06	0.10	0.06	0.03	0.03	994	823	444	350	1275	1250	81.5	86.67	5.45	0.93
p_1ca_2	0.09	0.04	0.16	0.08	0.08	0.08	925	1282	509	359	989	1225	75.8	69.17	1.90	2.39
p_2ca_1	0.13	0.08	0.08	0.08	0.03	0.03	302	394	549	326	1264	1350	70.3	52.5	1.05	2.33
p_2ca_2	0.07	0.08	0.11	0.10	0.20	0.20	584	886.8	383	434	1175	1375	94.17	104.17	6.54	1.94
CD (0.05)	0.004		0.004		0.004		35		74.53		81.56		17.39		0.04	

Table 41.4 K × Ca × S

Treatments	N (%)		P (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1ca_1	1.04	1.28	0.07	0.08	0.09	0.06	0.01	0.02	392.7	1002	282.5	208	4.55	1.69
k_1ca_2	0.88	1.01	0.09	0.05	0.13	0.12	0.06	0.05	823	896	675.8	267.5	5.09	2.82
k_2ca_1	1.30	1.00	0.18	0.06	0.09	0.07	0.05	0.05	904	215.5	710.8	468	1.95	1.58
k_2ca_2	1.18	1.08	0.08	0.06	0.14	0.06	0.22	0.05	686.7	1272.8	216.7	526	3.35	1.51
CD (0.05)	0.03		0.004		0.004		0.004		34.39		74.53		0.04	

4.8.3.3 Interaction between P, Ca and S

P, Ca and S interaction effects (Table 41.3) showed that lower levels of application were better in respect of contents of P, Ca, S, Mn, Fe and Si as compared to increased application of S. However when Ca application was increased to 300 kg ha^{-1}, Ca and Mg contents were significantly increased, while S, Fe and Si contents tended to decrease. An increment of 50 kg ha^{-1} of S had a reverse effect on Ca and S contents. Mg content remained same, but P, Mn and Si contents were decreased.

P at higher level along with Ca and S at lower levels gave highest contents of P and Mn, but Ca, S and Si contents were considerably reduced. Further increase in S level had a detrimental effect on contents of all elements except Fe which remained on par with $p_1ca_1s_1$.

Contents of P, S and Fe were also reduced when S at lower level interacted with P and Ca at higher levels. But Ca, Mg and Si were favourably affected. Contents of Mg, Fe and Zn were seen to be higher when S was applied at its highest dose, but P, S and Si were significantly lowered.

4.8.3.4 Interaction between K, Ca and S

Data on interaction effects of K, Ca and S are presented in table 41.4. Lower levels of K, Ca and S were found to be beneficial on the contents of Ca and Si in comparison with $k_1ca_1s_2$. However the latter was better in increasing the contents of N, P and S. $k_1ca_2s_1$ was better in increasing P, Ca, Mg, S, Mn and Si than application of the three elements at lower levels. When S was increased by 50 kg, P and Si were increased but Ca, Mg and S contents were found to decrease.

Table 42. Four factor interaction effects of treatments on elemental composition of straw (P×K×Ca×S)

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	1.07	1.51	0.07	0.06	0.15	0.18	0.15	0.05	0.02	0.02	533	1520	298	266	1250	1250	63	53	8.03	0.33
$p_1k_1ca_2$	1.03	1.11	0.11	0.05	0.17	0.18	0.21	0.08	0.04	0.09	1424	1438	818	318	1128	1250	71	38	1.85	3.20
$p_1k_2ca_1$	1.65	0.74	0.17	0.05	0.13	0.18	0.04	0.06	0.04	0.04	1455	127	590	433	1300	1250	100	120	2.87	1.53
$p_1k_2ca_2$	1.21	0.93	0.08	0.02	0.32	0.16	0.11	0.07	0.12	0.07	427	1126	200	400	850	1200	80	100	1.95	1.54
$p_2k_1ca_1$	1.02	1.05	0.07	0.09	0.34	0.16	0.02	0.06	0.01	0.12	252	484	266	150	1400	1350	90.67	43	1.07	3.05
$p_2k_1ca_2$	0.73	1.02	0.07	0.06	0.78	0.25	0.05	0.15	0.08	0.02	222	354	533	216	1150	1500	98	116.67	8.30	2.40
$p_2k_2ca_1$	1.02	1.26	0.18	0.07	0.13	0.16	0.14	0.09	0.05	0.05	353	304	831	503	1128	1350	50	61.67	1.03	1.62
$p_2k_2ca_2$	1.14	1.23	0.07	0.11	0.14	0.16	0.17	0.04	0.31	0.02	946	1419	233	652	1200	1250	90	91.67	4.75	1.48
CD (0.05)	0.06		0.01		0.06		0.01		0.01		69.0		149		163.0		34.79		0.08	

Highest contents of N, P and Mn and increases in Mg and S contents were obtained when K at 105 kg ha^{-1} was combined with Ca and S at lower levels. But this effect on N and P was reversed when S application was increased to 100 kg ha^{-1} and it also caused decrease in Ca, S and Si contents when compared to $k_1ca_1s_1$.

Combination of highest levels of K and Ca with lower levels of S resulted in highest contents of Ca and Mg, and N, P and S contents were also raised. S content was maximum when S dose increased to 50 kg ha^{-1} and an increase was also seen in N, Mg and Mn contents while P and Si contents were reduced in comparison with $p_1ca_1s_1$.

4.8.4 Four factor interactions

4.8.4.1 Interaction between P, K, Ca and S

A perusal of the data in tale 42 showed that Ca and Si contents were higher when the four elements were applied at lower levels, but when S application was increased by 50 kg there were significant increases in contents of N and Si. Increasing Ca application by 150 kg ha^{-1} significantly raised the contents of P, Ca, Mg, S and Mn. To increase the contents of Mg and S still further, S had to be applied at 100 kg ha^{-1} but Ca and Zn contents were significantly reduced.

Increasing K dose to 105 kg ha^{-1} with other elements kept at lower levels increased the N, P, Mg, S, Mn and Zn contents over $p_1k_1ca_1s_1$. Simultaneous increase in S level led to decrease in contents of N, P, Ca, S and Si while contents of Mg, Mn and Zn were significantly increased.

Increasing the levels of both K and Ca with P and S at lower levels raised the contents of N and Mg and addition of another 50 kg S resulted in lowering of contents of N, P, Ca, Zn and Si.

When P was applied at 35 kg ha^{-1} in combination with K, Ca and S at their lower levels, contents of K, Fe and Zn were raised and the supplementation of another 50 kg of S led to increases in P, Ca, Mg, S and Si contents over $p_2k_1ca_1s_1$.

P and Ca at higher levels along with K and S at lower levels significantly reduced the contents of N, Ca, S and Zn over $p_1k_1ca_1s_1$. An increase in the S level to 100kg ha^{-1} resulted in increase of K and Zn contents.

When P and K at 35 and 105 kg ha^{-1} were applied along with Ca and S at 150 and 50 kg ha^{-1} the S and Si contents were found to be significantly lower than at lowest levels of all four elements. Increasing the S dose further reduced the S content along with Ca.

Highest levels of the all four elements interacted to produce higher contents of N, P, S, Mn and Zn in comparison with the lowest levels. But a lowered dose of 50 kg ha^{-1} S in the combination resulted in higher Ca and Mg contents.

4.9 Elemental composition of kernel

4.9.1a Between controls

Significant effect was seen due to interactions on all the elements studied when controls were compared (Table 43.1). Application of N, P, K as per POP recommendations resulted in significantly higher contents of N, P, Ca, Mg, S and Si in the kernel. Absolute control recorded significant values with regard to K, Mn, Fe and Zn contents.

Table 43. Effect of treatments on elemental composition of kernel

Table 43.1 Between controls

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
C_1	1.71	0.15	0.21	0.04	0.04	838.0	85.00	127.67	33.0	2.03
C_2	1.10	0.01	0.33	0.021	0.031	51.67	125.00	251.00	56.00	1.17
CD(0.05)	0.10	0.01	0.04	0.01	0.02	20.34	28.78	39.50	3.15	0.09

Table 43.2 Control Vs the rest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
Control	1.41	0.08	0.27	0.03	0.04	445.00	105	189.33	44.67	1.60
Rest	1.63	0.18	0.19	0.07	0.07	650.46	81	112.00	35.00	1.63
CD(0.05)	0.10	0.01	0.04	0.01	0.02	20.00	NS	39.50	3.15	NS

Table 43.3 Mean main effects

Treatments	Kernal									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
P_1	1.58	0.18	0.21	0.08	0.07	800.08	78.92	115.17	30.04	1.71
P_2	1.68	0.17	0.18	0.06	0.07	500.8	83.92	109.04	39.73	1.56
K_1	1.64	0.18	0.19	0.087	0.07	832.25	71.29	118.17	33.77	1.72
K_2	1.61	0.18	0.19	0.06	0.07	468.67	91.54	106.04	36.0	1.55
Ca_1	1.68	0.17	0.20	0.06	0.09	685.3	67.54	119.42	27.25	1.75
Ca_2	1.58	0.19	0.18	0.08	0.06	615.58	95.29	104.79	42.52	1.52
S_1	1.55	0.18	0.19	0.07	0.07	713.17	63.33	117.79	29.52	1.27
S_2	1.71	0.17	0.20	0.07	0.08	587.75	99.50	106.42	40.25	2.00
C_1	1.707	0.148	0.212	0.039	0.043	838	85	127.67	33.0	2.03
C_2	1.103	0.013	0.33	0.021	0.031	51.67	125.0	251	56	1.167
CD(0.05)	0.10	0.01	0.04	0.01	0.02	20.34	28.78	39.5	3.15	0.09

4.9.1b Control Vs the rest

When controls were compared with rest of treatments (Table 43.2) only K, Fe and Zn contents were found to be higher in the former. The rest of the treatments were found to be superior with regard to N, P, Ca, Mg and S contents.

4.9.1c Mean main effects

Table 43.2 records the main effects of treatments on elemental composition of kernel. S and Si contents were found to be highest in C_1. Absolute control recorded highest contents of K, Mn, Fe and Zn. Comparing the treatment effects, application of P at 17.5 kg ha^{-1} gave the highest K content of 0.21%. Highest P content was obtained when Ca was applied at 300 kg ha^{-1}. Lower level of K resulted in highest contents of Ca and S in the kernel. But a similar effect in N, Mn, Zn and Si was obtained when S was applied at 100 kg ha^{-1}. Fe content was found to be maximum and Zn content minimum when Ca was applied at 150 kg ha^{-1}.

4.9.2 Two factor interactions

4.9.2.1 Interaction between P and K

P at 17.5 kg ha^{-1} and K at 70 kg ha^{-1} interacted to produce highest contents of 0.23% K and 1182.50 mg kg^{-1} S in the kernel. Additional application of 35 kg ha^{-1} of K gave the highest Mg content of 0.08%, this value was also produced when P was applied at 35 kg ha^{-1} along with K at 70 kg ha^{-1}. This combination also gave highest values for N, Fe and Si which were 17,36 and 26% higher than p_1k_1 (Table 44.1).

Table 44. Two factor interaction effects of treatments on elemental composition of kernel

Table 44.1 P × K

Treatments	N (%)		K (%)		Mg (%)		S (mg kg^{-1})		Fe(mg kg^{-1})		SiO_2 (%)	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
p_1	1.51	1.65	0.23	0.20	0.06	0.08	1182.5	417.67	100	130	1.52	1.91
p_2	1.77	1.58	0.17	0.19	0.08	0.07	482	519.67	136	81.9	1.92	1.19
CD (0.05)	0.02		0.01		0.006		5.09		9.87		0.02	

Table 44.2 P × Ca

Treatments	N (%)		P (%)		Mg (%)		S (mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1	1.60	1.56	0.20	0.15	0.08	0.06	890.50	709.70	1.39	2.03
p_2	1.76	1.59	0.13	0.22	0.09	0.05	480.00	521.50	2.10	1.01
CD (0.05)	0.02		0.002		0.006		5.09		0.02	

Table 44.3 P × S

Treatments	N (%)		S (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	1.58	1.58	900.67	699.50	26.92	33.17	1.20	2.23
p_2	1.52	1.83	525.67	476.00	32.13	47.33	1.35	1.76
CD (0.05)	0.02		5.09		1.57		0.02	

Table 44.4 K × Ca

Treatments	N (%)		P (%)		K (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe(mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
k_1	1.67	1.62	0.12	0.23	0.23	0.15	0.08	0.06	767	897	42.58	100	116.42	119.92	250	560	2.55	1.57
k_2	1.69	1.54	0.21	0.14	0.17	0.21	0.10	0.05	603	333	92.50	90.58	122.42	89.67	404	460	1.64	2.1
CD (0.05)	0.02		0.002		0.01		0.006		5.09		7.20		9.87		1.57		0.02	

4.9.2.2 Interaction between P and Ca

Table 44.2 shows that interaction effect of P and Ca was significant only for N, P, Ca, Mg, S and Si contents in kernel. Combination of P and Ca at their lower levels gave highest content of S in the kernel (890mg kg^{-1}). Increasing P to 35 kg ha^{-1} raised the N, Mg and Si contents by 10,12.5 and 51%. Highest P content of 0.22% was obtained when P at 35 kg ha^{-1} interacted with Ca at 300 kg ha^{-1}.

4.9.2.3 Interaction between P and S

N, S, Zn and Si contents of kernel were significantly affected by interactions between P and S. Table 44.3 showed that highest content of S was obtained by the combination of P and S at their lower levels. Increasing the S dose to 100 kg ha^{-1} gave 86 % increase in Si content. When both P and S contents were maximised, increases worked out to 16 and 43% over p_1s_2.

4.9.2.4 Interaction between K and Ca

Data on K × Ca interaction are presented in table 44.4. K, Mg and Si contents were favourably influenced by the interaction of 105 kg ha^{-1} K with 150 kg ha^{-1} Ca. Incremental application of 150 kg ha^{-1} Ca increased the contents of S, Mn and Zn. When K level was doubled keeping Ca at lower level, N and Fe contents were maximised.

4.9.2.5 Interaction between K and S

Table 44.5 showed that K and S in their lower levels interacted to give highest S content. Doubling the S dose increased the Fe and Si contents by 14 and

Table 44.5 K × S

Treatments	P (%)		S ($mg\ kg^{-1}$)		Fe($mg\ kg^{-1}$)		Zn($mg\ kg^{-1}$)		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	0.15	0.20	1030.92	633.58	110.42	125.92	30.79	36.75	1.32	2.12
k_2	0.21	0.14	395.42	541.92	125.17	86.92	26.25	43.75	1.22	1.88
CD (0.05)	0.002		5.09		9.87		1.57		0.02	

Table 44.6 Ca × S

Treatments	P (%)		Mg (%)		S ($mg\ kg^{-1}$)		Mn ($mg\ kg^{-1}$)		Zn($mg\ kg^{-1}$)		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
ca_1	0.15	0.18	0.07	0.10	612.00	758.50	40.17	94.92	16.50	38.00	1.62	1.88
ca_2	0.21	0.16	0.06	0.05	814.20	417.00	86.50	104.08	42.54	42.50	0.93	2.11
CD (0.05)	0.004		0.006		5.09		7.20		1.57		0.02	

60%, while when K was doubled, P content was increased by 40%. Doubling both K and S levels resulted in the highest Zn content of 43.75 mg kg^{-1} in the kernel.

4.9.2.6 Interaction between Ca and S

S at 100 kg ha^{-1} and Ca at 150 kg ha^{-1} produced the highest Mg content of 0.1% in the kernel (Table 44.6). When Ca dose was increased to 300 kg ha^{-1} with S kept at 50 kg ha^{-1}, contents of P, S and Zn increased to the tune of 40,33 and 158% over ca_1s_1. When S application was further increased by 50 kg, Mn and Si contents were maximised. Zn content was also maximum in this combination which was on par with ca_2s_1.

4.9.3 Three factor interactions

4.9.3.1 Interaction between P, K and Ca

Data in table 45.1 showed that K content was highest when P, K and Ca were combined in their lower levels. Increasing the Ca dose by 150 kg ha^{-1} raised the S content of the kernel by 18%, but N and Si contents were significantly reduced. When K alone was increased to 105 kg ha^{-1} N, P, Mg and Si contents were significantly increased. But this effect was reversed in P, Mg and Si contents when Ca level was increased by 300 kg ha^{-1}.

P at 35 kg ha^{-1} interacted with K at 70 kg ha^{-1} and Ca at 150 kg ha^{-1} to significantly increase the N content by 14 % over $p_1k_1ca_1$. Si content was also raised but contents of P, K and S were lowered. When Ca application was increased by 150 kg ha^{-1}, P and Zn contents were maximised but K, S and Si contents were comparatively low.

Table 45. Three factor interaction effect of treatments on elemental composition of kernel

Table 45.1 P × K × Ca

Treatments	N (%)		P (%)		K (%)		Mg (%)		S (mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1k_1	1.56	1.47	0.18	0.19	0.25	0.19	0.07	0.06	1086.67	1278.00	21.33	35.50	1.62	1.41
p_1k_2	1.65	1.65	0.22	0.12	0.19	0.21	0.09	0.07	694.33	141.00	21.00	42.33	1.67	2.65
p_2k_1	1.78	1.76	0.06	0.26	0.21	0.12	0.08	0.07	447.83	516.17	20.33	57.92	2.64	1.21
p_2k_2	1.73	1.42	0.20	0.17	0.16	0.22	0.11	0.03	512.5	526.83	46.33	34.33	1.57	0.81
CD (0.05)	0.05		0.004		0.02		0.01		10.17		3.15		0.04	

Table 45.2. P × K × S

Treatments	N (%)		K (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	1.52	1.50	0.23	0.21	1597.80	767.12	48.67	86.67	111.67	88.67	18.83	38.00	1.14	1.89
p_1k_2	1.63	1.67	0.20	0.21	203.50	631.80	85.33	95.00	134.67	125.67	35.00	28.33	1.25	2.57
p_2k_1	1.58	1.97	0.13	0.20	464.00	500.00	56.0	93.83	109.17	163.17	42.75	35.50	1.51	2.34
p_2k_2	1.46	1.69	0.19	0.18	587.00	452.00	63.33	122.50	115.67	48.17	21.50	59.17	1.19	1.18
CD (0.05)	0.05		0.02		10.17		14.39		19.74		3.15		0.04	

Higher levels of P and K together with 150 kg Ca increased the N, P, Mg and Zn contents while doubling the Ca dose gave higher value only in the case of Zn. In comparison with $p_1k_1ca_1$ contents of N, K, Mg, S and Si were significantly lower.

4.9.3.2 Interaction between P, K and S

Table 45.2 showed that application of P, K and S at 17.5, 35 and 50 kg ha^{-1} increased the contents of S and Fe to a higher level than when S was applied at higher dose. When K application was also increased, N, Mn, Fe, Zn and Si contents were significantly increased. Further application of 50 kg ha^{-1} S increased the N, Mn, Zn and Si contents but reduced the S content.

P in its higher level interacted with K and S in their lower levels to significantly increase the kernel contents of N, Zn and Si but K and S were decreased. When S dose was increased to 100 kg ha^{-1}, N, K and S were significantly lowered, but Mn, Fe, Zn and Si contents in the kernel were increased.

Significantly higher Mn content was observed with $p_2k_2s_1$ in comparison with $p_1k_1s_1$. This was further increased significantly when S dose was raised to 100 kg ha^{-1}. Contents of N, Mn and Zn were similarly affected, but K, S and Fe contents were significantly low.

4.9.3.3 Interaction between P, Ca and S

Data presented in table 45.3 showed that interaction effects were significant only in N, S, Fe, Zn and Si. Comparison of elemental contents when P and Ca at lower levels were combined with S at its lower and higher levels showed that only N content was higher in the former case. When Ca was applied at 300 kg ha^{-1} along with P and S at 17.5 and 50 kg ha^{-1} respectively, S content was found to be highest

Table 45.3 P × Ca × S

Treatments	N (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1ca_1	1.63	1.58	778.50	1002.50	120.67	133.67	17.67	24.00	1.25	1.54
p_1ca_2	1.52	1.60	1022.80	396.50	124.00	81.00	36.00	72.00	1.14	2.92
p_2ca_1	1.59	1.92	445.80	514.50	126.00	98.00	15.00	51.00	1.98	2.23
p_2ca_2	1.45	1.73	605.50	437.50	99.17	114.00	48.92	43.00	0.71	1.30
CD (0.05)	0.05		10.17		19.74		3.15		0.04	

Table 45.4. K × Ca × S

Treatments	Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1ca_1	0.07	0.08	776.17	758.00	38.00	47.17	136.67	96.17	14.00	27.67	1.65	2.61
k_1ca_2	0.07	0.06	1285.67	808.83	66.67	133.00	84.17	155.67	47.58	45.80	1.00	1.62
k_2ca_1	0.07	0.12	448.17	758.67	42.00	142.67	109.67	135.00	19.00	48.33	1.58	1.15
k_2ca_2	0.06	0.04	342.67	325.00	106.00	74.85	140.67	38.67	37.50	39.17	0.86	2.60
CD (0.05)	0.01		10.17		14.39		19.74		3.15		0.04	

and Zn was also found to be significantly increased. Adopting a higher dose of S succeeded in rising Zn and Si contents significantly over $p_1ca_1s_1$.

Only the Si content was significantly increased in the combination $p_2ca_2s_1$ but when S dose was doubled maximum N content was recorded. Higher values were also obtained for Zn and Si. However the highest value of 48.92 mg kg^{-1} Zn was obtained in the kernel when P and Ca at higher levels combined with S at 50 kg ha^{-1}. When S was also tried at higher dose N, Zn and Si contents were significantly increased but S content was lower than in $p_1ca_1s_1$.

4.9.3.4 Interaction between K, Ca and S

Interaction effects of K, Ca and S are presented in table 45.4. Higher dose of S along with K and Ca in their lower levels resulted in significantly higher contents of Zn and Si in the kernel. When Ca effect was studied keeping K and S at lower levels, S, Mn and Zn contents were significantly increased and this increase was maintained when S dose was doubled in the case of Mn, Zn and Si. S content however declined.

K at 150 kg ha^{-1} interacted with Ca and S at 150 and 50 kg ha^{-1} resulting in significantly lower contents of S, Fe and Si in the kernel. When the S dose was doubled this trend was reversed for S and Fe. In the case of Zn, Mg and Fe, contents were significantly superior while Si remained inferior to $k_1ca_1s_1$.

Higher levels of K, Ca and S increased the Si, Mn and Zn contents while Mg and S remained inferior. When S was applied at the lower dose of 50 kg ha^{-1}, Mn content was significantly raised and Si content reduced.

Table 46. Four factor interaction effect of treatments on elemental composition of kernel (P×K×Ca×S)

Treatments	N (%)		K (%)		Mg (%)		S (mg kg^{-1})		Mn (mg kg^{-1})		Zn (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	1.53	1.58	0.27	0.24	0.08	0.05	1305	868	47.00	23.00	16.67	26.00	1.27	1.97
$p_1k_1ca_2$	1.51	1.43	0.18	0.18	0.05	0.06	1890	666	50.00	150.00	21.00	50.00	1.02	1.81
$p_1k_2ca_1$	1.73	1.57	0.18	0.21	0.05	0.12	252	1136	37.00	134.67	18.67	23.33	1.23	1.10
$p_1k_2ca_2$	1.54	1.77	0.21	0.21	0.09	0.05	155	127	133.00	55.00	51.33	33.33	1.27	4.03
$p_2k_1ca_1$	1.63	1.93	0.14	0.28	0.05	0.11	247	648	28.67	71.00	11.33	29.33	2.03	3.25
$p_2k_1ca_2$	1.53	2.00	0.13	0.12	0.08	0.06	680	351	83.00	116.67	74.17	41.67	0.98	1.44
$p_2k_2ca_1$	1.55	1.91	0.17	0.14	0.10	0.11	644	380	47.00	150.67	19.33	73.33	1.93	1.20
$p_2k_2ca_2$	1.38	1.47	0.21	0.22	0.02	0.03	530	523	79.30	94.33	23.67	45.00	0.45	1.17
CD (0.05)	0.10		0.04		0.02		20.34		29		3.15		0.09	

4.9.4 Four factor interactions

4.9.4.1 Interaction between P, K, Ca and S

Interaction effects of P, K, Ca and S on elemental composition of kernel are presented in table 46. The four elements in their lower levels interacted to give significantly higher contents of Mg and S, than $p_1k_1ca_1S_2$. Instead of S, when Ca dose was doubled contents of K and Mg significantly declined. Addition of another 50 kg S resulted in lower content of S along with K, but Mn, Zn and Si contents were significantly increased.

K at its higher level interacted with P, Ca and S at their lower levels to increase the content of N in the kernel. When S was applied at 100 kg ha^{-1}, Mg, Mn and Zn contents were raised but K and S contents were significantly reduced.

Combination of P and S at lower levels with K and Ca at higher levels significantly increased the Mn and Zn contents in the kernel but reduced K and S contents. Addition of an increment of 50 kg S significantly raised the N, Zn and Si contents but K, Mg and S remained low.

Application of P at 35 kg ha^{-1} together with K, Ca and S at 70, 300 and 50 kg ha^{-1} increased N and Si contents of the kernel, but when S application was raised to 100 kg ha^{-1}, N, Mg, Mn, Zn and Si contents were significantly improved.

Higher doses of P and Ca interacted with lower doses of K and S to significantly lower K, S and Si contents while the Mn and Zn contents were improved. When S was raised to its higher level, N content was found to be highest in the kernel. Mn, Zn and Si contents were also significantly improved.

Table 47. Effect of treatments on elemental composition of husk

Table 47.1 Between controls

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
C_1	0.06	0.06	1.71	0.11	0.05	124	158	257	32	13.53
C_2	0.43	0.04	1.30	0.10	0.08	33	225	324	75	10.06
CD(0.05)	0.05	0.01	0.04	0.01	0.02	20	NS	NS	28	0.78

Table 47.2 Control Vs the rest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
Control	0.52	0.05	1.51	0.10	0.07	78.67	192.00	290.80	53.50	11.80
Rest	0.76	0.11	1.80	0.14	0.05	263.00	174.00	415.67	60.63	5.34
CD (0.05)	0.05	0.01	0.04	0.01	0.02	20.00	NS	103.00	NS	0.78

K and S were found to be significantly decreased when P and K in their higher levels were applied along with Ca and S at their lower levels. Their contents were further lowered when S dose was increased to 100 kg ha^{-1}. However N, Mg, Mn and Zn were significantly affected by an increase in contents.

Lower S dose when combined with P, K and Ca at higher levels was found to significantly increase only the Mn and Zn contents. This increase was further advanced when an incremental dose of 50 kg S was applied. N, K, Mg, S and Si were all found to be significantly inferior to $p_1k_1ca_1s_1$.

4.10 Elemental composition of husk

4.10.1c Between controls

Table 47.1 Showed that husk contents of P, K, Ca, S and Si were higher in the plants which received fertilizer as per POP recommendations. Contents of N, Mg and Zn were significantly higher in absolute control and the increases worked out to 617,60 and 134%.

4.10.1b Control Vs the rest

Highest Mg and Si contents were recorded in control plots as seen in table 47.2 buf rest of the treatments recorded significantly higher contents of N, P, K, Ca, S and Fe to the tune of 46,120,19,40,234 and 43%.

4.10.1c Mean main effects of treatments

C_1 was seen to be significantly higher in the content of Si when compared to all other treatments (Table 47.3). Absolute control was also higher in Si content and

Table 47.3 Mean main effects

Treatments	Husk									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	SiO_2 (%)
P_1	0.76	0.14	1.89	0.15	0.06	223.25	187.58	485.67	65	5.56
P_2	0.76	0.08	1.71	0.13	0.05	303.13	160.63	345.67	56.25	5.13
K_1	0.83	0.13	1.87	0.12	0.07	276.46	131.17	328.42	60	4.85
K_2	0.69	0.08	1.73	0.17	0.04	249.92	217.04	502.92	61.25	5.84
Ca_1	0.78	0.12	1.98	0.13	0.06	239.08	221.08	464.04	70.63	7.17
Ca_2	0.71	0.10	1.62	0.15	0.04	287.29	127.13	367.29	50.63	3.52
S_1	0.79	0.10	1.79	0.14	0.05	277.88	156.29	475.92	63.0	3.96
S_2	0.73	0.12	1.81	0.14	0.05	248.50	191.92	355.42	58.25	6.73
C_1	0.06	0.06	1.71	0.105	0.049	124	158	257.33	32.33	13.53
C_2	0.43	0.041	1.30	0.095	0.084	33	225	324	74.67	10.06
CD(0.05)	0.05	0.01	0.04	0.01	0.02	20.34	153.5	103	27.46	0.78

Table 48. Two factor interaction effect of treatments on elemental composition of husk

Table 48.1 P × K

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe(mg kg^{-1})		Zn(mg kg^{-1})		SiO_2 (%)	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
p_1	0.81	0.71	0.17	0.10	1.92	1.87	0.10	2.20	0.06	0.06	155.92	290.58	393	577	55.83	74.17	1.82	9.29
p_2	0.85	0.66	0.10	0.07	1.83	1.59	0.13	0.14	0.07	0.02	397	209.25	263	428	64.17	48.33	7.88	2.38
CD (0.05)	0.01		0.01		0.01		0.006		0.004		3.02		2.59		6.87		0.19	

Table 48.2 P × Ca

Treatments	K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1	2.05	1.74	0.16	0.14	0.09	0.03	207	238.83	593.67	377.67	7.90	3.22
p_2	1.92	1.50	0.11	0.16	0.03	0.06	270.50	335.75	334.42	356.92	6.44	3.82
CD (0.05)	0.01		0.006		0.004		3.02		2.59		0.19	

also in contents of Mg, Mn and Zn. However when compared to other treatments, control plots registered lower contents of N, P, Ca, S and Fe.

Application of 17.5 kg ha^{-1} P significantly increased the P content. Highest content of S (305 mg kg^{-1}) was obtained when 35 kg P was applied.

K at 70 kg significantly increased the N and Mg contents. A similar effect on Ca and Fe was obtained only when K dose was increased to 105 kg ha^{-1}. Significantly higher contents of K, Zn and Si were recorded when 150 kg ha^{-1} Ca was applied. S was effective only in increasing the Mn content to 191.9 mg kg^{-1}, when application was done at a higher rate of 100 kg ha^{-1}.

4.10.2 Two factor interactions

4.10.2.1 Interaction between P and K

It can be seen from the table 48.1 that P at 17.5 kg ha^{-1} and K at 70 kg ha^{-1} had the maximum effect on increasing the P and K contents. Increased Ca, Fe, Zn and Si contents were however obtained when K level was raised to 105 kg ha^{-1}. Increased P application to the tune of 35 kg ha^{-1} resulted in maximum N, Mg and S contents in the husk and the increases worked out to 5,17 and 154% over p_1k_1.

4.10.2.2 Interaction between P and Ca

Interaction effects of P and Ca were evident at the lower levels with regard to K, Ca, Mg, Fe and Si. Combining higher levels of P and Ca maintained this increase in the case of Ca and raised the S content (Table 48.2)

Table 48.3 P × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe(mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1	0.75	0.77	0.10	0.17	1.91	1.88	0.18	0.12	0.08	0.05	344.42	102.08	468.67	502.67	5.35	5.77
p_2	0.83	0.68	0.09	0.07	1.68	1.74	0.10	0.17	0.03	0.06	211.30	394.92	483.17	208.17	2.58	7.68
CD (0.05)	0.01		0.01		0.01		0.006		0.004		3.02		2.59		0.19	

Table 48.4 K × Ca

Treatments	N (%)		P (%)		K (%)		Ca (%)		S (mg kg^{-1})		Mn(mg kg^{-1})		Fe(mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
k_1	0.80	0.86	0.17	0.10	2.00	1.75	0.13	0.10	269.42	283.50	123.17	139.17	281.17	375.67	5.69	4.02
k_2	0.75	0.62	0.06	0.10	2.00	1.49	0.14	0.20	208.75	291.08	319.00	115.08	646.92	358.92	8.65	3.02
CD (0.05)	0.01		0.01		0.01		0.006		3.02		38.38		2.59		0.19	

4.10.2.3 Interaction between P and S

Data presented in table 48.3 revealed that higher K, Ca and Mg contents were produced when P and S were applied at 17.5 and 50 kg ha^{-1}. Increase in the S level to 100 kg ha^{-1} resulted in highest Fe content of 902.67 mg kg^{-1}. While increasing P to 35 kg ha^{-1} gave an increase of 11% in the N content, P and S in their higher levels interacted to give highest husk contents of S and Si which were 15 and 43.5% higher than p_1s_1.

4.10.2.4 Interaction between K and Ca

From the data on interaction of K and Ca presented in table 48.4 it was evident that higher contents of P and K could be obtained in the husk by applying K and Ca at their lower levels. Increasing Ca application to 300 kg ha^{-1} significantly increased the N and Mn contents by 7.5 and 13 % but when K was applied at the higher level, contents of K, Fe and Si were significantly increased. A similar effect could be obtained in S content only by the interaction of K and Ca at 105 and 300 kg ha^{-1} respectively.

4.10.2.5 Interaction between K and S

K × S interaction effects are presented in table 48.5. P and K contents were at their highest in k_1s_1 and increase of 25 and 7% were recorded in N, Mg and Si contents when S dose was increased to 100 kg ha^{-1}. However, when K application was increased to 105 kg ha^{-1}, Fe and Zn contents were highest and the increases worked out to 37 and 52% over k_1s_1. Ca and S contents were maximised when 100 kg ha^{-1} of S was applied.

Table 48.5 K × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe(mg kg^{-1})		Zn(mg kg^{-1})		SiO_2	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1	0.82	0.85	0.15	0.12	1.94	1.81	0.12	0.11	0.05	0.08	344.42	102.08	401.17	255.67	50.17	69.83	2.20	7.50
k_2	0.77	0.61	0.05	0.11	1.65	1.81	0.16	0.17	0.06	0.03	211.33	394.92	550.67	455.17	75.83	46.67	5.72	5.95
CD (0.05)	0.01		0.01		0.01		0.006		0.004		3.02		2.59		2.87		0.19	

Table 48.6 Ca × S

Treatments	N (%)		P (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn(mg kg^{-1})		Fe(mg kg^{-1})		Zn(mg kg^{-1})		SiO_2	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
ca_1	0.79	0.76	0.13	0.10	0.14	0.13	0.08	0.05	199.08	279.08	153.83	288.33	406.17	521.92	53.75	87.50	4.82	9.53
ca_2	0.80	0.69	0.07	0.14	0.14	0.16	0.03	0.06	356.67	217.92	158.75	95.50	545.67	188.92	72.25	29.00	3.11	3.93
CD (0.05)	0.01		0.01		0.006		0.004		3.02		38.38		2.59		6.87		0.19	

4.10.2.6 Interaction between Ca and S

Data in table 48.6 showed that 0.08% Mg was recorded when 150 kg Ca was applied along with 50 kg S. Increasing the S dose to 100 kg ha^{-1} increased the contents of Mn, Zn and Si by 87,63 and 98% over ca_1s_1. In ca_2s_1 contents of N, S and Fe were higher by 2,79 and 34.5% over ca_1s_1. When S was applied at 100 kg ha^{-1} P and Ca contents were seen to increase by 100 and 14%.

4.10.3 Three factor interactions

4.10.3.1 Interaction between P, K and Ca

P, K and Ca interaction effects presented in table 49.1 revealed that P and Ca contents in the husk was highest when 17.5 kg ha^{-1} P, 70 kg ha^{-1} K and 150 kg ha^{-1} Ca were combined. Increasing the K dose to 105 kg ha^{-1} significantly raised the K, Fe and Si contents. A similar effect could be obtained in Ca with an increment of 150 kg Ca ha^{-1}. However this led to decreased contents of N, P, K, Mg and Fe.

K and Ca at their lower levels with P at 35 kg ha^{-1} brought about significant increases in S and Si contents. This effect was sustained along with increased contents of N, when Ca dose was increased to 300 kg ha^{-1}.

P and K applied at 35 kg ha^{-1} and 105 kg ha^{-1} in combination with 150 kg ha^{-1} of Ca had significant beneficial influence on P, K, Ca and Mg contents but the Fe and Si contents were decreased. Combining all three elements in their higher levels of application resulted in significant decline in the contents of N, P, K, Ca, Mg and Si while S and Fe contents increased.

Table 49. Three factor interaction effect of treatments on composition of husk
Table 49.1 P × K × Ca

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Fe(mg kg^{-1})		SiO_2 (%)	
	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2	ca_1	ca_2
p_1k_1	0.82	0.80	0.21	0.14	1.99	1.84	0.17	0.04	0.10	0.03	187.67	124.00	336	450	1.85	1.80
p_1k_2	0.76	0.67	0.08	0.11	2.10	1.64	0.15	0.24	0.09	0.04	227.00	353.50	850	304	13.95	4.64
p_2k_1	0.78	0.93	0.14	0.06	2.01	1.65	0.10	0.16	0.05	0.09	351.00	228.67	225	300	9.54	6.23
p_2k_2	0.75	0.56	0.04	0.10	1.83	1.34	0.13	0.15	0.01	0.03	189.63		443	413	3.35	1.40
CD (0.05)	0.03		0.01		0.02		0.01		0.01		6.03		5.17		0.39	

Table 49.2. P × K × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		S (mg kg^{-1})		Mn(mg kg^{-1})		Fe(mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1k_1	0.81	0.82	0.15	0.20	1.94	1.89	0.13	0.07	174.00	137.83	169.30	134.00	461	325	1.24	2.41
p_1k_2	0.70	0.73	0.06	0.14	1.88	1.87	0.23	0.16	514.80	66.30	121.00	325.80	475	679	9.45	9.14
p_2k_1	0.83	0.87	0.15	0.04	1.93	1.73	0.11	0.15	194.00	599.70	111.00	110.00	340	185	3.17	12.60
p_2k_2	0.83	0.49	0.04	0.09	1.42	1.75	0.09	0.19	228.30	190.17	223.67	197.67	625	230	1.98	2.77
CD (0.05)	0.03		0.01		0.02		0.01		6.03		76.75		5.17		0.39	

Table 49.3 P × Ca × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (mg kg^{-1})		Mn(mg kg^{-1})		Fe(mg kg^{-1})	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
p_1ca_1	0.61	1.00	0.13	0.16	2.14	1.96	0.21	0.11	0.12	0.06	262.00	152.00	87.00	358.00	336	850
p_1ca_2	0.10	0.58	0.08	0.18	1.68	1.80	0.15	0.13	0.03	0.03	426.00	51.50	203.00	101.67	600	155
p_2ca_1	0.96	0.56	0.14	0.04	1.83	2.01	0.08	0.15	0.04	0.03	135.50	405.50	220.67	218.00	475	193
p_2ca_2	0.70	0.80	0.06	0.10	1.52	1.47	0.12	0.19	0.02	0.10	287.17	384.00	114.00	89.33	490	223
CD (0.05)	0.03		0.01		0.02		0.01		0.01		6.03		76.75		5.17	

Table 49.4 K × Ca × S

Treatments	N (%)		P (%)		K (%)		Ca (%)		Fe(mg kg^{-1})		Zn(mg kg^{-1})	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
k_1ca_1	0.73	0.88	0.20	0.14	2.12	1.89	0.14	0.13	186	375	30.80	104.17
k_1ca_2	0.91	0.82	0.10	0.10	1.76	1.74	0.11	0.09	615	135	69.50	35.50
k_2ca_1	0.85	0.65	0.06	0.06	1.85	2.08	0.15	0.12	625	668	76.67	70.83
k_2ca_2	0.68	0.57	0.04	0.17	1.45	1.54	0.16	0.23	475	242	75.00	22.50
CD (0.05)	0.03		0.01		0.02		0.01		5.17		13.73	

4.10.3.2 Interaction between P, K and S

Table 49.2 depicts the interaction effects of P, K and S. Compared to the lower levels of the three elements, application of S at higher dose significantly increased the husk contents of P and Si. When K dose was increased to 105 kg ha^{-1} N, P, K and Mn contents significantly declined, but that of Ca, S, Fe and Si were significantly raised. A similar effect was observed in all the elements when S application was raised to the higher level except in the case of S, Mn and Fe which were significantly increased.

When P was applied at 35 kg ha^{-1} along with K and S at 70 and 50 kg ha^{-1}, Ca and Fe were found to decrease significantly. S and Si contents were, however, increased. Addition of another 50 kg of S gave highest content of 0.87% N and 12.6% Si in the husk. Contents of Ca and S were also increased.

4.10.3.4 Interaction between K, Ca and S

Lower levels of K, Ca and S interacted to produce higher Ca content in the husk (Table 49.4). But higher N, Fe and Zn contents were observed when S application was increased by 50 kg ha^{-1}.

Application of 70 kg ha^{-1} K and 50 kg ha^{-1} S with 300 kg ha^{-1} Ca significantly increased the contents of N, Fe and Zn over the lowest levels. But when S application was increased by another 50 kg this effect was seen only in the case of N, P, K, Ca and Fe which were all found to decrease significantly.

Significant increases in N, Fe and Zn were also noticed over $k_1ca_1s_1$ when K at higher level was combined with Ca and S at lower levels. Increased S application reduced the contents of N, P, K, Mg and Ca while Fe and Zn contents increased.

Table 50. Four factor interaction effect of treatments on elemental composition of husk (P × K × Ca × S)

Treatments	N (%)		K (%)		Mg (%)		S (mg kg^{-1})		Fe (mg kg^{-1})		SiO_2 (%)	
	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2	s_1	s_2
$p_1k_1ca_1$	0.65	1.00	2.15	1.83	0.09	0.10	172	202	173	500	1.03	2.66
$p_1k_1ca_2$	0.97	0.64	1.72	1.96	0.03	0.02	175	73	750	150	1.45	2.15
$p_1k_2ca_1$	0.58	0.93	2.12	2.09	0.16	0.02	352	102	500	1200	12.65	15.24
$p_1k_2ca_2$	0.82	0.52	1.64	1.64	0.04	0.03	677	30	450	158	6.25	3.03
$p_2k_1ca_1$	0.81	0.75	2.08	1.94	0.06	0.04	68	634	200	250	3.13	15.94
$p_2k_1ca_2$	0.85	1.00	1.79	1.51	0.01	0.16	320	565	480	120	3.20	9.26
$p_2k_2ca_1$	1.12	0.37	1.59	2.07	0.01	0.02	202	177	750	135	2.45	4.25
$p_2k_2ca_2$	0.54	0.61	1.25	1.44	0.02	0.03	254	203	500	325	1.52	1.28
CD (0.05)	0.05		0.08		0.02		12.07		10.35		0.78	

When higher levels of K and Ca interacted with 50 kg ha^{-1} S, N, P and K contents decreased while Ca, Fe and Zn increased over $k_1ca_1s_1$. A similar effect was noticed when S was applied at its higher level except in the case of Zn which failed to increase.

4.10.4 Four factor interactions

4.10.4.1 Interaction between P, K, Ca and S

Data on P, K, Ca and S interaction effects are depicted in table 50. Combination of lower levels of the four elements gave higher K content in the husk, when compared to $p_1k_1ca_1s_2$. Increase of Ca application by 150 kg ha^{-1} resulted in significantly higher N and Fe contents when compared to lowest levels. But when S dose was increased to 100 kg ha^{-1}, N content was on par while Fe content decreased. Contents of K, Mg, S and Fe were seen to decrease while Si content recorded a significant increase.

P, Ca and S at lower levels interacted with 105 kg ha^{-1} K to significantly lower N content, while Mg, S, Fe and Si contents were significantly increased. An increment of 50 kg ha^{-1} S increased the N, Fe and Si contents but K, Mg and S contents were significantly decreased.

N, S, Fe and Si contents increased, while K and Mg contents decreased when P and S at lower levels interacted with K and Ca at higher levels. Increasing the S application had similar effect on K, Mg and Si contents but N, S and Fe contents decreased significantly.

$p_2k_1ca_1s_1$ combination gave significantly higher N, S, Fe and Si contents and when S dose was increased a similar effect was noted in N, S and Si but Fe content

Table 51. Nutrient ratios

Table 51.1 Effect of treatments on nutrient ratios of leaf blade and sheath at various stages of growth

Treatments	P/Fe (MTL)	P/Fe (MTS)	P/Fe (PIL)	P/Fe (PIS)	P/Mn(MTL)	P/Mn (MTS)	P/Mn (PIL)	P/Mn (PIS)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
$p_1k_1ca_1s_1$	1.57	4.50	2.55	2.80	0.39	1.42	0.85	2.30	4732.93	3211.63
$p_2k_1ca_1s_1$	3.80	0.66	1.00	0.45	1.20	0.80	0.73	0.45	5206.22	3921.57
$p_1k_2ca_1s_1$	7.00	9.00	1.00	3.00	2.00	2.00	0.88	0.46	4394.86	7268.42
$p_2k_2ca_1s_1$	2.00	4.00	5.00	2.00	2.00	3.00	0.81	2.00	5747.13	4225.83
$p_1k_1ca_2s_1$	3.00	2.00	3.00	4.00	0.70	1.00	0.65	0.99	4462.47	3718.73
$p_2k_1ca_2s_1$	3.00	6.00	2.00	0.34	1.00	6.00	1.00	0.73	4732.93	3515.89
$p_1k_2ca_2s_1$	7.00	3.00	0.28	0.30	1.00	0.80	0.27	0.38	4732.93	3380.66
$p_2k_2ca_2s_1$	2.00	6.00	0.42	2.00	0.90	2.00	0.40	0.29	4530.09	3076.40
$p_1k_1ca_1s_2$	0.57	2.00	1.00	1.00	0.62	1.00	1.00	0.70	5070.99	3380.66
$p_2k_1ca_1s_2$	7.00	4.00	3.00	2.00	2.00	1.00	1.00	0.81	4597.70	2704.53
$p_1k_2ca_1s_2$	5.00	1.00	2.00	4.00	3.00	0.24	2.20	0.28	4462.47	3245.44
$p_2k_2ca_1s_2$	7.70	4.00	5.00	3.00	7.00	2.00	3.00	1.00	4394.86	3380.66
$p_1k_1ca_2s_2$	3.00	3.00	6.00	2.00	3.00	2.00	2.00	0.90	4327.25	2704.53
$p_2k_1ca_2s_2$	3.00	7.00	1.00	9.00	2.00	2.00	0.61	0.73	4800.54	3211.63
$p_1k_2ca_2s_2$	3.00	1.00	3.00	3.00	3.00	1.00	2.00	2.00	5138.61	3718.73
$p_2k_2ca_2s_2$	3.00	3.00	2.00	3.00	2.00	2.00	1.00	0.54	4394.86	3042.60
C_1	3.00	4.00	1.00	2.00	1.00	1.00	0.49	0.64	4254.64	2434.08
C_2	1.00	0.67	1.00	5.00	0.90	0.22	0.70	0.35	1757.94	1724.14
CD(0.05)	0.01	0.10	0.15	0.10	2.10	3.15	0.42	0.42	399.00	350.00

was found to decrease significantly along with K. Mg content registered a significant increase.

P and K at 35 and 105 kg ha^{-1} when applied with Ca and S at 150 and 50 kg ha^{-1} significantly increased the N, S, Fe and Si contents over $p_1k_1ca_1s_1$. N and Fe contents decreased when the higher dose of S application was adopted.

Higher levels of P, K and Ca with lower level of S was seen to reduce the contents of N, K and Mg while S, Fe and Si were increased and the effect when S application was increased to 100 kg was found to be the same.

4.11 Effect of treatment combinations on nutrient ratios

Table 51 is a record of effect of treatment combination on nutrient ratios of leaf blade and sheath at various stage of growth. Lowest level combination of elements produced lowest P/Mn ratio in leaf blade at maximum tillering and P/Mn ratio in the sheath at PI stage. While an increment in the P dose lowered the P/Fe ratio of sheath at maximum tillering stage, a reverse trend was also observed when K level was also increased. At maximum tillering highest P/Mn ratio was noticed in the sheath, when higher levels of P and Ca were combined with lower levels of K and S.

In the leaf blade and sheath a lower P/Fe ratio was noticed when K at 105 kg ha^{-1} and Ca at 300 kg ha^{-1} combined with P and S at 17.5 and 50 kg ha^{-1} respectively, at PI stage. Increment of S dose over lower level combination of other nutrients significantly lowed the P/Fe ratio of leaf blade at maximum tillering stage. Increase in K dose along with this could significantly lower P/Mn ratio of leaf blade at PI stage (Table 51.1).

Table 51.2. Effect of treatments on nutrient ratios of leaf blade and sheath at various stages of growth

Treatments	K/Fe (MTL)	K/Fe (MTS)	K/Fe (PIL)	K/Fe (PIS)	K/Mn(MTL)	K/Mn (MTS)	K/Mn (PIL)	K/Mn (PIS)
$p_1k_1ca_1s_1$	34.70	13.80	41.80	33.20	8.50	4.37	12.43	27.66
$p_2k_1ca_1s_1$	25.00	12.00	132.00	13.89	7.89	20.00	8.80	8.52
$p_1k_2ca_1s_1$	32.26	39.68	20.95	30.60	7.41	5.09	12.84	19.55
$p_2k_2ca_1s_1$	10.00	20.00	79.00	40.94	8.00	18.27	13.17	17.50
$p_1k_1ca_2s_1$	22.00	5.00	27.11	108.57	5.07	3.74	6.59	19.00
$p_2k_1ca_2s_1$	19.07	10.00	30.40	1.38	9.50	9.00	16.89	0.63
$p_1k_2ca_2s_1$	50.00	13.82	31.78	16.13	10.10	3.89	7.94	6.05
$p_2k_2ca_2s_1$	47.50	42.86	36.82	11.82	17.27	10.71	17.05	4.95
$p_1k_1ca_1s_2$	28.42	9.65	18.00	132.00	30.62	6.07	16.00	9.17
$p_2k_1ca_1s_2$	115.33	23.46	60.80	11.20	38.44	12.74	27.64	6.22
$p_1k_2ca_1s_2$	41.33	24.80	22.93	1.21	24.80	7.76	17.20	8.96
$p_2k_2ca_1s_2$	29.71	26.40	40.67	20.36	29.71	5.42	22.40	7.72
$p_1k_1ca_2s_2$	20.33	12.12	58.82	19.07	20.33	6.45	15.38	8.55
$p_2k_1ca_2s_2$	38.00	18.29	16.23	92.00	26.28	3.66	9.86	7.67
$p_1k_2ca_2s_2$	17.27	6.20	25.09	18.92	15.83	6.43	16.24	12.30
$p_2k_2ca_2s_2$	13.33	19.38	16.25	4.72	9.52	8.70	11.82	6.80
C_1	25.33	23.60	10.15	26.29	1.13	8.94	4.06	10.82
C_2	3.75	6.00	11.88	6.28	2.61	2.05	6.73	3.96
CD (0.05)	7.34	7.39	11.68	3.83	7.22	2.84	4.11	3.48

Combination of 35 kg P, 105 kg K, 150 kg Ca and 100 kg S significantly increased the P/Fe and P/Mn ratios of leaf blade at maximum tillering and P/Mn ratio of leaf blade at panicle initiation. $p_2k_1ca_2s_2$ combination was effective only in raising the P/Fe ratio of sheath significantly at maximum tillering and PI stages.

Data presented in table 51.2 reveal that K/Fe ratio recorded a higher value in the leaf blade at maximum tillering, when higher levels of P and S combined with lower levels of K and Ca in their higher levels. The same treatment recorded highest K/Mn ratio in the leaf blade at both maximum tillering and PI stages. Lower level combination produced highest K/Mn ratio in the sheath at PI stage, while an increment in the phosphorus level led to higher K/Fe ratio in the leaf blade at PI stage and K/Mn ratio in the sheath at maximum tillering stage. A lower K/Fe ratio of 5.0 was observed in the leaf blade at MT when Ca level was doubled keeping P, K and S at their lower levels of 17.5, 70 and 50 kg ha^{-1}. K/Mn ratio in leaf blade at MT was also lowest in this combination, but this could produce a higher K/Fe ratio in the sheath at PI stage.

K/Fe ratio of sheath at maximum tillering was found to be highest when higher levels of P, K and Ca were combined with lower dose of S. But when K and S at their higher levels combined with P and Ca in their lower levels, K/Fe ratio in the sheath at PI stage was decreased significantly. Absolute control was effective in lowering K/Fe ratio and K/Mn ratio at maximum tillering stage in the leaf blade and in the sheath respectively, while POP control significantly lowered the K/Fe ratio in the leaf blade at PI stage.

Higher dose of K along with lower doses of P, Ca and S resulted in a lower Ca/Mn ratio of 0.19 in the leaf blade at PI stage (Table 51.3). Highest and lowest ratio of Ca/Fe in the leaf blade and sheath respectively was observed when K and Ca doses were increased over lower doses of four elements at maximum tillering stage.

Table51.3 Effect of treatments on nutrient ratios at leaf blade and sheath at various stages of growth

Treatment	Ca/Fe (MTL)	Ca/Fe (MTS)	Ca/Fe (PIL)	Ca/Fe (PIS)	Ca/Mn(MTL)	Ca/Mn (MTS)	Ca/Mn (PIL)	Ca/Mn (PIS)
$p_1k_1ca_1s_1$	2.40	0.67	6.55	1.20	0.60	0.22	2.18	1.00
$p_2k_1ca_1s_1$	5.80	0.40	18.00	2.21	1.84	0.67	1.20	1.35
$p_1k_2ca_1s_1$	2.26	1.19	3.15	5.34	0.52	0.31	0.19	0.34
$p_2k_2ca_1s_1$	3.50	1.00	9.00	0.88	2.80	0.67	1.50	0.38
$p_1k_1ca_2s_1$	4.57	0.28	11.33	42.86	0.73	0.63	0.86	2.00
$p_2k_1ca_2s_1$	2.93	2.67	3.20	2.00	3.20	0.20	5.00	1.37
$p_1k_2ca_2s_1$	16.00	0.18	10.00	3.20	1.14	0.47	1.06	0.25
$p_2k_2ca_2s_1$	8.50	2.57	4.32	1.14	3.09	0.29	3.26	1.14
$p_1k_1ca_1s_2$	2.43	0.47	7.75	12.00	2.62	0.30	6.89	0.83
$p_2k_1ca_1s_2$	2.22	0.62	12.40	1.20	5.78	0.24	5.64	0.67
$p_1k_2ca_1s_2$	14.23	0.67	0.67	1.60	1.33	0.14	0.50	1.19
$p_2k_2ca_1s_2$	4.43	0.93	6.00	0.36	4.43	0.45	3.60	0.14
$p_1k_1ca_2s_2$	17.78	1.58	24.12	1.23	5.78	0.51	6.30	0.55
$p_2k_1ca_2s_2$	54.33	3.71	1.65	36.00	2.98	0.93	1.00	3.00
$p_1k_2ca_2s_2$	1.45	0.90	2.55	1.69	1.33	0.93	1.65	1.10
$p_2k_2ca_2s_2$	1.07	1.75	3.75	0.67	0.76	1.22	2.72	0.96
C_1	2.00	0.60	3.54	0.86	0.80	0.18	1.42	0.35
C_2	0.38	0.27	1.53	0.25	0.26	0.09	0.87	0.16
CD (0.05)	1.14	1.04	1.03	0.34	1.76	0.63	1.36	0.31

However a higher Ca/Fe ratio of sheath at PI stage was noticed when only Ca dose was doubled. A higher dose of sulphur along with lower doses of other three elements produced higher Ca/Mn ratio in the leaf blade at PI Stage. Increase in P and S doses increased the Ca/Mn ratio of leaf blade at maximum tillering stage of the crop, while when instead of P, K level was raised along with S, significantly lower Ca/Fe ratio was produced in the leaf blade at the PI stage. An increment in the P level along with this led to lowest Ca/Mn ratio at sheath in the PI stage.

Significantly higher Ca/Fe and Ca/Mn ratios in the leaf blade at PI stage and at maximum tillering stage respectively were observed when higher levels of Ca and S were combined with 17.5 kg P and 70 kg K. An increment of P dose along with this could significantly increase the Ca/Fe ratio of sheath at maximum tillering and Ca/Mn ratio of sheath at panicle initiation stages. When P, K, Ca and S were combined in their higher levels Ca/Mn ratio of sheath at maximum tillering stage was observed to be highest. Lowest Ca/Fe ratio of leaf blade at maximum tillering and sheath at PI stage was recorded in absolute control. Similarly absolute control recorded significantly lower Ca/Mn ratio in leaf sheath and in blade at maximum tillering stage.

Lower level combination of P, K, Ca and S resulted in highest S/Mn ratio of sheath at PI stage. Absolute control recorded lower S/Fe ratio of leaf blade at PI stage and S/Mn ratio of leaf blade and sheath at PI stage and maximum tillering stages respectively. Higher level of P along with lower levels of K, Ca and S resulted in highest S/Fe ratio of blade at PI stage, while when K dose was increased over lower doses of other three elements, S/Fe ratio of leaf sheath at maximum tillering stage was increased significantly but S/Mn ratio of leaf blade at MT was lowest (Table 51.4).

Table 51.4 Effect of treatments on nutrient ratios of leaf blade and sheath at various sage of growth

Treatments	S/Fe (MTL)	S/Fe (MTS)	S/Fe (PIL)	S/Fe (PIS)	S/Mn(MTL)	S/Mn (MTS)	S/Mn (PIL)	S/Mn (PIS)
$p_1k_1ca_1s_1$	4.32	3.29	5.46	3.00	1.06	1.04	1.62	2.50
$p_2k_1ca_1s_1$	6.70	1.44	37.25	1.58	2.12	2.40	2.48	0.97
$p_1k_2ca_1s_1$	2.34	5.56	1.47	1.02	0.54	1.43	0.90	0.65
$p_2k_2ca_1s_1$	1.89	1.70	8.75	2.19	1.51	1.13	1.46	0.94
$p_1k_1ca_2s_1$	4.21	0.50	2.72	11.25	0.98	0.38	0.66	1.97
$p_2k_1ca_2s_1$	1.33	1.61	1.95	0.22	0.67	1.45	1.08	0.10
$p_1k_2ca_2s_1$	9.17	4.68	4.96	2.67	1.8	1.36	1.24	1.00
$p_2k_2ca_2s_1$	12.13	4.29	2.39	3.41	4.41	1.07	1.11	1.43
$p_1k_1ca_1s_2$	0.57	5.10	3.81	11.50	0.62	3.20	3.39	0.80
$p_2k_1ca_1s_2$	14.33	3.07	2.80	3.03	4.78	1.21	1.27	1.69
$p_1k_2ca_1s_2$	7.10	4.00	1.83	0.83	4.23	0.82	1.38	0.61
$p_2k_2ca_1s_2$	1.89	3.57	6.33	2.32	1.89	1.73	3.80	0.88
$p_1k_1ca_2s_2$	2.58	1.89	5.15	2.31	2.58	0.89	1.35	1.03
$p_2k_1ca_2s_2$	3.15	1.86	1.85	10.00	2.18	0.46	1313	0.83
$p_1k_2ca_2s_2$	3.72	0.69	4.59	2.70	3.42	0.71	2.97	1.75
$p_2k_2ca_2s_2$	4.17	2.69	2.50	0.88	2.98	1.87	1.82	1.26
C_1	5.17	1.05	2.42	1.75	2.07	0.31	0.97	0.72
C_2	1.94	0.67	0.59	0.46	1.35	0.23	0.33	0.29
CD (0.05)	1.07	1.22	1.91	0.92	1.71	0.75	0.91	0.72

Significantly lower S/Fe ratio of leaf sheath at maximum tillering was noticed when higher level of S combined with lower level of P, K and Ca. Lowest S/Fe and S/Mn ratio of leaf sheath at PI stages were noticed when P at 35 kg, Ca at 300 kg and K at 70 kg interacted with S at 50 kg.

Narrow S/Fe ratio of leaf blade at maximum tillering and wider S/Fe and S/Mn ratios of sheath at PI and MT stages were produced when higher dose of 100 kg S interacted with lower levels of 17.5, 70 and 150 kg ha^{-1} P, K and S respectively. Combination of higher level of P and S with lower levels of K and Ca could increase S/Fe and S/Mn ratios of the leaf blade at maximum tillering stage. Significant increase in S/Mn ratio of leaf blade at PI stage was observed in $p_2k_2ca_1s_2$ combination.

A perusal of the data in table 51.5 showed that higher levels of 35 kg and 105 kg P and K combined with lower levels of 150 kg Ca and 50 kg S to significantly lower the K/Ca ratio of leaf blade at maximum tillering while lower K/Ca ratio in leaf sheath at maximum tillering and PI stages were noticed when higher levels of P and Ca interacted with lower levels of K and S. Increment in S dose over basal levels of P, K and Ca significantly lowered the K/Ca ratio of leaf blade at PI sage. Highest K/Ca ratio in the leaf blade at maximum tillering and PI stage were noticed in $p_1k_2ca_1s_2$, while in sheath it was noticed in $p_1k_2ca_2s_1$ and $p_2k_2ca_1s_2$ combinations respectively.

Ca+Mg/K ratio in leaf blade at MT stage was highest when 35 kg P and 105 kg K combined with lower levels of Ca and S. But when higher level of K combined with lower levels of other three elements, this ratio was widened in sheath at maximum tillering. Narrowest Ca+Mg/K ratio in the leaf blade and in the sheath at maximum tillering was recorded in POP control and in both $p_2k_1ca_1s_2$ and $p_1k_2ca_1s_1$ treatment combinations respectively.

Table 51.5 Effect of treatments on nutrient ratios of leaf blade and sheath at various stages of growth

Treatment	K/Ca (MTL)	K/Ca (MTS)	K/Ca (PIL)	K/Ca (PIS)	Ca+Mg/K (MTL)	Ca+Mg/K (MTS)	Ca+Mg/K (PIL)	Ca+Mg/K (PIS)
$p_1k_1ca_1s_1$	14.46	19.30	6.46	27.21	0.09	0.07	0.22	0.06
$p_2k_1ca_1s_1$	4.25	29.41	4.25	6.19	0.32	0.07	0.13	0.19
$p_1k_2ca_1s_1$	13.70	20.00	6.63	5.73	0.28	1.65	0.21	0.25
$p_2k_2ca_1s_1$	2.82	28.54	8.63	46.67	0.48	0.15	0.16	0.05
$p_1k_1ca_2s_1$	4.69	18.26	2.39	2.52	0.27	0.18	0.44	0.40
$p_2k_1ca_2s_1$	6.41	3.72	9.66	0.68	034	0.33	0.47	1.60
$p_1k_2ca_2s_1$	3.11	58.46	3.16	5.02	0.40	0.13	0.04	0.20
$p_2k_2ca_2s_1$	5.49	17.44	8.35	10.02	0.24	0.13	0.14	0.03
$p_1k_1ca_1s_2$	11.71	19.07	2.32	11.48	0.13	0.10	0.44	0.34
$p_2k_1ca_1s_2$	6.58	41.95	4.89	9.88	0.16	0.04	0.34	0.21
$p_1k_2ca_1s_2$	18.6	25.09	32.45	7.66	0.09	0.04	0.14	0.18
$p_2k_2ca_1s_2$	6.65	27.89	6.740	53.43	0.19	0.06	0.32	0.09
$p_1k_1ca_2s_2$	4.50	10.75	2.43	15.50	0.34	0.19	0.52	0.31
$p_2k_1ca_2s_2$	8.73	5.14	9.68	2.55	0.16	0.27	0.12	0.67
$p_1k_2ca_2s_2$	11.50	6.72	9.58	10.98	0.12	0.16	0.16	0.14
$p_2k_2ca_2s_2$	12.05	11.48	4.39	7.02	0.15	0.08	0.61	0.15
C_1	12.56	36.88	2.93	30.16	0.28	0.05	0.34	0.13
C_2	10.00	30.00	7.59	26.92	0.39	0.25	0.17	0.06
CD (0.05)	6.50	4.50	11.25	11.00	0.30	0.27	0.40	0.33

Table 52. Leaf-sheath ratio of nutrients at different stages of growth

Treatments	P		K		Ca		S		Fe		Mn		Grain
	MT	PI	MT	PI	MT	PI	MT	PI	MT	PI	MT	PI	$kgha^{1}$
$p_1k_1ca_1s_1$	0.42	1.02	2.93	1.39	3.91	5.84	1.54	1.94	1.17	1.10	1.50	3.08	4732.93
$p_2k_1ca_1s_1$	4.52	1.69	1.00	1.00	6.92	0.85	2.21	2.48	0.48	0.11	2.53	0.97	5206.22
$p_1k_2ca_1s_1$	1.05	0.92	2.00	1.16	2.92	1.00	0.52	2.82	1.23	1.69	1.37	1.76	4934.86
$p_2k_2ca_1s_1$	1.03	1.24	0.73	1.13	7.38	6.10	2.20	2.34	2.00	0.58	1.67	1.50	5747.13
$p_1k_1ca_2s_1$	0.69	1.92	2.13	0.80	8.31	0.85	4.07	0.777	0.48	3.21	1.58	2.31	4462.47
$p_2k_1ca_2s_1$	0.76	1.66	3.18	13.80	1.84	0.99	13.9	5.30	1.69	0.63	3.00	0.51	4732.93
$p_1k_2ca_2s_1$	1.32	0.89	1.97	1.18	37.0	1.88	1.07	1.11	0.55	0.60	0.78	0.90	4732.93
$p_2k_2ca_2s_1$	0.24	0.53	0.63	3.11	2.01	3.73	1.61	0.69	0.57	1.00	0.39	0.90	4530.09
$p_1k_1ca_1s_2$	0.22	0.48	2.43	0.55	3.95	2.70	0.10	1.31	0.82	4.00	0.48	0.31	5070.99
$p_2k_1ca_1s_2$	0.42	0.51	1.01	1.81	6.41	3.66	1.08	0.33	0.23	0.33	0.27	0.41	4597.70
$p_1k_2ca_1s_2$	2.26	0.46	1.45	1.42	1.96	0.34	1.08	1.63	0.60	0.75	0.21	0.74	4462.47
$p_2k_2ca_1s_2$	2.06	0.83	1.05	1.09	4.41	8.62	0.50	1.48	0.93	0.55	0.45	0.34	4394.86
$p_1k_1ca_2s_2$	1.10	0.68	1.83	0.81	5.62	5.15	1.50	0.57	1.09	0.26	0.51	0.45	4327.25
$p_2k_1ca_2s_2$	0.82	1.04	3.85	1.50	2.26	0.40	3.12	1.56	1.86	8.50	0.67	1.17	4800.54
$p_1k_2ca_2s_2$	1.14	1.09	1.06	1.12	0.62	1.29	2.03	1.50	0.38	0.85	0.43	0.85	5138.61
$p_2k_2ca_2s_2$	0.43	0.99	0.65	1.53	0.61	2.45	1.46	1.27	0.94	0.44	0.91	0.88	4394.86
C_1	0.95	0.44	1.29	0.36	3.78	3.69	5.94	1.28	1.20	0.93	0.88	0.86	4254.64
C_2	1.92	1.02	0.67	0.99	2.00	3.50	3.33	0.71	1.07	0.52	0.52	0.59	1757.94
CD (0.05)	0.07	0.05	1.40	1.28	1.00	0.08	1.25	0.42	1.49	1.00	0.85	0.85	399.00

When higher level of K and Ca interacted with lower levels of P and S it significantly lowered the Ca+Mg/K ratio of leaf blade at PI stage. But when P dose also doubled, it lowered this ratio in the sheath. Higher level combination of P, K, Ca and S significantly lowered the Ca+Mg/K ratio of the blade at PI stage, but in the sheath it was highest in $p_2k_1ca_2s_2$ combination.

4.12 Effect of treatments on leaf sheath ratios of nutrients at various stages of growth

A perusal at the data presented in table 52 shows that higher level of phosphorus at 35 kg ha^{-1} with lower levels of K, Ca and S was effective in widening the leaf-sheath ratio of P at maximum tillering but this narrowed the Fe ratio at PI stage while, instead of P, when S was tried at its higher level of 100 kg ha^{-1}, it significantly narrowed this ratio.

Lower doses of P, K, Ca and S combined effectively to increase the ratio of Mn at PI stage of crop. Interaction between higher levels of P and K with lower levels of Ca and S widened the leaf sheath ratio of Fe at maximum tillering. At PI stage a combination of higher level of Ca with lower levels of P, K and S could significantly raise the P leaf-sheath ratio.

Leaf-sheath ratios of S and Mn at PI and MT respectively were higher in $p_2k_1ca_2s_1$. Highest ratio of K at maximum tillering was observed in $p_2k_1ca_2s_2$. At PI stage it was highest when higher levels of P and Ca combined with lower level of K and S, but this combination recorded lowest K leaf-sheath ratio at maximum tillering. In PI stage it was lowest in C_1.

Highest and lowest leaf-sheath ratio of Ca at maximum tillering was in $p_1k_2ca_2s_1$ and $p_2k_2ca_2s_2$ respectively. While at PI stage lower doses of P and Ca along

Table 53. Nutrient uptake as influenced by different levels of elements P, K, Ca and S (kg ha^{-1})

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	SiO_2
P_1	150.65	17.75	103.92	14.30	8.21	8.60	7.00	2.73	0.77	434.39
P_2	150.00	14.64	106.58	12.86	8.00	5.61	6.66	2.60	0.72	413.54
K_1	151.20	16.77	105.07	13.16	7.86	7.80	6.49	2.17	0.69	425.95
K_2	149.05	15.37	95.33	13.98	8.41	6.16	7.21	3.20	0.77	420.16
Ca_1	157.00	12.59	108.55	11.85	8.11	6.64	7.49	2.90	0.73	507.38
Ca_2	142.46	15.72	91.99	14.32	7.66	6.09	6.22	2.46	0.81	340.43
S_1	149.23	16.65	101.72	13.77	8.50	7.16	7.06	2.75	0.72	379.74
S_2	151.39	15.50	98.41	12.50	7.41	6.77	6.62	4.26	0.72	470.28
C_1	110.63	12.72	90.65	9.80	4.54	8.22	6.19	1.45	0.71	561.39
C_2	26.29	2.19	56.78	3.61	3.17	0.33	4.42	2.21	0.52	311.81
CD (0.05)	80.85	11.48	43.40	NS	2.20	0.04	0.14	0.12	0.02	23.75

with higher doses of K and S lead to a narrow ratio with regard to Ca, increase in the P content in this combination resulted in widest ratio.

Increment in S level over basal doses significantly lowered the leaf-sheath ratio of S and Mn in the MT and PI stages respectively. Lower S and Fe leaf-sheath ratio were noticed in $p_2k_1ca_1s_2$ at PI and MT stages respectively. Combination of higher levels of P, Ca and S with lower level of K significantly increased the leaf-sheath ratio oft Fe at PI stage.

4.13 Effect of treatments on uptake of nutrient (kg ha^{-1}) at harvest

Data presented in table 53 show that uptake of P and S was highest when P was applied at its lowest level of 17.5 kg ha^{-1}, while K uptake was maximum when P dose was doubled to 35 kg ha^{-1}. Similarly significantly higher uptake of N and Fe were observed when 150 kg ha^{-1} Ca was applied and an increase in its dose led to an increased uptake of Ca and Zn. S at its lower level of 50 kg ha^{-1} significantly increased the Mg uptake. When 100 kg ha^{-1} S was applied it significantly increased the Mn uptake to 4.26 kg ha^{-1}. Si uptake was highest in POP plot. Lowest uptake of all the elements except Mn was observed in absolute control. Lowest uptake of Mn was noticed in package of practices treatment which was significantly inferior to all others including absolute control. The results point out that (except in the case of Ca), application of a particular element did not lead to an increased uptake of that element, but to that of some other elements.

4.14 Correlation of yield attributes

Data on correlation of yield attributes are presented in Table 54.1. A scrutiny of the figures on correlation with yield. revealed that it was the total number of grains, filled grain number and test weight that had high positive relation with yield.

Table 54. Correlations

Table 54.1. Correlation of yield attributes with yield

	Productive tillers	Panicle length	Total grains	Chaff No.	Filled grains	Test weight	Yield
Productive tillers	1.0						
Panicle length	0.067	1.0					
Total grains	0.430*	0.171	1.0				
Chaff No.	-0.147	-0.228	-0.156	1.0			
Filled grains	0.438*	0.208	0.981**	-0.345	1.0		
Test weight	0.392*	0.166	0.619**	-0.429*	0.673**	1.0	
Yield	0.442*	0.063	0.662**	-0.420*	0.712**	0.759**	1.0

* Significant at 5% level

Table 54.2. Correlation between physiological attributes and yield

	pH (PI)	pH (50% flowering)	Chl. 'a'	Chl. 'b'	Total	yield
pH (PI)	1.0					
pH (50% flowering)	0.68*	1.0				
Chl. 'a'	0.57*	0.42	1.0			
Chl. 'b'	0.33	0.17	0.38	1.0		
Total	0.35	0.31	0.56*	0.32	1.0	
Yield	0.71*	0.63*	0.36	0.23	0.34	1.0

* Significant at 5% level

Table 54.3. Correlation between chlorophyll at PI stage and yield

	Chl. 'a'	Chl. 'b'	Total	Straw	Grain
Chl. 'a'	1.0				
Chl. 'b'	0.54*	1.00			
Total chlorophyll	0.77**	0.63*	1.0		
Straw	0.34	0.39	0.43	1.0	
Grain	0.36	0.39	0.29	0.44	1.0

* Significant at 5% level

Table 55. Correlation of nutrients with yield at maximum tillering stage

	N	P	K	Ca	Mg	S	Mn	Fe	Zn	SiO_2	Yield
N	1.00										
P	0.114	1.00									
K	-0.084	0.050	1.00								
Ca	-0.032	0.284	0.345*	1.00							
Mg	-0.329*	0.202	-0.149	0.152	1.00						
S	0.015	0.233	0.128	0.177	-0.415*	1.00					
Mn	-0.180	0.189	0.128	0.147	0.024	0.394*	1.00				
Fe	-0.223	0.127	0.056	0.193	0.307*	0.004	0.324*	1.00			
Zn	0.015	0.243	-0.150	-0.047	0.294	0.026	0.289	0.481*	1.00		
SiO_2	0.031	-0.129	0.413*	0.264	0.110	-0.217	0.225	-0.029	0.020	1.00	
Yield	0.166	0.106	0.302*	0.401*	-0.132	0.084	-0.067	-0.222	-0.348*	0.122	1.00

* Significant at 5% level

Table 56. Correlation of nutrients with yield at PI stage

	N	P	K	Ca	Mg	S	Mn	Fe	Zn	SiO_2	Yield
N	1.00										
P	-0.089	1.00									
K	0.157	0.196	1.00								
Ca	0.100	0.096	-0.057	1.00							
Mg	-0.169	0.080	0.145	-0.061	1.00						
S	-0.055	0.357*	0.323*	0.001	-0.056	1.00					
Mn	0.173	0.123	0.253	0.286*	-0.240	0.316*	1.00				
Fe	-0.230	0.123	0.001	-0.278*	0.061	-0.059	0.221	1.00			
Zn	0.103	-0.264*	0.094	-0.267*	-0.133	-0.112	-0.209	0.455**	1.00		
SiO_2	0.198	-0.213	-0.036	0.055	-0.399*	0.077	-0.086	-0.258*	-0.069	1.00	
Yield	0.085	0.075	0.193	0.140	-0.018	0.361*	-0.225	-0.279	0.047	0.213	1.00

* Significant at 5% level

The contribution of number of productive tillers was less, while there was practically no correlation at all with panicle length. The negative correlation of chaffy grain with other attribute was as expected.

4.15 Correlation of physiological attributes

Table 54.2 depicts the correlation of chlorophyll content and cell sap pH at PI stage and at 50% flowering with grain and straw yield. Data showed that correlation with grain yield was low, indicating inadequacy of chlorophyll content. Higher correlation was seen to be with straw yield. A comparatively high correlation was observed between grain yield and cell sap pH at both PI and 50% flowering.

4.16 Correlation of nutrients with yield at maximum tillering

Table 55 is a record of correlation of various nutrients with yield. N, P, K, Ca, S and Si were positively correlated with yield, while Mg, Mn and Fe were negatively correlated.

4.17 Correlation of nutrients with yield at panicle initiation

Table 56 depicts correlation of nutrients with yield at PI stage of the crop. N, P, K, Ca, S and Si were favourably correlated with yield and others were negatively correlated.

4.18 Minimum contents of nutrients to produce an yield of more than 4300 kg ha^{-1}

Table 57 shows the minimum levels of various nutrients required to produce an average yield of more than 4300 kg ha^{-1}. The levels of N, P, K, Ca, Mg, S, Mn,

Table 57. Minimum contents of nutrients to produce yield of more than 4300 kg ha^{-1}

Nutrient element	MT			PI		
	Minimum content	Yield ($kgha^{-1}$)	Treatment	Minimum content	Yield ($kgha^{-1}$)	Treatment
N (%)	1.02	4935	$p_2k_1ca_1s_1$	1.14	4394	$p_1k_1ca_1s_1$
P (%)	0.05	4710	$p_2k_2ca_2s_1$	0.02	4552	$p_1k_2ca_2s_1$
K (%)	0.90	4485	$p_1k_2ca_1s_1$	0.72	4958	$p_1k_1ca_1s_2$
Ca (%)	0.07	4485	$p_1k_2ca_1s_1$	0.05	4552	$p_1k_2ca_2s_1$
Mg (%)	0.03	4868	$p_1k_2ca_2s_2$	0.02	4732	$p_2k_1ca_2s_2$
S (mg kg^{-1})	433	4958	$p_1k_1ca_1s_2$	725	4462	$p_2k_1ca_1s_2$
Mn (mg kg^{-1})	233	4710	$p_2k_2ca_2s_1$	213	4732	$p_1k_1ca_2s_2$
Fe (mg kg^{-1})	450	4462	$p_2k_1ca_1s_2$	450	4958	$p_1k_1ca_1s_2$
Zn (mg kg^{-1})	32.67	4485	$p_1k_2ca_1s_1$	40	4980	$p_2k_2ca_1s_1$
SiO_2 (%)	1.14	4935	$p_2k_1ca_1s_1$	0.28	4485	$p_1k_2ca_1s_1$

Table 58. Range of nutrient contents of leaf blade

Nutrient element	Maximum tillering		Panicle initiation		Harvest	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
N (%)	2.63	5.57	0.06	1.76	0.81	1.16
P (%)	0.10	0.19	0.08	0.01	0.06	0.11
K (%)	0.63	1.82	0.71	1.63	0.17	1.12
Ca (%)	0.03	0.29	0.14	0.32	0.05	0.11
Mg (%)	0.02	0.17	0.02	0.19	0.02	0.09
S (mg kg^{-1})	1533	3110	514	1932	542	1219
Mn (mg kg^{-1})	512	802	404	852	100	800
Fe (mg kg^{-1})	756	1736	818	1636	1176	2154
Zn (mg kg^{-1})	53	102	37	102	52	128
SiO_2 (%)	1.53	2.65	0.78	7.060	1.23	3.74

Table 59. Deviation in nutrient content from the nutrient content in lowest yielding treatment at PI stage

Element	C_2 Lowest	p_1k_1 ca_1s_1	p_2k_1 ca_1s_1	p_1k_2 ca_1s_1	p_2k_2 ca_1s_1	p_1k_1 ca_2s_1	p_2k_1 ca_2s_1	p_1k_2 ca_2s_1	p_2k_2 ca_2s_1	p_1k_1 ca_1s_2	p_2k_1 ca_1s_2	p_1k_2 ca_1s_2	p_2k_2 ca_1s_2	p_1k_1 ca_2s_2	p_2k_1 ca_2s_2	p_1k_2 ca_2s_2	p_2k_2 ca_2s_2	C_1
N (%)	1.31	-0.31	0.61	-0.10	-0.02	1.27	0.02	0.22	1.04	-0.45	0.36	0.04	0.64	-0.08	0.75	-0.3	-0.10	-0.23
P (%)	0.10	0.03	0.04	0.01	0.04	0	-0.05	-0.06	-0.09	-0.03	-0.08	0.04	0	0.80	0.08	0.03	0.03	0
K (%)	1.01	1.29	0.31	0.98	0.57	0.21	0.51	0.42	1.52	-0.29	0.51	0.71	0.21	-0.01	0.37	0.37	0.29	-0.35
Ca (%)	0.13	0.15	0.22	0.05	0.17	0.05	0.38	0.03	0.32	0.06	0.18	0.18	-.08	0.05	0.28	0.01	0.01	0.10
Mg (%)	0.02	0.07	0	0.06	0.06	0.04	0.48	0.19	0.03	0.01	0.14	0.16	0.19	0.08	0	0.10	0.43	0.01
S(mg kg^{-1})	5.20	2480	3205	880	1230	705	455	1713	530	1005	180	855	1380	355	1055	2005	1480	1058
Fe(mg kg^{-1})	1630	-1080	-1530	-680	1430	1180	-1130	1180	-1190	-1230	-1380	-880	-1330	-1460	-780	-1080	-830	-980
Zn(mg kg^{-1})	102	-25	-36	-19	-62	-32	-36	-19	31	-52	-2	34	-17	-52	14	14	-36	-65
Mn(mg kg^{-1})	1505	345	-5	45	-305	345	-605	295	-555	-1055	0	-505	-1005	-855	-105	-655	-405	145
Yield gain	1757.94	4732.93	5206.2	4394.86	5747.13	4462.47	4732.93	4732.93	4530.1	5070.99	4597.7	4462.47	4394.86	4327.25	4800.54	5138.61	4394.86	4254.64
Straw	1724.14	3211.63	3921.57	7268.42	4225.83	3718.73	3515.89	3380.66	3076.4	3380.66	2704.53	3245.44	3380.66	2704.53	3211.63	3718.73	3042.60	2434.08

Fe, Zn and Si required were 1.14%, 0.02%, 0.72%, 0.05%, 0.02%, 725mg kg^{-1}, 213mg kg^{-1}, 450mg kg^{-1}, 40mg kg^{-1} and 0.28% respectively.

4.19 Range of nutrient contents in the leaf blade

At maximum tillering stage the minimum and maximum N contents recorded in the leaf blade were 2.63% and 5.57% respectively. Similarly there was reduction in the nutrient content from maximum tillering stage to panicle initiation stage, except in the case of Si (Table 58).

4.20 Deviation in nutrient contents at PI stage

Data on the deviation of the nutrients contents at PI stage from the treatment producing lowest grain yield are presented in table 59. Variation was seen to occur in the nutrient content, with both increases and decreases as well as exactly the same contents being recorded in the treatment combinations. The highest yielding treatment ($p_2k_2ca_1s_1$) was seen to contain lower N, Fe, and Zn while all other nutrients recorded an increase. Fe, Mn and Zn contents were seen to be lower in most of the treatments, indicating their inhibitory role on yield expression.

Discussion

5. DISCUSSION

The direct and interactional influences of application of P, K, Ca and S on the progressive pattern of foliar contents of these elements as well as their individual and cumulative effects on the absorption and content patterns of N, Mg, Fe, Mn, Zn and Si and yield expression of rice were investigated in a field trial during 1999-2000 in the Agricultural Research Station, Mannuthy. The results obtained are discussed in the following pages.

5.1 Treatments Vs controls

The significant influence of nutritional inputs on yield expression had been well demonstrated by the 89 % increase in grain yield and 90% increase in straw yield over absolute control (Table 17.1). Mean increase in yield of 40% over the presently recommended practice by the treatment components pointed out to the probable inadequacy of the latter and the possibility for higher yield expression through better perfection of the current input management system. Substantial yield improvement and nitrogen use efficiency over POP in rice have been reported by Musthafa (1995).

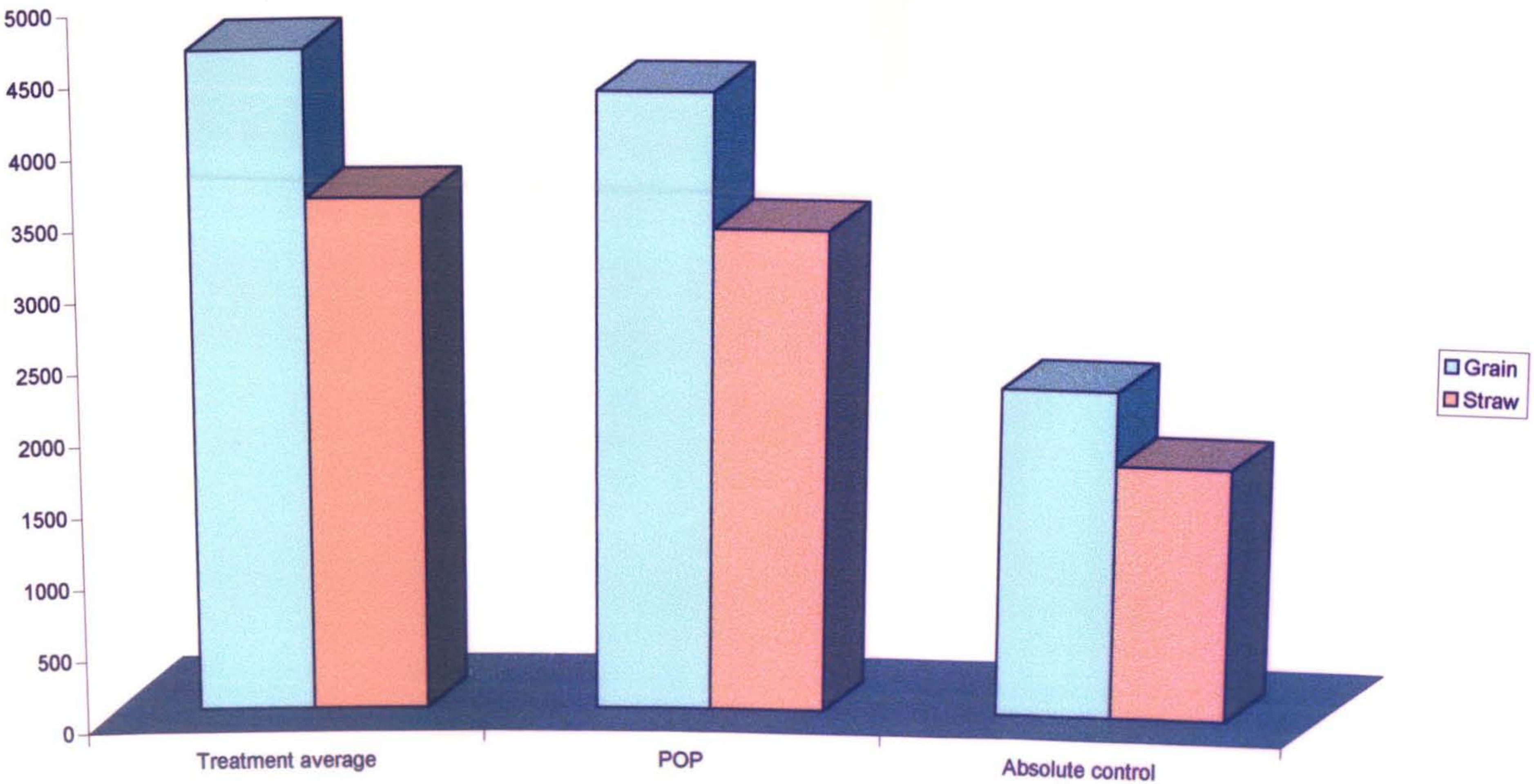
A close scrutiny of the data in table 17.1 will show that yield improvement over absolute control and POP by P, K, Ca and S had been more or less constant irrespective of the variations in the functional role of these elements. Near uniform increase in yield due to the mean main effects of the four elements is indicative of their utility for improvement of yield, but would also suggest that specific element based management would not be of much avail in the lateritic soils of Kerala. Such a contention is further strengthened by the fact that the realisable yield potential of the variety Jyothi has been proved to be above 10 MT ha^{-1}. Data on mean main effects would lead to the conclusion that interactions among the elements will have a decisive role on yield expression. Bridgit (1999) has reported that low productivity of rice is not due to real deficiency of any nutritional element. These results thus justify the present project.

5.2 Yield

Contrary to the mean marginal direct effects of the elements tested, their specific combinations had been able to raise the productivity by 1000 to 1500 kg ha^{-1} which further confirmed the contention that combinations of elements decide yield expression. The simple fact that significant improvements were brought about by including Ca and S and increasing the dose of K would suggest the inevitability of including Ca and S and increasing the level of K for higher yields. The data further showed that near similar yields shall be produced by different elemental combinations, which pointed out to the overriding influence of combinations over levels of elements. Discussing on the nearly similar yield levels in highly acid kole soils and alkaline black soils, Bridgit (1999), has also opined similarly.

An in depth perusal of the data has brought to light the apparent inter changeability of elements (as $p_2k_1ca_1s_1$ and $p_1k_1ca_1s_2$) between anions, and between cations (as in $p_1k_2ca_1s_1$ and $p_1k_1ca_2s_1$), to get the same yield (Table 21). The four elements being functionally variable, the interchangeability would appear to be due to the inherent ionic nature and characteristics. It is noticed that chemical characteristics and interrelation precede physiological availability and use efficiency. Similar results have been reported by Sreekumaran (1998) in pepper. It is possible that requirement of any element is the sum total of electrochemical and physiological requirements.

Fig. 2. Mean main effects of treatments on grain and straw yield



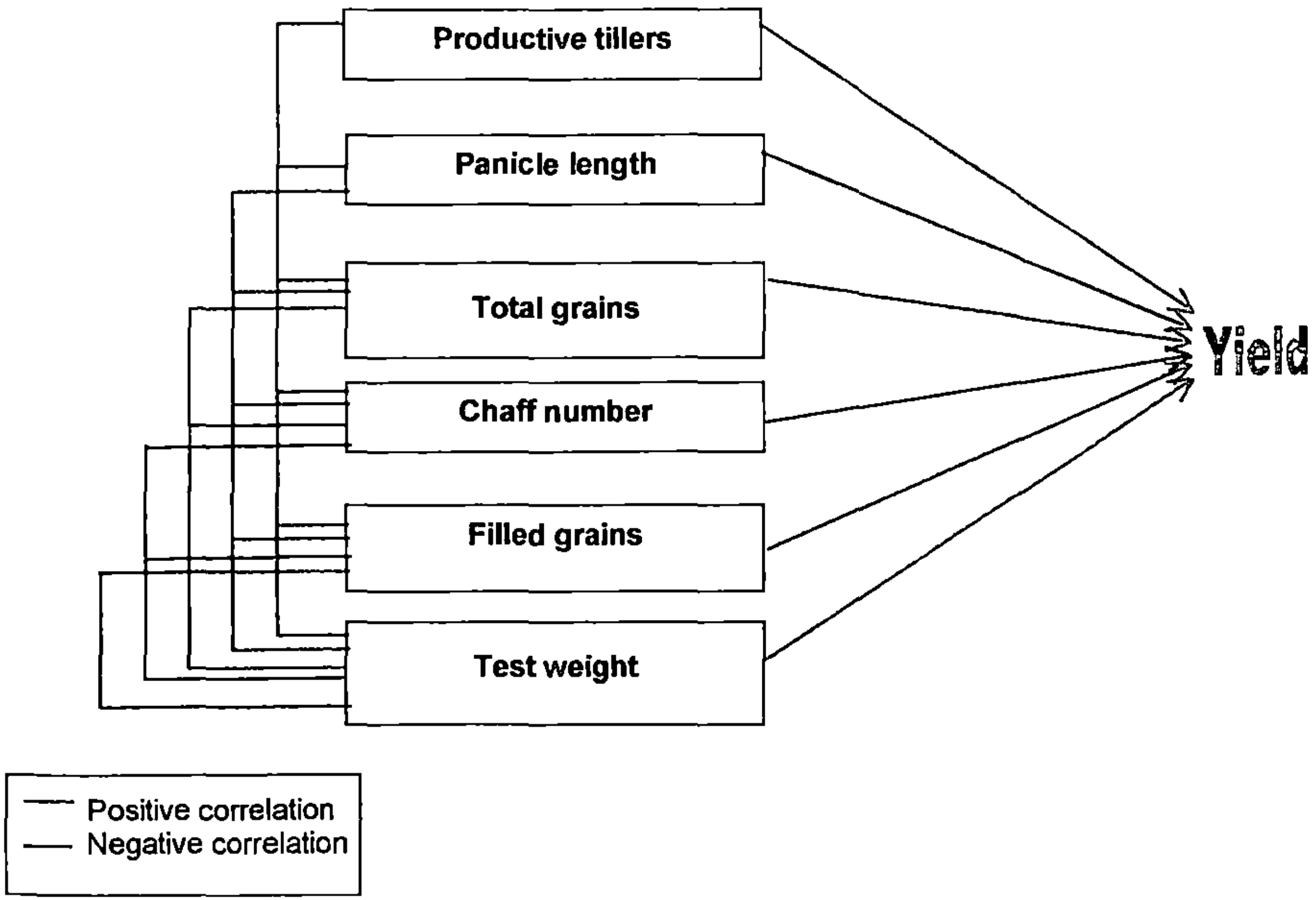
5.3 Yield attributes

Grain yield is the combined product of yield attributes – productive tillers, panicle length, number of grains, grain weight as well as the total dry matter produced. Critical evaluation of the data in Table 17.3 and fig.2 showed that yield realised under the mean main effects did not manifest specific influences of the nutrient combinations but had mainly been the reflection of the dry matter. Near independence of the yield components from one another can only be the result of lack of co-ordination in the yield process. Thus 69 and 81 filled grains gave more or less the same yield. The same was the case with all other yield attributes. Functional specificities under mean main effects were uncoordinated and pointed out to the significance of interaction effects, which is confirmed by the maximum yield level of 5700 kg ha^{-1}.

In addition to lack of co-ordination, failure in yield expression is indicative of some suppressing influences at the differentiation phase and near constant yield of 4600 kg ha^{-1} in spite of variation in number of grains is suggestive of reduced photosynthesis in the later stages. Progressive decline in chlorophyll and very high levels of cell sap pH appeared to be the prime causes of the inhibitory effects at floret differentiation and for chlorophyll decline.

Nutritionally, the suppressing effects would appear to be due to the excess contents of Fe and Zn. Contents of both these elements had been far higher than the critical limits. Yoshida (1984) had reported that ultimate critical limits of Fe and Zn were 300 and 20 mg kg^{-1}. Yoshida had also reported that silicate deficiency is to be expected when the content falls below 6%. Application of P, K, Ca and S might have failed to restrict the uptake of Fe and Zn and might have favoured the uptake of Si.

Fig. 3. Correlation of yield attributes and yield



Realised yield in rice is defined as the integrated product of container capacity and filling (Murata, 1969). Number of florets and floret size decides the container capacity which in turn is decided by the number of productive tillers (total panicle length) and differentiation efficiency at panicle initiation. Results of the present study as evidenced by the strong and significant correlation of number of grains with yield indicated that realised yield had been a function of number of filled grains. Similar results of increased yield with increasing grain number have also been reported by Musthafa (1995), Bridgit (1999) and Lakhshmikanthan (2000).

A closer scrutiny of the data will indicate that number of productive tillers and panicle length were unrelated. Maximum yield was actually recorded with minimum panicle length (Table 17.3). This is contrary to any natural level of expectation and would suggest absence of integrated development of the yield attributes.

Yield components develop in a sequential pattern and are temporally spaced and develop under a 'switch-key mechanism'. This implies that yield is an integrated product of yield components. Absence of integration among yield components, therefore, would appear to be the cause of low realised productivity of Jyothi in the present study as against its realisable potential of over 10 MT ha^{-1}.

The steady and progressive decline of tiller count from 45^{th} DAT in the present study (Table 6.3), contrary to normally professed growth, is an indication of "growth under stress". Similar stress influences in rice have also been reported by Musthafa (1995) and Menon (1996) in laterite soil environments. Absence of integrated development of the yield components would seem to be a direct consequence of the stress influences.

The data presented in Table 17.3 will further show that mean main effects of nutritional inputs did not significantly differ among themselves in affecting yield attributes or yield. Apart from the functional specificity of the elements in the system, this may be due to the fact that only interactional influences affect yield as it is the integrated sum of the different temporally spaced components. Yield attributes and yield have varied due to interaction effects and highest yield of 4980 kg ha^{-1} had been recorded in $p_2ca_1k_2s_1$.

5.4 Physiological attributes

Chlorophyll, being a primary proteinaceous product and the seat of photosynthesis, serves as the index for both. Positive correlation between chlorophyll contents and yield as recorded in the present study has also been reported by several workers in rice (Bridgit, 1999).

Results of the present study have shown that chlorophyll content has a more pronounced relationship with straw than with grain. This may be because of the fact that grain yield is a product of post flowering photosynthate accumulation supplemented by translocation from earlier growth, which is not a chlorophyll function.

Data on the influence of mean main effects of treatment elements as well as interactions showed that while the former did not affect chlorophyll, interaction occurred among elements affected, though they were not components of chlorophyll. These interaction effects have arisen from the balancing as well as additive effects among elements in the biosynthetic processes with Ca and S behaving in opposite ways at least in the early stages (Table 13).

Moving pattern in chlorophyll from PI stage to 50% flowering showed a general tendency towards decline in chl. 'a' and increase in chl. 'b' as well as total chlorophyll. As chl. 'b' is formed from chl. 'a', these results are indicative of declining conversion of chl. 'a' to 'b', which is a sign of instability and so, stress. Comparatively low interrelation of chl. 'a', the actual photosynthetic pigment, with yield would therefore seem to be the result of stress effect.

The lesser relationship of total chlorophyll and specifically of chl. 'a' to yield may be due to two other possible reasons. Either the contents of chl. 'a' and total chlorophyll themselves were inadequate and the biosynthesis might have been affected. Chlorophyll 'a' and total chlorophyll contents of above 3 mg g^{-1} have been reported by Bridgit (1999) in rice. Otherwise, the efficiency of chl. 'a' itself might have been low. Whatever they may be, stress effects on biosynthetic pathways get confirmed by these results.

Analysing the cell sap pH effects, strong positive relationship of cell sap pH with total chlorophyll as well as its constituents and yield (Table 54.2) on the one side, and the effect of elemental combination on pH on the other, make it an easily adaptable index. Marykutty *et al.* (1992) and Bridgit (1999) have reported that optimum leaf sap pH for high yield in rice in 6.2, below and above which yield will be lower. Failure of yield to rise beyond 5.8 MT ha^{-1} in the present study shall therefore be attributed to failure of the treatments to keep the pH at lower level. Higher pH of leaf sap has been reported to be due to non metabolic accumulation of heavy metals like Fe (Singh, 1970).

5.5 General nutritional characteristics and productivity

A critical evaluation of the data on the individual elemental status of the leaf (Table 31.3 and 22.3) showed that the plants absorbed not only the elements that were applied but other elements as well. It could also be seen that the tissue status of the elements, with the exception of Ca, Mg, Zn and Si, tended to decline sharply within the interval of two weeks between MT and PI stages. Menon (1996) has reported that the decline is due to dilution of these elements resulting from dry matter accumulation. Thus nutritionally, two distinct phases – phases of accumulation and dilution corresponding to differentiation, development and grand growth phases could be identified.

A close scrutiny of the data further showed that phasic variation in the content of elements was influenced at least by three factors viz., the original content of the element and valency and bonding strength of other elements. This type of behaviour is in tune with the Ratio Law of Schofield (1957). Tinker (1964), Seena *et al.* (2000) and Sajnanath *et al.* (2000) have also reported similar results.

A comparison of the leaf blade elemental composition of C_1 and C_2, which had not received any fertilizer, recorded significantly higher content of N, P and K over C_1. Similarly, P, K, Ca and S also affected elements other than the concerned element. In the same way, P application did not affect P level at all. This would imply that application of any element by itself is not a guarantee for its uptake. As such, increase or decrease in yield brought about by application of any element need not necessarily be consequent of its variation in the plant, but can be due to variation in the contents of other elements.

This is further illustrated from the observation on yield variation between C_1 and C_2 (Table 17.1). C_2 recorded only 1700 kg ha^{-1} grain in spite of higher contents of N, P and K compared to C_1. This was due to the decreased Mn and Zn contents and increased Ca, Mg and Si contents in the plant in C_1. Naturally this would mean that the effect of yield increase due to C_1 had been through its effect on native elements. Comparative analysis of the uptake of nutrients and yield of grain also

Fig. 4.1. Nutrient uptake as influenced by management

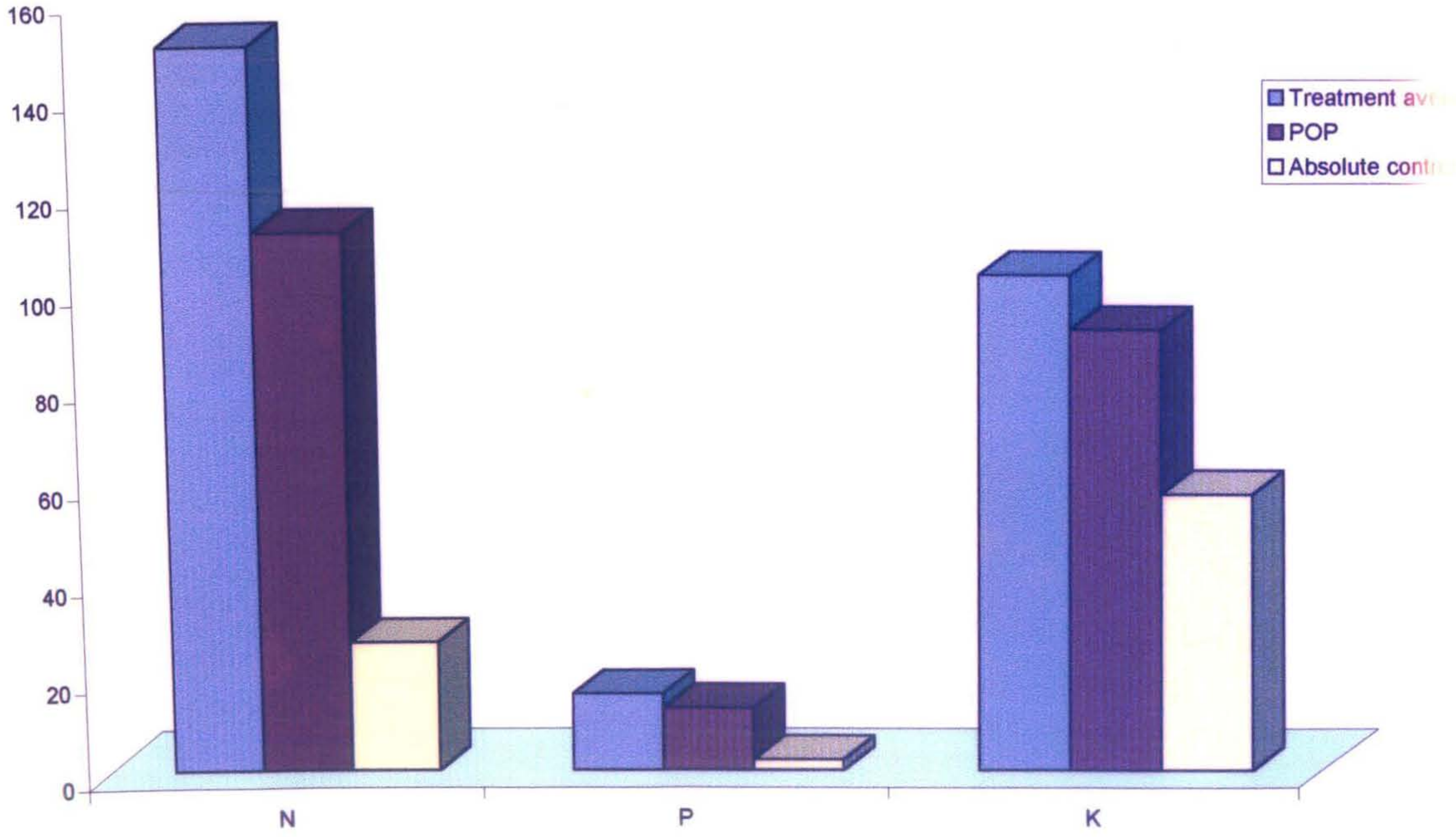
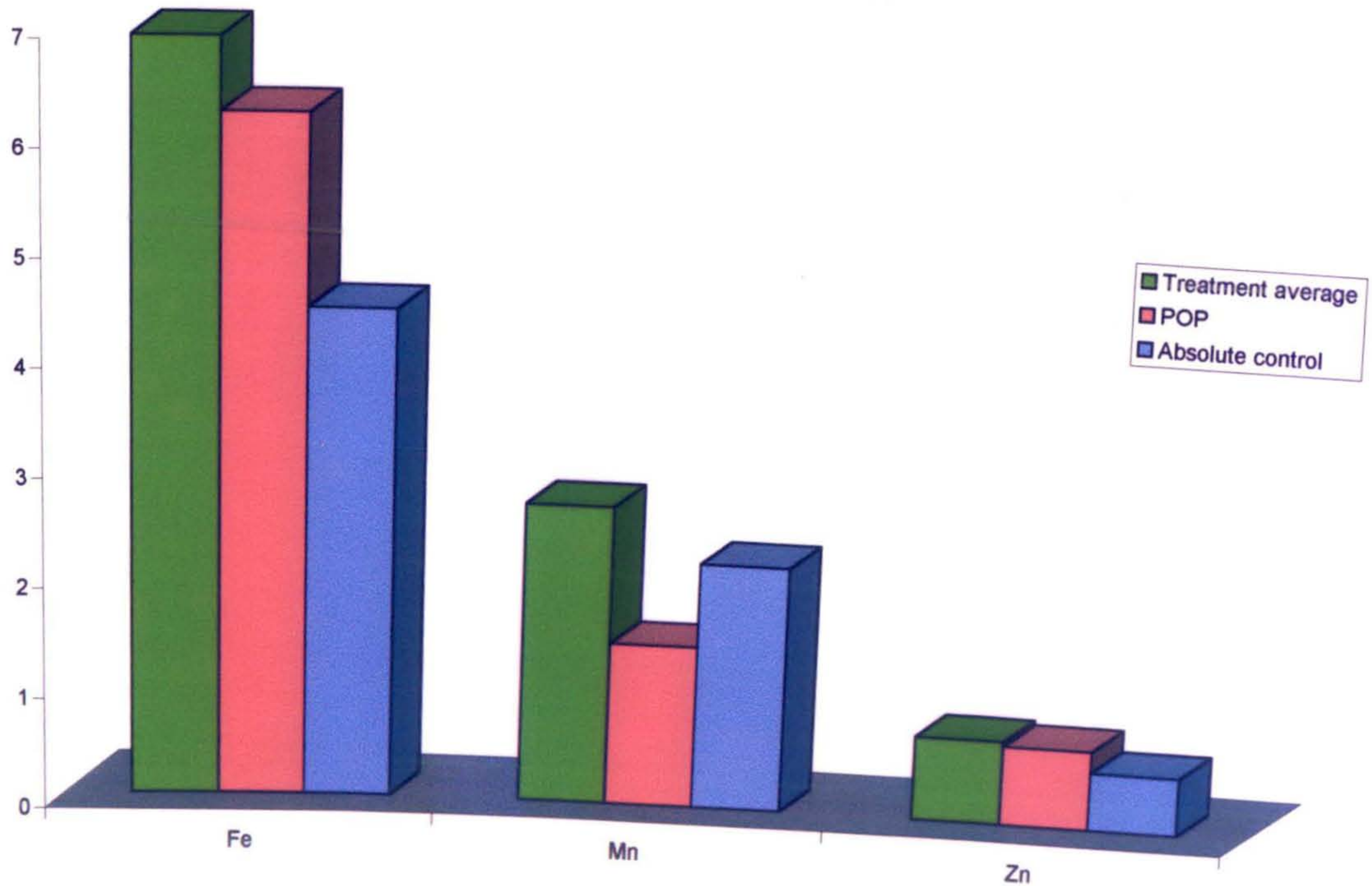


Fig. 4.2. Nutrient uptake as influenced by management



showed that they need not be related (Table 53 and fig.4). Uptake of 26 kg ha^{-1} N in absolute control had resulted in a yield of 2276 kg ha^{-1} grain and 1757 kg ha^{-1} straw, while 150 kg ha^{-1} N uptake resulted in 4600 kg ha^{-1} grain and 3300 kg ha^{-1} straw yield. This stands in testimony to the contention that uptake is the product of growth and is conditioned by many other factors. Similar results have also been reported by Menon (1996) and Bridgit (1999).

The reverse analysis of near specific yield levels and the individual elements status range presented in Table 41 showed that yield level of over 4500 kg ha^{-1} grain can be realised with minimal individual levels *per se* of 1.14%, 0.02%, 0.72%, 0.05%, 0.02%, 725 mg kg^{-1}, 213 mg kg^{-1}, 450 mg kg^{-1}, 40 mg kg^{-1}, 0.28% of N, P, K, Ca, Mg, S, Mn, Fe, Zn and Si respectively. However a combination of all the elements at minimal level would appear to be hypothetical from the fact that each of these values had been recorded in the different combinations of the treatments. These results would also therefore imply that specific levels of any element in the plant is a function of some combination, that is, of interaction. Thus the results would lead to the conclusion that plant contents of elements and yield expressed are products of interaction.

From the very same contention it will follow that the content *per se* of any element is a function of interaction and that plant content of some elements may be higher because interactions probably demanded it through it may be more than the physiologic demand. Varying charges characteristic of ions and the possibility of inter-ion reaction – the chemical demand – may be another aspect of demand. Thus the total content of any element in the plant would appear to be the sum of the chemical and biological fractions. Sreekumaran (1998) also reported similar results.

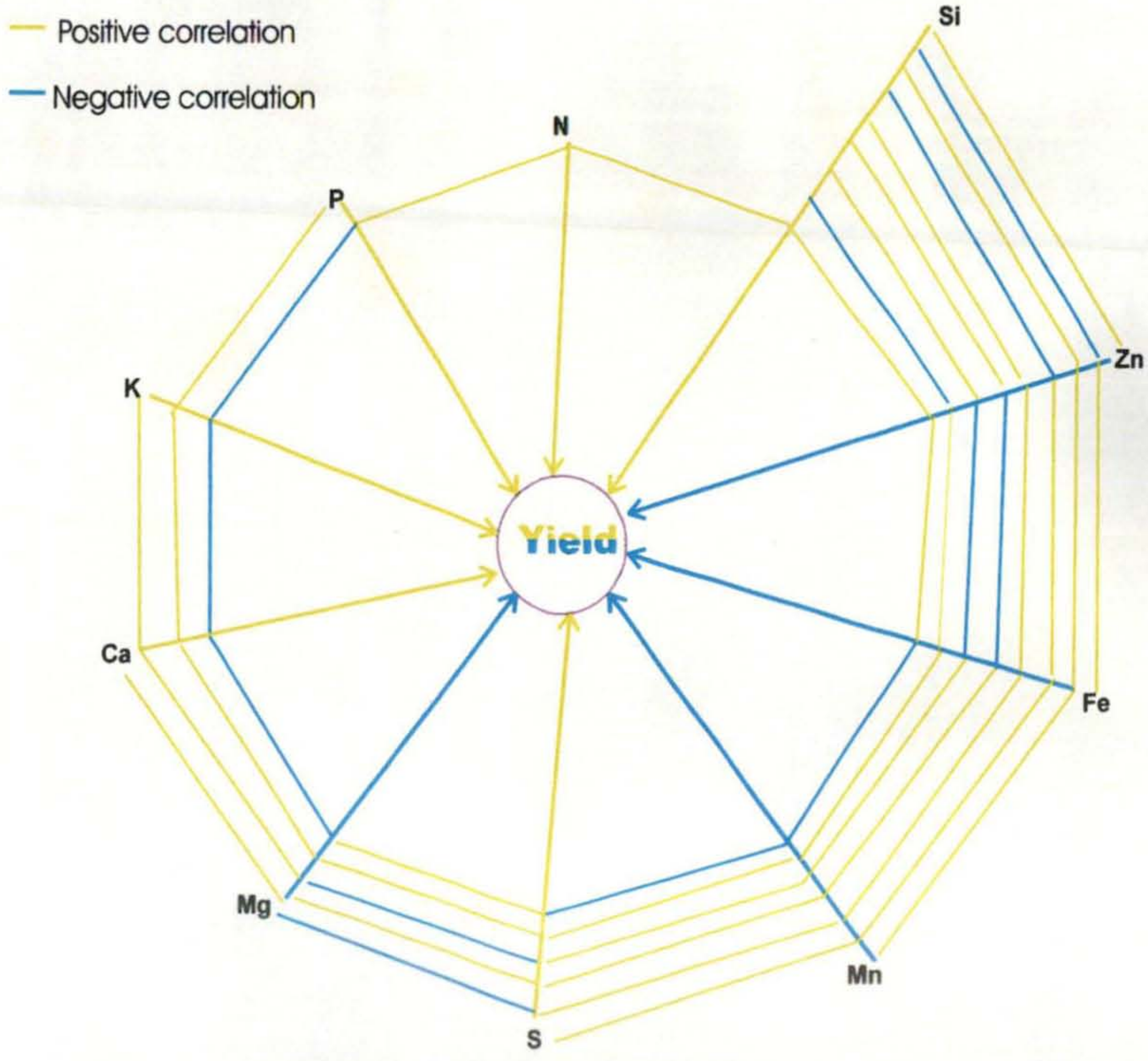
Thus yield improvements realised from any nutritional input need not necessarily be due to its increased content but is the product of the changed interactions among the elements. The foregoing paragraphs would lead to the following natural conclusions:

(1) Any nutritional input brings about variation in the content of all the elements in the plant system which suggests that plant content of elements is a product of interactions.
(2) Fertility management therefore would mean not merely making up the deficiency of any element through its addition but should be an effort to ensure optimum combination of the elements.

5.6 Nutritional relations to productivity and interrelations among elements

Analysis of the nutritional relations to productivity at MT stage (Table 55 and fig.6) has shown that plant contents of K, Ca and Zn alone have significantly affected yield expression. The negative significant effect of Zn and similar trends observed in the case of Fe and Mn showed that yield limiting influences are inherant in the soil and that yield advantage realised due to applied elements is actually the net product of balance between positive and negative effects of nutrients on the yield process. Absence of any worth while effect due to N and P would appear to be unexpected. Positive correlation is to be expected when the range of the element is spread over from deficiency range. As the lowest nitrogen content under treated plots was 3.9 %, it is possible that there was no felt deficiency of the element. Bridgit (1999) has also reported that at least upto 6.4 MT yield could be obtained with less than 0.8 % N in the leaf blade. Thus the high nitrogen content associated with less than 6 MT yield would imply that the plants had failed to metabolically utilise the higher N absorbed by them. The fact that none of the cations studied in the trial significantly affected N content may be because of low bonding strength of the former. The negative effect of Zn also would be unexpected as universal response is expected because of the induced unavailability of Zn through bonding

Fig. 6. Inter relation among nutrients and yield at maximum tillering stage



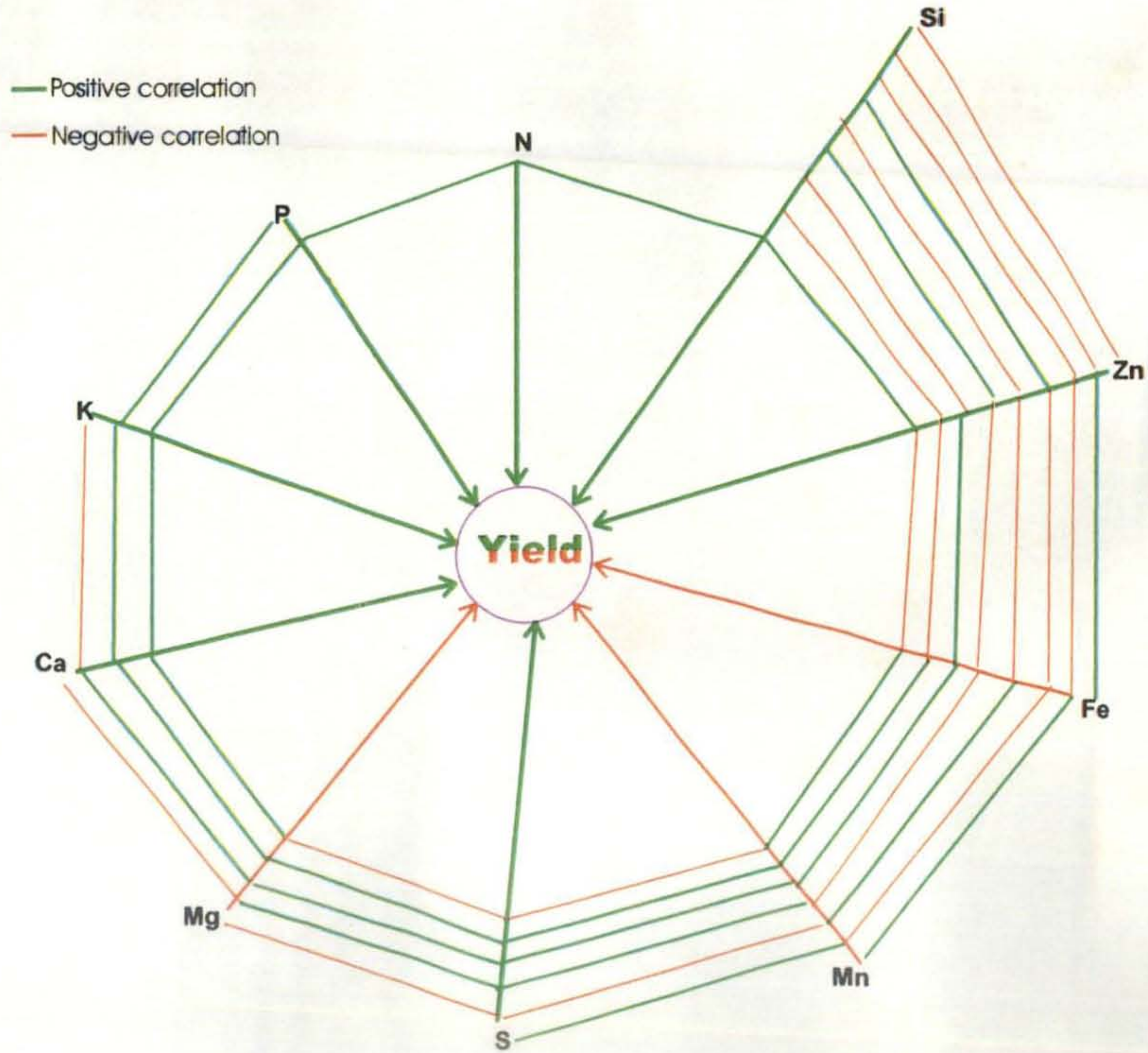
with P. The positive relation between Zn and P would probably mean that cation binding of P was the reason for its inhibited metabolic use and lack of response in terms of yield cannot be ruled out.

The negative correlation Zn and Fe with yield and the absence of any effect of N and P as well as the highest contents of Fe and Zn in the plants under absolute control would suggest that low productivity had been exclusively due to negative influences of these elements. Bridgit (1999) has reported similar results.

Interrelationship among the plant contents of elements have thrown some insight onto the significance of interaction. Increase in the content of Zn had been positively associated with increase in the contents of Fe and Mn, all of which had negative influence on yield. Similarly Zn had been negatively related with K and Ca which had positive relation with yield. These results showed that the effect of any element on productivity is the sum of its direct influence and indirect influence through other elements as the interrelations are multifaceted in nature and magnitude.

An overall comparison of the interrelationship of elements among themselves as well as to productivity in the MT and PI stages (Table 55 & 56) showed that they were not identical, which underline the significance of phasic management. Menon (1996) also reported the importance of phasic management in *Njavara*. Significant relationship of K and Ca in the MT stage alone suggested that they probably influenced yield through the effect on early growth, whereas the effect of S on PI stage would point out to its necessity for differentiation either directly or through enhanced nitrogen use efficiency. The negative influence of Mn and Fe were also felt at PI stage signifying their influence on differentiation. Fe is an immobile element in the plant. Its significant negative influence on productivity pointed out to its continued absorption in the later stages to levels beyond critical levels. The

Fig. 7. Inter relation among nutrients and yield at panicle initiation stage



present trial had recorded 1636 mg kg^{-1} of Fe at PI stage in the plant as against 300 mg kg^{-1} as the upper critical limit suggested by Yoshida (1981). The negative effect of Fe can be seen on the plant not merely from its direct effect but also through its limiting influences on absorption of N and Ca as well as its positive influence on Mn and Zn.

Another significant result from the Table 56 and fig.7 had been that the only element inhibiting Fe uptake had been silica. The negative interrelationship between these elements could be taken advantage of to ameliorate excess Fe. This trend would seen natural as laterites are leached of silica with a SiO_2/R_2O_3 ratio of less than 1.33. These results would suggest that reversal of the process of laterisation holds the key to higher yields. Bridgit (1999) had obtained significant increases in yield of rice by the application of silica.

Yet another valuable information arising out of the comparative evaluation of the correlation values at MT and PI stages is the differential tolerance levels of the crop at these stages. Marginal correlation of Fe and Mn in spite of higher contents at MT and vice versa at PI stage suggest that PI stage is more critical to vulnerability. The reverse was true in the case of Zn.

K and Ca showed significant positive relation with yield at MT which, with a reduction in content at PI stage was not discernable. Ca offers structural stability which in turn would minimise tiller decline. A higher K content might have been necessary to compensate shedding of K to circumvent Fe stress. Musthafa (1995) and Menon (1996) have reported nutritional shedding as primary causes of tiller decline and yield reduction in rice.

Thus results of the study confirmed differential requirement of elements at various growth phases - higher K and Ca for better vegetative growth and higher Zn and S for panicle initiation. Indirectly, the results indicated that basal dressing of Ca and top dressing of S can help in tiding over stagnation in production. Similar results have also been reported by Bridgit (1999). Reducing the application of P can minimise negative influence of Zn and Mg.

Positive and increasing correlation of silica with yield and negative influence of P and S on it would probably indicate that by reducing the dose of P and withholding basal dressing of S, Si and consequently, yield could be increased. Silicate content of the plant had been increasing from MT to PI stage and had reached the maximum of only 4.3 %.

Discriminatory transfer of the individual elements between blade and sheath is an important internal regulatory factor deciding yield expression. Increase in the blade-sheath ratio of Ca and Mn and decreases in K and S had been the main factor for the lowest yield in absolute control (Table 52), implying that Ca and Mn dynamics are the natural yield limiting factors in this soil environment. Yield improvement in the POP system had been by reducing the Ca and Fe effects. Highest yield of 5747 kg ha^{-1} had resulted when blade sheath ratio between MT and PI declined in respect of Ca, Fe and Mn and increased in respect of K and S. These results showed that factoral requirements for yield improvement changes with progressive yield levels. Ameliorative management for Ca, Mn and Fe can improve the yield initially through its gradational imposition and then additive management of S and K would appear to take over. Realisation of yield levels beyond 6000 kg ha^{-1} probably depends upon magnitude of variation brought about. These results would indicate that factoral management system alone can of use in realising reasonable yields.

Exclusive effect of ratios led to the conclusion that none of these elements were in the deficiency range. It is probable that relative proportion assumes significance only when the plant contents are not in the deficiency range. Apparent absence of specific patterns for discriminatory transfer of any element between sheath and blade suggest this to be a multi ionic rather than an individual effect.

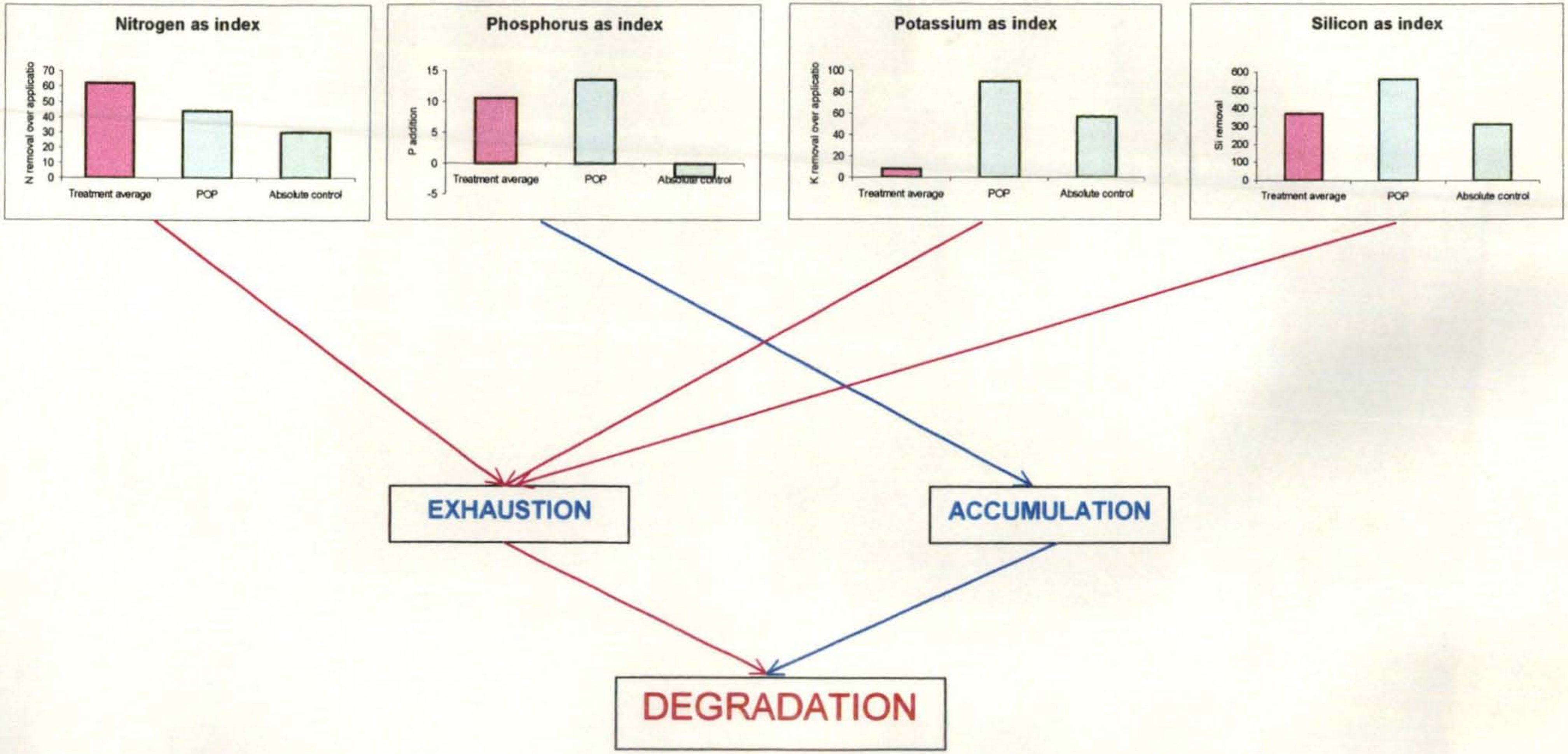
Equally important to the ratio of content of an element in the blade and sheath of rice plant is the ratio between elements in the blade (Table 51). Direct bearing of Ca+Mg/K, K/Fe and K/Mn ratios in the leaf were indicative of ameliorative effect of K on suppressing the ill effects of Fe and Mn. Yield improvement may be effected either by ameliorating effect on Fe or Mn or both. Similar results have also been reported by Bridgit (1999).

Scanning through the data in table 57 would appear to present an intriguing picture of nutritional relations to productivity. The minimum requirement at individual level of any element studied for yield levels above 4300 kg ha^{-1} is unexpectedly very small and virtually deficiency of no element in any treatment combination was ever recorded. This is confirmed by the range of nutrient elements, when related to yields produced in various treatment combinations (Table 58). This would naturally lead to the conclusion that low productivity in laterite soil is not due to deficiency of any individual element. Secondly, no field situation can normally be realised where all the elements record minimum or maximum values. What is to be expected is a range in the content of elements resulting in specific combinations and varying yield levels at different combinations. If specific combinations result in specific yield levels, factors affecting combination component levels will be deciding the adequacy or deficiency in combinations to decide the yield expression. This would then imply that the concept of deficiency or sufficiency critical level should be replaced with concept of relative deficiency/relative sufficiency. This is confirmed by the data on nutrient ratios as well (Table 51). This hypothesis is confirmed by an all round change in plant content of the elements by addition of any single factor. This is interaction among elements. These results naturally lead to the conclusion that sustainable and scientific management could mean not making up the deficiency but ensuring appropriate combinations. It would appear that very wide variation in the individual content of elements without any apparent effect should be viewed in this context.

Uptake of elements being the product of growth, this may not serve as accurate index of the use efficiency. However it may serve as a useful guideline in studying nutritional requirements and interrelations that lead to productivity. Data present in Table 53 showed that Ca, S and Si had manifested significant variation actually not in proportion with yield improvement. 140 kg variation in silica associated with 70 kg increase in grain yield and 2 kg Ca decline with 20 kg grain, pointed out to the fact that two types of apparent yield improvement are to be expected. The real yield improvement, which probably combined quality and quantity, is one resulting from increased use efficiency. The other one is marginal and results from accumulation of minerals. A comparison of silica in C_1 and S_1 showed that additional accumulation of 180 kg silica accompanied by a decrease of 39 kg N, 4 kg P and 11 kg K produced 300 kg less grain per hectare in C_1. This is the case of simultaneous decrease in quantity and quality. These results pointed out that quality deterioration is a function of irregular nutrition.

A scrutiny of elemental composition of husk (Table 47.3) showed that absolute control as well as POP had recorded the highest silica content. Similar results have also been reported by Bridgit (1999) and Lakshmikanthan (2000). This would imply that silica often can contribute to non-metabolic and wasteful yield like mere increase in husk weight . Overremoval of silica in laterites characterised by low SiO_2/R_2O_3 ratio is a sign of steady soil degradation. The fact that S has been found to keep down silica content in the grain would indicate its necessity in preventing soil degradation.

Fig. 5. Degradation consequence of rice production system in soil



Data on deviation analysis (Table 59) had further established that on an individual elemental basis, Fe, Mn and Zn excesses had because the most pronounced factors for low yield and nitrogen use efficiency. This would mean that they are really in excess. In the light of the fact that S had never been limiting in its range of 520 to 3200 mg kg^{-1}, the role of sulphur would appear to be in neutralising the three cations viz., Fe, Mn and Zn and keeping them out of the metabolic stream. Similarly, Mg might have been neutralising the excess N and P. This would mean that internal balancing among elements holds the key to higher yield.

The above discussion has revealed that nutritional management in its essence seeks to ensure variable relative contents of nutrients, for photosynthetic efficiency and growth, for differentiation as well as for translocation. This could be achieved through a regulatory management system aimed at increasing and restricting the levels of elements through specific additive management. Compensation of removal through addition to ensure sustainability has to be super imposed on the above(fig.5). Thus fertility management for productivity becomes a three dimensional phenomenon of addition, restriction and compensation. In the light of the above, the present study in its totality led to a management system of rice in laterite soil as indicated below:

1. Use efficiency indices on foliar content and removal pattern showed that the current level of application of N is sufficient to produce yield levels above 5000 kg grain ha^{-1}.
2. Current level of P addition is in excess of requirement. P, being an acid forming source, will trigger release of more Fe, Mn, Zn etc. which suppresses yield expression. Absorption pattern shows that it should be reduced to half of the current dose.
3. Data on nutrient uptake showed that low realised yields are reflections of relative K deficiency. As such its application level will have to be doubled.

4. Absorption of excess levels of Ca, Mg, Fe, Mn and Zn are the limiting factors of productivity. Enhancement of K level, though incidental, will restrict uptake of these elements.
5. Variability in realised yield has been found to result primarily from number of grains per panicle, as well as grain weight. As these are post panicle initiation phenomenon, use efficiency of N, P and K should be increased at this phase which can be achieved by applying S at this stage. As higher dose of S is likely to increase weight of husk, lower dose will be sufficient. Top dressing N with sulphur containing fertilizers will appear to serve this purpose.

Summary

6. SUMMARY

The project entitled "Effect of nutrient interrelations on productivity of rice in lateritic soils" was conducted during the first crop season (*virippu*) of 1999-2000 at the Agricultural Research Station, Mannuthy. In the study, the pattern of interacting influences of P, K, Ca and S at two levels, among themselves as well as on the native elements, were investigated using Jyothi as the test variety. The summary of the results is presented below:

1. Treatments had a significant influence on yield expression as demonstrated by the 90 and 10 % increases in yield over absolute control and the presently recommended package of practices. The yield improvement had been more or less constant in all the treatment combinations.
2. Significant improvements in yield by including Ca and S in treatment combinations point to the necessity of including these elements in the nutrient management system.
3. Realised yields in treatment combinations had been the reflection of dry matter.
4. Inhibitory effects manifested at floret differentiation stage may have resulted from decline in chlorophyll content and very high levels of cell sap pH.
5. Nutritionally, the suppressing effects appear to be due to excess contents of Fe and Zn, leading to stress conditions.
6. Plant content of elements with the exception of Ca, Mg, Zn and Si tended to decline sharply from maximum tillering to panicle initiation stages, and this phasic variation in content of elements is influenced by the original content of elements as well as the valency and bonding strength of other elements.

7. Application of any element by itself was seen to be not a guarantee for its uptake and could bring about an increase or decrease in yield by affecting the plant content of other elements.
8. Nutrient uptake is a product of growth and need not be related to yield of grain.
9. Yield limiting influences like the negative effects of Zn, Fe and Mn are inherent in soil and yield improvement due to applied elements is actually the net product of the balance between positive and negative effects of nutrients on the yield process.
10. There was no felt deficiency of N in the treatments but high N content associated with less than 6 MT yield would imply lack of metabolic utilisation of absorbed N.
11. Lack of response to P application in terms of yield indicated inhibited metabolic use probably due to cation binding.
12. Zn was seen to be positively correlated to Fe and Mn contents, and negatively to K and Ca contents, showing that the effect of any element on productivity is the sum of its direct and indirect influences on other elements.
13. K and Ca were seen to be significantly related in the maximum tillering stage, whereas S had effect at panicle initiation stage. The negative influence of Fe and Mn were also felt at panicle initiation stage, indicating the need for phasic management.
14. The only element inhibiting Fe uptake had been Si, suggesting that the reversal of the process of laterisation holds the key to higher yields.
15. The results indicated that basal dressing of Ca and top dressing of S at moderate levels can help in tiding over stagnation in productivity.
16. Reducing the dose of P and withholding basal application of S could increase silicate influence and improve the yield.

17. Discriminatory transfer of individual elements between leaf blade and leaf sheath appeared to be an important regulatory factor in deciding yield expression.
18. Ca+Mg/K, K/Fe and K/Mn ratios in the leaf blade had a direct bearing on yield, indicating the ameliorative effect of K on suppressing the ill effects of Fe and Mn. K application dose will have to be doubled to increase realised yield as well as to ensure sustainability by preventing soil degradation.
19. Highest yield resulted when blade-sheath ratio between maximum tillering and panicle initiation declined in respect of Ca, Fe and Mn and increased in respect of K and S.
20. Realised yield is a function of specific combinations and not of *per se* levels of any element, indicating that only factoral management system can be of use in realising potential yields.
21. Yield improvement is of two types, apparent and real, the latter results from increased use efficiency while the other is marginal and results from accumulation of minerals (like Si).
22. S at moderate levels was found to keep down Si levels in the grain, indicating its necessity in preventing soil degradation.
23. The study has resulted in development of the broad base of a management technology for high productivity and sustainability. The components include keeping N at the present recommended level, reducing P by 50%, increasing K by 100% and top dressing N using S containing fertilizers as well as moderate basal dressing with Ca.

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Appendix

APPENDIX-1

Weekly weather data during the crop period

Date	Temperature (°C)			Relative humidity (%)		Sunshine hours (hr day^{-1})	Rain fall (mm)	Evaporation (mm day^{-1})
	Maximum	Minimum	Mean	Morning	Evening			
4/6-10/6	28.9	22.4	25.65	96	83	2.0	319.7	2.5
11/6-17/6	29.9	22.8	26.35	94	75	3.3	106.9	3.7
18/6-24/6	29.6	23.2	26.4	95	74	3.1	55.9	3.3
25/6-1/7	29.4	22.5	25.95	94	75	4.1	104.3	2.8
2/7-8/7	28.9	22.0	25.45	93	76	1.5	87.8	2.5
9/7-15/7	29.2	21.5	25.35	94	74	3.5	170.0	3.1
16/7-22/7	30.1	22.8	26.45	93	66	5.7	48.9	3.6
23/7-29/7	30.9	23.2	27.05	92	62	8.5	5.9	4.3
30/7-5/8	31.1	23.6	27.35	92	69	6.4	9.0	3.6
6/8-12/8	29.0	22.8	25.9	94	80	2.5	93.3	3.7
13/8-19/8	29.4	22.6	26.0	93	78	4.1	139.5	2.9
20/8-26/8	27.7	22.0	24.85	95	88	0.3	232.8	2.3
27/8-2/9	29.4	22.1	25.75	94	73	4.6	44.2	3.2
3/9-9/9	30.6	22.9	26.75	92	69	7.1	31.9	3.5
10/9-16/9	31.2	23.3	27.25	90	65	7.5	-	7.6
17/9-23/9	30.4	22.9	26.65	92	72	3.9	16.2	3.1
24/9-30/9	30.7	23.3	27.0	90	76	4.6	150.0	2.7
1/10-7/10	28.9	22.0	25.45	92	79	3.2	79.3	2.7

EFFECT OF NUTRIENT INTER-RELATIONS ON PRODUCTIVITY OF RICE IN LATERITIC SOILS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The effect of nutrient inter-relations on productivity of rice in latritic soils was investigated during the first crop season (*Virippu*) of 1999-2000 at the Agricultural Research station, Mannuthy. The objective of the study was to arrive at the minimum level combination of applied elements for maximum productivity based on the interaction pattern between applied and native elements so as to develop a sustainable management system. Jyothi was used as the Fest variety to analyse the pattern of interacting influences of P, K, Ca and S at two levels each, among themselves as well as on the native elements.

The results showed that treatments had significant beneficial influence on yield expression, causing 90 and 10% increases in yield over absolute control and the presently recommended package of practices. This indicated the necessity of including Ca and S in the nutrient management system. Decline in chlorophyll content and high levels of cell sap pH, together with excess contents of Fe and Zn appear to act as the supressors of yield expression. The latter influences are inherent in soil and are actually the net product of the balance between positive and negative effects of nutrients. A significant finding was that application of any element by itself was not a guarantee for its uptake, and was subject to the effect of other elements, and similarly, had direct or indirect influences on other elements. The positive influence of K and Ca at the maximum tillering and S at the panicle initiation stage, and negative influence of Fe and Mn at the panicle initiation stage pointed out to the need for phasic management of nutrients. The only element inhibiting Fe uptake had been Si, suggesting that the reversal of the process of

laterisation holds the key to higher yields. Discriminatory transfer of individual elements between leaf blade and leaf sheath appeared to be an important regulatory factor in deciding yield expression. Highest yield resulted when blade-sheath ratio was maximum tillering and panicle initiation declined in respect of Ca, Fe and Mn and increased in respect of K and S. the study resulted in development of the broad base of a management technology for high productivity and sustainability. The components included keeping N at the present recommended level, reducing P by 50%, increasing K by 100% and top dressing N using s containing fertilizers as well as moderate basal dressing with Ca.