NUTRITIONAL BALANCE ANALYSIS FOR PRODUCTIVITY IMPROVEMENT OF RICE IN IRON RICH LATERITIC ALLUVIUM

By
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THESIS

**Submitted in partial fulfilment of the
requirement for the degree**

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DECLARATION

I hereby declare that the thesis entitled "**NUTRITIONAL BALANCE ANALYSIS FOR PRODUCTIVITY IMPROVEMENT OF RICE IN IRON RICH LATERITIC ALLUVIUM**" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that the thesis entitled "**NUTRITIONAL BALANCE ANALYSIS FOR PRODUCTIVITY IMPROVEMENT OF RICE IN IRON RICH LATERITIC ALLUVIUM**" is a record of research work done independently by **Smt. T.K. Bridgit** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Dedicated

To

The loving memory of

My beloved mother

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Introduction

INTRODUCTION

Rice is the staple food in Kerala. Singularly hydrophylic and highly labour dependant, rice is the exclusively adopted crop over three lakh hectares of low lands for the entire non-water stressed period of the year. With its problems and prospects rice constitutes the agrarian base of our economy. Unfortunately this at present, faces a dismal future. Stagnant production levels and creeping productivity on the one side, steady inflationary trends coupled with apparent lack of response to inputs and a consequential negligence and/or avoidence of cultivation especially in laterite soils on the other side characterise the rice front today. This had almost led to a stalemate situation which cannot be salvaged by alleviating the socio-economic constraints. Technology alone can provide an answer.

Scientifically, crop growth and yield is a function of the harmonious integration of soil and weather with the plant. Varieties under cultivation are proven high yielders and have yielded well above 10t ha^{-1} in certain soil situations. They also fit in well with the specific seasons which define the weather. This narrows down the cause of low yield in laterite soils to soil-plant interaction arising from soil. Significance of soil, apart from that it provides anchorage to the plant, is that it is the source sphere from which nutrients are absorbed.

Generally and conceptually, fertility management for productivity improvement is based upon making up the deficiencies of major nutrients on the oneside and ameliorating the ill effects of acidity, alkalinity etc. on the other. Specific deficiency of minor elements are also attended to by their application. Though soil is dominated by Ca, Fe, Mn etc. and deleterious influence due to their excesses is possible, it is neglected as toxicity is seldom expressed.

Failure of even continuous application of 18 t ha^{-1} FYM per season to raise the yield level beyond 4 t ha^{-1} (Anilakumar *et al.*, 1992), ineffectiveness of neutralisation of acidity by lime (Marykutty, 1986) and absence of response to N beyond 40 kg ha^{-1} (Anilakumar *et al.,* 1992) point out that some unknown factors are limiting yield expression by the plant through limiting the response to nutrients.

Investigations carried out to identify the limiting factors and their mode of action revealed that direct effect of excess iron absorption (Potty *et al.*, 1993), its metabolic interferences (Bridgit and Potty, 1992) and unfavourable $\frac{Ca + Mg}{K}$ ratio are some of them. Mathewkutty (1994) pointed out that relative contents of elements regulate the expression of yield. Mathewkutty *et al.* (1994) also pointed out that deficiency of some elements may be manifested as negative effects of some others. All these suggest the necessity of a new and comprehensive research programme to identify the limiting factors of production and evolve some means to circumvent them. Such a study should embrace as many elements as possible which are expected to have a bearing on plant growth as well as management techniques that may modify the absorption of these elements. As the elements are absorbed as anions and cations, they are bound to interact through increasing or decreasing the effect of one or both which may prove more important than the individual levels of elements themselves.

Yield formation is a three phased sequential metabolic process represented by number of panicles, number of florets per plant and filled grains and thousand grain weight (Mureta, 1969). A three dimensional evaluation - morphological, physiological and nutritional - of the three sequential phases is expected to generate the required information on limiting influences and formulation of a viable production technology. Present project is an effort in this direction.

This was attempted through the conduct of seven seperate experiments with the following objectives.

1. to find out the yield and nutritional range of rice in farmer's fields.
2. to evaluate the soil potential for yield expression through a pot culture trial.
3. to find out the effect of dry seeding, wet seeding and transplanting on elemental composition and balances on growth and yield of rice.
4. to find out seasonal influences on elemental composition and growth and productivity of rice.
5. to find out the effect of K, Ca and S on elemental composition and balances on growth and yield of rice.
6. to find out the effect of Zn and silica on elemental composition and growth and yield of rice and
7. to find out the combined effect of best treatment combinations derived from the above experiments under two soil moisture regimes viz., continuous submergence and irrigation at three days after disappearance of ponded water.

Review of Literature

REVIEW OF LITERATURE

Laterite soils of the state, often referred to as middle valley laterites, occupy 23500 km^2 of the land area of the state. It accounts for more than 60 per cent of the rice soils in Kerala. The productivity and fertilizer responsiveness of rice in laterite soil is low compared to `kole', "Kuttanadu" and black soils areas of the state. Yield expressed can best be defined as the net product of interaction of environment and the plant. Environmental effect itself is the product of interaction among their components. Nutritional environment is the one which can be manipulated most. An effort to solve the low yield problem of rice in laterite soils should naturally rely in more or less attended nutritional elements with a background of currently realised effectiveness of nutrition, season etc. This has been attempted in this chapter.

2.1 Method of establishment and rice growth

The system of growing rice and the soil and crop management practices that have evolved for each system are complex and unique. The systems were developed to suit specific environments and socio-economic conditions of the farmer and the method of establishment of rice vary with the systems.

Experimental results suggest that the yield potential for direct seeded rice is similar or higher than transplanted rice (Ali and Sankaran, 1975; Rao, *et al.*, 1973; Purushothaman and Morachan; 1994, Sekhar and Singh 1991; Bridgit and Mathew, 1995).

2.2 Tillage and rice growth

Tillage practices generally have their greatest effects on plant growth during germination, seedling emergence and stand establishment stages. The degree and kind of land preparation are closely related to the method of planting and moisture availability. However, because rice is grown in diverse land and water management systems, tillage practices for land preparation vary with the systems. Puddling, the common practice in low land rice culture, aids to quick establishment and tillering of transplanted rice and a greater competition and suppression of weed growth (De Datta, 1981).

Puddling creates an unfavourable rooting medium for upland crop and puddling and subsequent continuous submergence cause several nutritional disorders of rice in tropical Asia. The formation of a hard pan by puddling heavy clay laterite soils leaves a plough layer too thin to permit adequate root development. Hardpan formation is also undesirable in saline paddy soils. Low grain yields from puddled soils often due to accumulation of Fe^{2+} and H_2S especially on acid sulphate soils (De Datta, 1981). Mosand *et al.* (1993) observed an increased WUE in deep tilled soil during first crop and a reverse trend during second crop in maize. Maximum yield was obtained with deep tillage and minimum with minimum tillage.

Sanchez (1973) recorded a large decrease in drainage rates of puddled rice soils. Terasawa (1975) noted that continuous puddling for many years resulted in developing plough pan of 5-10 cm thick immediately below the puddled layer. Ferrolysis is another long term effect of puddling that may lower soil productivity (Moormann and Baerman, 1978). Not much experimental evidence are available on the effect of hard pan on growth and yield of rice.

Croon (1978) and De Detta *et al.* (1979) have found that minimum and zero tillage have produced grain yields of transplanted rice similar to those from puddling.

Subsoil texture is also important as surface texture. A profile with a medium textured surface horizon and a clay subsoil is particularly good for rice.

2.3 Plant population and yield

Divergent opinion about the inter-relation of plant population with realised yield has been reported.

A lower plant population has been reported to be better during the *Kharif* season and the increase in yield came through greater number of panicles and spikelets (Murthy and Murthy, 1980), more number of grains per panicle and panicle weight (Trevedi and Kwatra, 1983 and Rao and Raju, 1987) and more number of filled grain (Budhar *et al.*, 1989).

If a lower population were largely better during *Kharif* season reverse was true in the case of *Rabi* which traditionally yield lower. During *Rabi* season higher elongation (Wough *et al*, 1988; Mohapatra *et al.*, 1989 and Moorthy and Saha, 1997) and larger number of tillers resulted when the population was higher though Reddy and Reddy (1986) contradicted the report.

Nair and George (1973), Sewaram and Gupta (1973) and Srinivasan and Purushothaman (1990) reported the necessity of a higher population for higher dry matter accumulation. A higher dry matter production from a higher population naturally will lead to higher yield which was the result of higher productive tillers (Reddy and Reddy, 1986) and filled grains (Budhar *et al.*, 1993).

2.4 Effect of season and rice production

Rice is grown in two seasons, April-May to September and August - September to December - January in the laterite soils of Kerala. Of these second crop yields lower than the first crop. Lower temperature range during flowering season, withdrawal of monsoon etc. have been suggested as possible causes.

Initial studies of Alexander *et al.* (1990) suggested failure of varieties to flower by December 10th due to delay in crop commencement as the cause. According to them weather components in the specific growth phases affect productive tillers per unit area, number of grains per panicle, weight of grains and sterility.

Choudhari and Ghildyal (1970) stated that low temperatures delay maturity and facilitate better translocation to the earhead and more number of filled grains and grain weight. Choudhari and Sodhi (1979) reported that at mean temperature of 27-28°C sterility will be less. Sreedharan and Vamadevan (1981) found that response to applied fertilizers should have been higher in this season.

Rainfall and soil moisture are other important weather parameters affecting rice growth. High panicle number (500) in rabi compared to Kharif (400) season, and corresponding higher yield in rabi were attributed to rainfall variability (Venkateswarlu *et al.*, 1976). It was also reported by Sahu and Murty (1976) that dry matter production and grain yield were invariably lower by about 50 and 54 per cent respectively in wet (July-October) season than in dry (January-May) season. Corroborating this view, Viswambharan *et al.* (1989) reported a negative correlation between yield and number of rainy days during maturity stage. Contrarily, a negative correlation between yield and moisture stress was reported by Lenka and Garnayak (1991) and Yang *et al.* (1995).

A gentle wind during the growing period of the rice plant is known to improve grain yields as it replenishes the carbon dioxide supply of the plant (Matsubayashi *et al.*, 1963). Strong winds, if they occur after heading, cause severe lodging and shattering in some rice varieties (De Detta, 1981), desiccate the panicles, increase floret sterility and number of abortive endosperm (Matsubayashi *et al.* 1963). Dry winds have known to cause desiccation of rice leave and thus adversely affected photosynthesis and dry matter accumulation (Vergara, 1976).

2.5. Organic matter and rice growth

Different authors have attributed the yield improvement effects of organic manures differently. Singh and Hari Ram (1977) and Soorian (1988) attributed the beneficial effects due to improved availability of exchangable cation. Singh and Pati Ram (1977) opioned yield increase due to organic manure was due to P uptake whereas Marykutty *et al.* (1992) were of the view that yield improvement result from a balancing effect between K on the oneside and Ca and Mg on the other. Musthafa (1995) attributed that the yield improvement due to organic manure was by widening of N/Fe ratio in laterite soils.

Sharma and Meelu (1975) viewed the beneficial effect of organic manure to increase Zn status. On the otherhand Sekharan (1996) found that organic manure increases the availability of all micro nutrients and reduced the availability of major nutrients.

Long term manurial trials at Regional Agricultural Research Station, Pattambi showed that even a total substitution of fertilizers with organic manure can not increase the yield beyond 4000 kg ha^{-1} (Anilakumar, 1993).

2.6 Mineral nutrition and rice growth

Mineral nutrition is one of the most important factors affecting growth and productivity of a crop. Where rice is concerned, the stage of growth is also important as it decides the physiological requirements of each elements. In addition to the specific functions of each nutrient, the interacting influences of the different nutrients absorbed by the rice plant have to be considered and nutrient ratios and its 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 toxic levels.

2.6.1 Nitrogen

Nitrogen is a vitally important plant nutrient, being involved in the formation of protein, as well as the chlorophyll content. Mitsui and Ishii (1938) found positive correlation of leaf content of N to chlorophyll and Tanaka (1961) reported that photosynthetic rate will go on increasing till the total N content of the leaf rises to 3-4 per cent. Specific responses to N absorbed at various growth stages have been fixed by different workers. Early N absorption is known to favour tiller production and panicles (Tisdale *et al.*, 1995). Nitrogen absorbed at PI stage increases spikelet number and that absorbed at maturity helps better filling of grain (De Detta, 1981). Gupta and O'toole (1986) were of the opinion that N requirement varies with duration. Increased yield with application of N was possible upto 180 kg ha^{-1} (Singh and Om, 1993 and Monapara *et al.*, 1993).

Anilakumar *et al.* (1993) reviewed the experimental results on nutrition and reported that responses by way of grain yield to N is dependant on several factors like sources of N and soil condition. Beena Jacob (1995) and Musthafa and Potty (1996) found that response of rice to N is limited to below 70 kg ha^{-1} in laterite soils. Menon (1987) found that rice crop manifests some inhibitions in the translocation of N to the leaf blade.

Investigating the reasons for declining NUE Pati Ram and singh (1993) attributed the cause to increase in exchangable Al and decrease in exchangable cations.

2.6.2 Phosphorus

Phosphorus is one of the three most important elements along with N and K. However, the concentration of phosphate in soil solution is far lower than that of the other two and is less than 1 ppm in almost all the soils in the world. In the case of rice, however the effect of phosphate fertilizer is not clearly recognised in general and the lack of phosphate is harder to observe.

Phosphorus is associated with root development, active tillering, early flowering and ripening (De Geus, 1954). It has an important role to play in many of the metabolic processes such as synthesis and breakdown of carbohydrates, fats and proteins and in the transfer and conservation of energy (Anonymous, 1961). An adequate supply of P is associated with greater strength of cereal straw (Tisdale *et al.*, 1995).

In rice, a plentiful supply of P in the early stages promotes early growth because such a high supply increases the content of nucleic acid P and phospholipid P. Nucleic acid can actually promote heading in rice as it controls vegetative growth through protein biosynthesis and reproductive growth through flower initiation (Fujiwera, 1964). Phosphorus manuring increases early tiller formation, the greater part of it ultimately provides more grain of heavier weight and also stimulates early synchronous flowering (Battacharya and Chatterjee, 1978). Favourable influence of P application on tillering was also observed by Nair *et al.* (1972), Bharadwaraj *et al.* (1974) and Chowdhary *et al.* (1978). However, Alexander *et al.* (1973a), Kalyanikutty and Morachan (1974) and Suseelan *et al.* (1977) have reported lack of any response to P application in rice tillering.

P nutrition effected a significant increase in the number of productive tillers and a high test weight (Majumdhar, 1971; Nair *et al.*, 1972; Battacharya and Chatterjee, 1978; Gupta and Gautham, 1988; Pradhan and Dixit, 1989).

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 fertilizer (Dargan and Chillar, 1978; Dargan *et al.*, 1980; Rao and Kumar, 1994).

Dandapani and Rao (1974) and Agarwal (1978) reported that increasing P application favourably influenced the protein N in grain. However, an opposite effect was reported by Ageeb and Yousif (1978).

Response to applied P varies with the type of soil. De Datta *et al.* (1966) reported that only 8 to 27 per cent of the total P in an Indian variety of rice tested was derived from applied P, whereas Majumdar (1973) found that recovery of applied P_2O_5 was only 2 per cent. Kalam *et al.* (1966) reported that the magnitude of response to P was much lower than that of N due to the high status of P in the soil, an opinion endorsed by Alexander *et al.* (1973b). Soil moisture content affects P uptake as is evident from the observation that drying of soil decreased the available P content (Patrick and Mahapatra, 1968). Mosi *et al.* (1973) concluded that low land rice was not as likely to respond to addition of phosphatic fertilizers as upland rice crop as the release of soil P in a flooded soil may be attributed to reduction of ferric phosphate to the more soluble ferrous phosphate and displacement of phosphate from ferric and aluminium phosphate by organic anions (Islam and Elahi, 1954; Ponnamperuma, 1955; Shapiro, 1958; Datta and Datta 1963). However, the beneficial effects of flooding on phosphate availability depend on the intensity of reduction and on the iron content of the soil (Davide, 1960).

Fujiwara and Ohira (1959) and Fujiwara *et al.* (1959) reported that the supply of large amount of Fe and Mn decreased P uptake. Takhashi *et al.* (1985) studied the effects of NH_4, NO_3 and SO_4 on the absorption of P and observed that NH_4 had a decisive role on the absorption of P. In a P deficient soil absorption of N and K decreased significantly and thus the yield. Reduction in P metabolism remarkably affected the redistribution of absorbed N to Panicles (Yoshida, 1981).

Gupta and Singh (1989) observed that the application of P decreased the toxic effect of Fe and Al. However, Alan and Azmi (1989), observed an increase in the content of N, P, K, Cu, Mn and Fe with P application and decreased Zn uptake and decreased the transformation of applied Zn into water soluble and exchangeable form of Zn (Mandal and Mandal, 1990).

Haque (1992) reported that P application increased S loss from flooded soil and resulted in a higher negative S balance for rice.

2.6.3 Potassium

Plant requirements of K, the third so-called major nutrient, are 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 function of carbohydrate metabolism, N metabolism and synthesis of protein, control and regulation of various essential mineral elements, promotion of physiologically important organic acids, activation of various enzymes, promotion of the growth of meristematic tissues and adjustment of stomatal movement and water relation (Tisdale *et al.*, 1995). 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) indicated that the rice plant was characterised by its high capacity of absorbing as well as exhausting K and thereby they 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 benefit of split application of K compared to basal application was noticed by De Datta (1981) and Das (1990).

Potassium application favourably influences yield attributes in rice. Potassium absorbed at the maximum tillering stage increases the number of panicles, spikelets/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 Gurmani *et al.* (1984). Similar results were reported by Ghosh *et al.* (1994), Mahalle and Thorat (1994).

Significant increase in rice plant height with increase in the level of K was observed by Vijayan and Sreedharan (1972) and Venkatasubbiah *et al.* (1982). A positive correlation between K application and leaf area index (LAI) in rice was observed by Mandal and Dasmahapatra (1983). Ray and Choudhuri (1980) observed increase in chlorophyll content of flag leaf due to K application. K checks the chlorophyll degradation and promotes the synthesis of both chlorophyll `a' and `b'. Mengal *et al.* (1981) and Ray and Choudhari (1980) reported that K increased the rate of translocation of amino acids to the grain and rate of protein formation.

Mikkelsen and Patrick (1968) indicated that 75 per cent of the total amount of potassium is absorbed prior to the booting stage and no absorption take place from grain forming to grain filling.

An increase in the lignin content in the rice stem with increased application of K was reported by Noguchi (1940).

Application of K tended to increase grain N content and total N uptake while P content was little affected. Applied K decreased Ca and Mg content in plants raised in alluvial soils (Chakravorti, 1989).

Dixit and Sharma (1993) observed a significant reduction in the concentration of Al, Fe and acidity of soil by addition of K. Sahu (1968) reported that high K content of leaf decreased the bronzing in rice plant due to higher Fe content. In a healthy plant the Fe : K ratio is 1:9.5 to 1:22.9 while in an infected plant it is 1:1.3 to 1;6.3 according to the degree of incidence. He also observed an inverse relationship between K and Fe. Application of higher dose of K increased the nutritional status of the crop as well as the yield. Mitra *et al.* (1990) evaluated the effects of higher level of K (0 to 160 kg/ha) on rice in a iron toxic laterite soil and reported that Fe toxicity symptoms decreased with increasing K application.

Singh and Singh (1987b) studied the effect of applied K on Fe toxicity and associated nutritional disorders in wetland rice rich in iron. The results indicated that K content was increased with K application and was more pronounced at flowering stage. Phosphorus content was increased with K application while Fe concentration reduced drastically indicating K-P synergism and K-Fe antagonism. Grain yield was highly correlated with K concentration of shoot at flowering (r = 0.78) and straw (r = 0.080) and K:P (r = 0.072) and K:Fe (r = -0.96).

Qadar (1989) reported that K application tended to increase the 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.

2.6.4 Calcium

The most important role of calcium is to maintain the integrity of the structure and function of biomembranes. Calcium stimulated the absorption of P and K (Tanaka, 1961; Jacobsen *et al.* 1961; Erdei and Zoldos, 1977) and accelerated more effectively the translocation of photosynthetic products compared to K and Mg.

Hati *et al.* (1979) reported that Ca did not show any significant influence on iron content of wheat and have negative correlation on the availability of plant Mn and Fe.

Laskar (1990) reported that exchangeable Al served as a good estimate of lime required for economic productivity of rice in acid sulphate soil. The results indicated that yield was maximised with lime equivalent to or less than the amount theoretically needed to neutralise toxic quantities of Fe and Al are supplied.

Application of lime increased rice yield by rectifying the ill effects of Fe and Al (Sahu, 1968; Dixit and Sharma, 1993; Laskar 1990).

Liming acid soil has been found to be beneficial in increasing the availability P and repressing the toxic level of Al, Mn and Fe (Mongia and Bandyopadhyay, 1993; Hati *et al.*, 1979). Verma and Tripati (1987) reported that application of lime under flooded condition increased rice yield and Mn content and decreased Fe.

Marykutty (1986) found that Ca application though raised the pH could not bring down Fe content below the critical level of 300 ppm in rice in laterite soil. Role of lime in decreasing K content of rice has also been reported by so many workers (Mackey and Mac Eachern, 1962; Borlan and Milizcescu, 1966; Kalia and Ryti, 1969). However, Mandal and Sinha (1968) could not find any effect of liming on availability of K content of plant in acid red loam soils.

2.6.5 Magnesium

Among the five major nutrients in plants, one is Magnesium, which should be added to the other elements N, P, K and Ca. Rice plants, However, have lower contents of Ca and Mg. Magnesium has similar function to that of calcium, which in addition, is a constituent of the chlorophyll molecule essential for photosynthesis and of several essential enzymes. It also involved in activation of ATP hydrolytic enzyme (ATP ase). Magnesium absorbed into rice plant is easily mobile in retranslocation and the distribution of Mg in the panicle is large, following P and N (Ishizuka and Tanaka, 1959) and is concentrated in the aleurone layer like K and P (Tanaka *et al.,* 1974).

Magnesium application was found to increase the grain yield in rice (Mani *et al.*, 1993; Muralidharan and Jose, 1993; Varghese and Jose, 1993). Pot culture experiments on rice conducted by Varghese and Money (1965) and Padmaja and Varghese (1966) indicated that Mg either alone or in combination with Ca and Si appreciably improved crop growth and significantly increased grain yield.

2.6.6 Sulphur

Sulphur is an essential element for plants and is now recognised as the fourth major nutrient in addition to N, P and K. It is a constituent element of amino acids, cysteine, cystine and methionine and the plant hormone thiamin and biotin. Sulphur is involved in the formation of chlorophyll, activation of enzymes and in the formation of glucosides or glucosinolates.

Tandon (1986) and Nair (1995) reported that more than 80 per cent of Indian soils are deficient in sulphur. Rice plant requires 1.67 kg S to produce 1 ton hulled grain (Suzuki, 1977). Singh *et al.* (1993) and Raju *et al.* (1995) reported that application of S upto 60 kg/ha increased the growth attributes and yield of rice. They have observed a significant positive correlation with growth attributes yield and sulphate. Nair (1995) have also reported similar results.

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 form the clay crystal lattice. Bansal (1991) observed a significant negative correlation between N:S and yield. A wide N: S ratio will drastically reduce the yield.

Sulphur application is known to reduce plant content of iron by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970; Pillai, 1972). Clarson and Ramaswamy (1992) found that rice plant removes 37-42 kg 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. Mukhi and Shukla (1991) reported that interacting influences of S with other elements is a function of the relative contents of these elements.

2.6.7 Iron

An important micro essential element affecting growth and yield of rice in Kerala is iron. High availability of iron in the soil and its excessive accumulation in the plant is suspected to be one of the reason of low fertiliser responsiveness of high yielding genotypes in the state. In rice plant, Fe is related to the formation of chlorophyll, but is not a constituent of it. It is a possible catalyst in organic form or combined with organic compounds as a component of redox enzymes and is an inhibitor of the absorption of K by the rice plant.

Rice is known to have a particular capacity to exclude Fe from its normal metabolic process by either preventing its absorption from the soil or by limiting its accumulation in the roots (Tadano and Yoshida, 1978). It is also known that varieties differ in their potential Fe exclusion power (Ponnamperuma, 1976; Elsy *et al.,* 1994) yield expression in rice is inhibited in laterite soils due to their susceptibility to excess iron (Bridgit *et al.*, 1993) and high yield varieties were more susceptible to iron toxicity than traditional local varieties (Srivastava *et al.*, 1977; Mohanty and Panda, 1991; Elsy *et al.*, 1994). Mensovorat *et al.* (1985) found that excess Fe reduces the yield by tilting the balance between Ca and K. Bulbule and Deshpande (1989) reported that tolerant varieties maintained a high nutrient ratios of N/Fe, P/Fe, K/Fe, Mg/Fe and Mn/Fe. They also stated that excess iron absorption is related with multiple nutritional stress and the resulting low K/Fe and P/Fe ratios lead to more serious yield reduction than Ca/Fe and Mg/Fe ratios.

Singh (1992) found that Fe toxicity caused fewer panicles and filled grains, delayed crop maturity and yield reduction of 1 to 2.0 t ha^{-1}. He also found that by increasing the grain uptake of P, K, Zn and Cu by proper use of these elements reduced Fe content and maintain a proper nutrient balance resulted in increased yield of 1.2 t ha^{-1}.

2.6.8 Manganese

Manganese is another element which occurs in excess concentration in soils of many parts of the state and is as important as iron in limiting rice productivity. Manganese serves as a factor in photosynthesis and as an activator of several enzymes. When present in interstitial water of the soil in large concentrations Mn is reported to inhibit biomass synthesis (Tate, 1987).

More than 60 per cent of Mn contained in the plant leaves is in chloroplast and Mn along with Fe and Cu take part in indispensable roles in the electron transport system (Hariguchi and Kitagishi, 1976). Bulbule and Deshpande (1989) reported that higher uptake of Mn reduced the injurious effect of Fe. Sahu (1968) found an inverse relationship between Mn and Fe and in bronzing affected plants the Fe:Mn ratio ranges from 0.15 to 0.4 and 0.5 to 1.3 respectively.

Tembhace and Rai (1967) noticed a negative relationship between pH and available Mn content while increased $CaCO_3$ content increased available Mn. Combination of high P and Mn levels in solution reduced the translocation of Fe to shoots. Precipitation of $MnPO_4$ in the root was likely to occur at high concentrations of P and Mn in the root (Vora *et al.*, 1979).

2.6.9 Zinc

A micronutrient of importance in rice involved in the activation of many enzymatic reaction and in N metabolism is Zn. Salam and Subramanian (1993) reported that Zn application improved grain yields, plant height, tillering, LAI and root growth and increased uptake of N, P, Zn and Fe. Similar results were reported by many workers (Balakrishnan *et al.*, 1985; Srinivasan, 1984; Hussain *et al.*, 1987; Tomer *et al.*, 1994) whereas Ghabrial (1979) could not observe any significant effect on growth and yield attributes by Zn application.

Zn application increased its content in root and shoot, decreased the content of P and Fe in root and Fe in shoot (Gangwar *et al.*, 1989). Yield increase upto 20 kg $ZnSO_4$ ha^{-1} was observed by Gill and Singh (1978) Sarkar *et al.* (1988) and Saravanan and Ramanathan (1986). Beneficial effect of Zn application on yield was reported by many workers (Illangovan and Palaniappan, 1989; Rajagopalan and

Narayanaswamy, 1973; Sadana and Takkur, 1983; Singh *et al.*, 1983). However, Singh (1987) reported that application of Zn alone or in combination with N did not show any significant effect on yield but in combination with P significantly increased the yield.

2.6.10 Copper

Copper, a micronutrient in rice which function as a component of a metalloenzyme and as a regulator of enzymatic action is reported to decrease grain yields when applied at the rate of 40 kg ha^{-1} (Agarwal and Gupta, 1994). However, Zhou *et al.* (1994) observed sterility of rice plants when Cu was deficient. Copper application was seen to inhibit plant growth (Che, 1993).

Cu along with Fe and Mn, have an important role in the electron transport system of photosynthesis (Kanematsu and Asada, 1989).

It was reported that Fe absorption increased with Cu deficiency and plant became sterile when Cu/Fe ratio of above-ground parts became less than 0.01 (Mizuno and Kamada, 1982). They also reported that excessive Cu hampers root elongation and caused damage to crops when Cu in soil is higher than 125 ppm.

2.6.11 Silica

Silica is a micronutrient required specially for rice. On soils low in silica, the application of silica will increase yields of a modern rice variety at high rates of N application (De Detta, 1981).

Application of silica upto 1000 kg ha^{-1} has shown increased yield of rice in laterite soils (Potty, 1965) which accounts for more than 60 per cent of the rice soils of Kerala and the increase has been attributed to more efficient utilisation of nutrients (Sadanandan and Varghese, 1968).

Rice absorb silica actively through roots and stored in the leaf. Silica uptake in plant is generally influenced by nutritional status of N and P of the rice plant and not by K, Mg and S. Tadano (1976) attributed beneficial effects of silica to reduced absorption of iron and manganese. The amount of silica absorbed by rice plant is six times as much as K, ten times as much as N, twenty times as much on P_2O_5 and thirty times on much as Ca.

Wang *et al.* (1994) reported that application of silica increased the plant height, grain weight and yield and decreased helminthosprium leaf spot and shoot blight of rice plant.

Application of silica promotes the utilisation of P, reduced absorption of iron and Mn ((Vora, 1979) and stimulates photosynthesis through increased plant height, leaf area expansion resulting in increased CO_2 assimilation rate/plant and thus a substantial increase in grain yield (Subramanian and Gopalaswamy, 1990). Increased grain and straw yields of rice due to Si application had been reported by many workers (Takahashi, 1968; Vyas and Motiramani, 1971; Su, 1982; Subramanian and Gopalaswamy, 1990) Lee *et al.*, 1989.

Multilocational trials have shown that many of the high yielding varieties of rice fail to express their yield potential in laterite soils (KAU, 1988). Marykutty *et al.* (1992) found that ratios of elements in tissues and not the absolute levels in tissues or levels of application to soil govern the productivity expression of rice. Thus it appears that the cause of low productivity of rice in laterite soils rest on unbalanced nutrition. Information on the ionic relation to their productivity will help to identify the limiting and promoting nutritional factors on yield of rice. Hasegawa *et al.* (1995) found that K deficiency caused preferential accumulation of

Na in leaf sheaths, while Mg and Ca were predominantly distributed in the leaf blades. Sreemannarayana and Sairam (1995) reported that increasing K rate decreased leaf Fe and Mn contents while it increased leaf Zn content slightly. Similarly, Koch and Mengel (1977) showed that K application increased N uptake of rice and N content in the grain. It was observed that the total uptake and percentage translocation of N, P and K by rice increased significantly with increasing levels of K (Singh and Singh, 1987). A similar trend with increasing S rate was noticed by Singh *et al.*, 1994.

Salam and Subramanian (1993) reported that increasing Zn application resulted in increased contents of P and Zn in the grain but lowered the Ca content. A reverse effect was seen in rice straw. Che (1993) observed that when N is at a high level, Cu can greatly improve N, P, Mg and Cu absorption and N and C metabolism of rice. It can also increase K and Ca absorption. Bridgit *et al.* (1993) reported that a wider N/Fe and S/Fe ratio in leaves and a narrow Fe/P ratio in stems and roots appeared to be the most important factors for obtaining better yield expressions in rice in the iron rich laterite soils of Kerala.

2.8 Integrated nutrient management in rice

Since nutrient availability is a major controlling factor in biomass productivity and ecosystem stability, understanding the process contributing to nutrient exchanges in the soil and arriving at an optimum integration of organic and inorganic nutrient sources become necessary. The efficiency of plant biomass synthesis and rate of return of this biomass to the soil ecosystem also controls ecosystem productivity (Tate, 1987).

Sahu and Nayak (1971) and Sinde and Ghosh (1971) have highlighted the manifold beneficial effects of the combined application of organic and inorganic manures on soils of rice and environment. Pooled analysis of grain yield data for 25 years generated from a permanent manurial experiment with tall indica rice varieties revealed that during virippu (kharif) season, the treatment receiving combined application of cattle manure and NPK was significantly superior to others (Anilakumar *et al.*, 1993). Similar results were reported by Pillai and Vamadevan (1978). Tanveer *et al.* (1993) reported that the yield and yield attributing characters of rice were significantly influenced by the residual effects of FYM and source and levels of P. Various experiments studying the effect of organic and chemical fertilizers alone and in combination showed that supplementing chemical fertilizers with organic fertilizers was always superior to chemical fertilizers alone (Saravanan and Ramanathan, 1984; Joseph and Kuriakose, 1985; Mahapatra *et al.*, 1987). Lui *et al.* (1990) explained that the use of OM in addition to chemical fertilizers increased soil organic matter and total N, increased the effectiveness of soil P and increased the activities of soil enzymes such as urease. Organic matter also increased the utilization of N, P and K by rice.

Susuki *et al.* (1990) studied the effects of continuous application of inorganic and organic fertilizers on rice soil fertility and rice yields in a 60 year long term field experiment. They found that the trend of initial lower yields in the organically fertilized plots was gradually reversed.

Materials and Methods

MATERIALS AND METHODS

Experiments of the research project entitled "Nutritional balance analysis for productivity improvement of rice in iron rich lateritic alluvium" were conducted during 1995-97 at the Agricultural Research Station, Mannuthy. The details of materials used and methods adopted in the conduct of the experiments are presented in this chapter.

3.1 Location

The Agricultural Research Station, Mannuthy located at 10°31'N latitude and 76°13'E longitude and at an altitude of 40.29 M above sea level is situated about 6 km East of Trichur town on the right side of Trichur-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 period are presented in Appendix I and II and Fig.3.1 and 3.2.

The mean maximum temperature experienced is 37.1°C while the mean minimum temperature is 21.7°C with an average mean of 29.4°C.

3.3 Soil

Laterite sandy clay loam of the oxisol group is the soil type of the area. The soils are acidic in reaction with a pH 6.1.

The physico-chemical characteristics of the soils of the experimental fields are presented in Table 3.1.

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

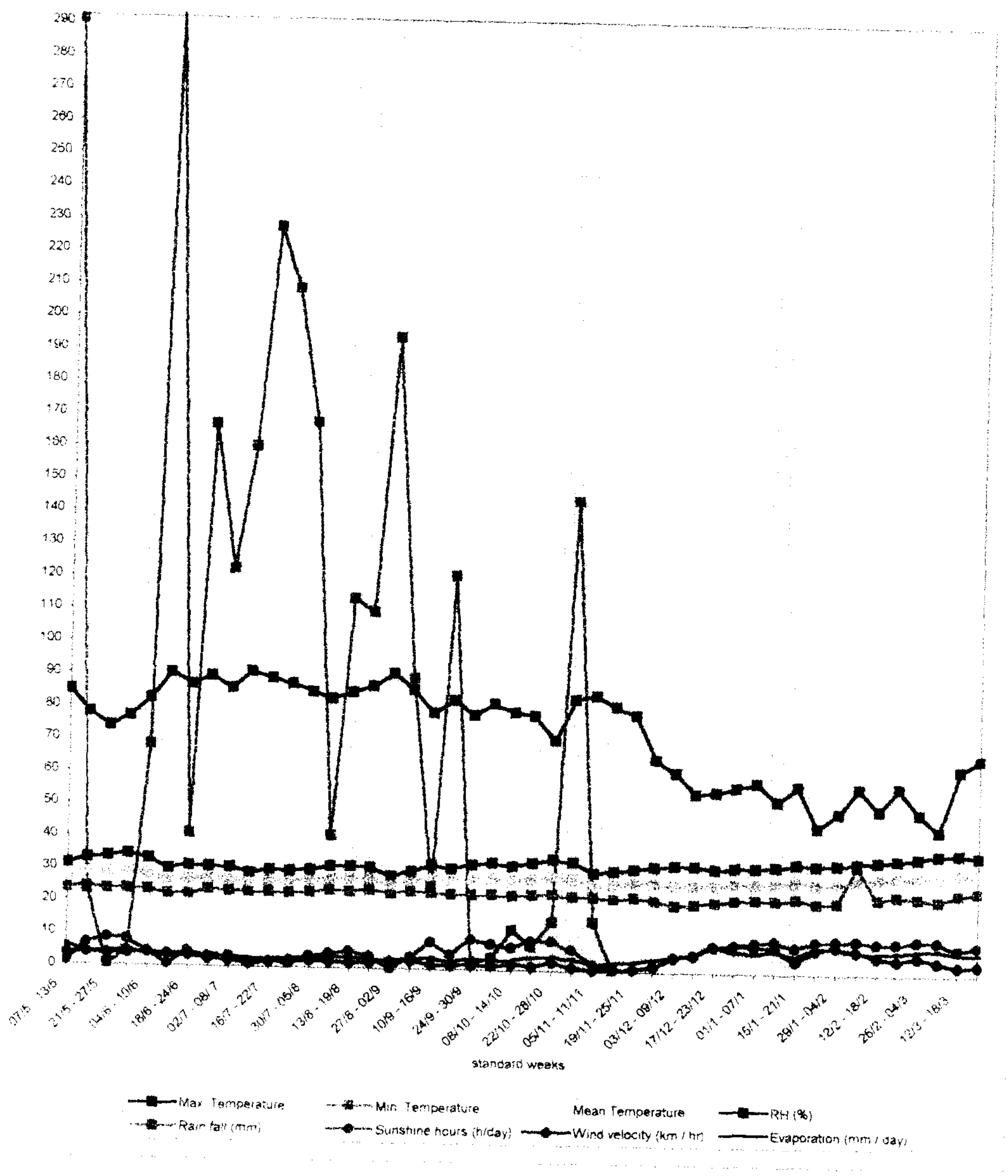


Fig. 3.1 Weekly weather at Mannuthy from 07-5-95 to 25-3-96

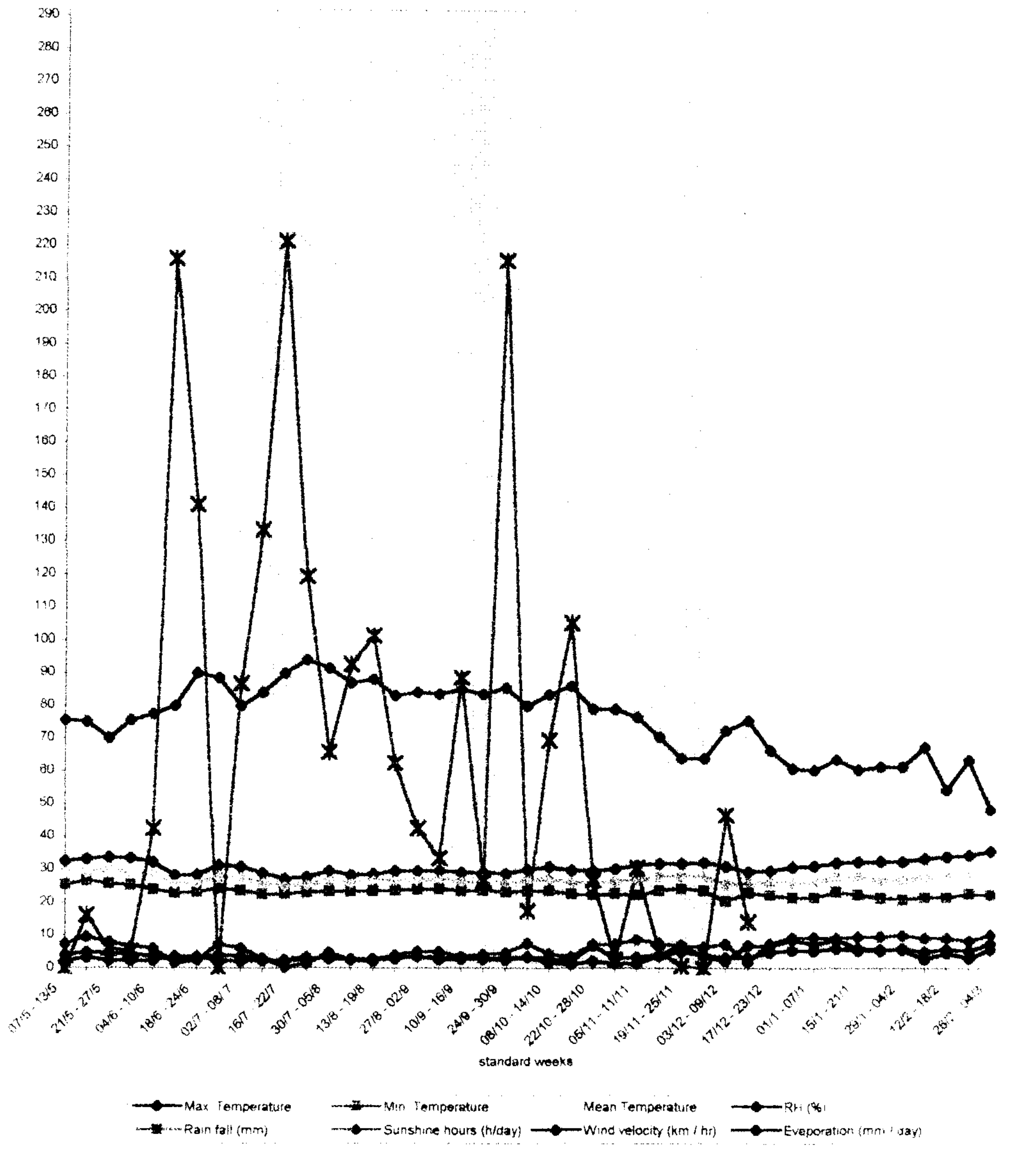


Fig. 3.2 Weekly weather at Mannuthy from 07-5-96 to 04-3-97

Table 3.1 Physico-chemical properties of the soil of experimental sites:

(a) Physical properties

Site No.	Bulk density gcc^{-1}	Particle density gcc^{-1}	Water holding capacity (%)	Porosity (%)	Mechanical composition (%)		
					Sand	Silt	Clay
1	1.33	2.30	49.68	48.84	75.76	4.44	18.64
2	1.347	2.46	48.29	49.3	76.25	4.38	17.7

(b) Chemical properties

Site No.	Soil reaction pH	Electrical conductivity dsm^{-1}	Organic carbon (%)	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})	N.N. NH_4AC extractable		Available S (kg ha^{-1})	DTPA extractable			
						Ca (kg ha^{-1})	Mg (kg ha^{-1})		Fe (kg ha^{-1})	Mn (kg ha^{-1})	Zn (ppm)	Cu (ppm)
1	6.08	0.13	0.66	3.70	138.9	125.0	367.5	322.2	801.9	132.2	2.0	8.76
2	6.08	0.24	0.95	3.70	132.2	192.5	421.3	205.0	817.9	132.2	1.24	8.80

transplanting during both First (*kharif*) and Second (*rabi*) crop season, tolerant to BPH and rice blast disease, moderately susceptible to sheath blight and capable of producing an yield of over 8 MT under favourable situations and moderately good yields under adverse conditions.

3.5 Cropping history of the experimental sites

The area is a typical double cropped wet land. Field plots with no experiments conducted in them for the two previous seasons were selected for the trials and each experiment was conducted in new plots.

3.6 Experimental methods

The research project consisted of seven experiments. The basic details regarding the title, design, replication, plot size etc. of Experiment III, IV V, VI and VII are presented in Table 3.2. Treatment details are provided in Table 3.3. Layout of experimental plots are depicted in Fig.3.2a, 3.2b, 3.2c, 3.2d, 3.2e and 3.2f. The sources of various elements are given in Table 3.4.

The details of Experiment I is presented below.

Experiment No.I

Cause and effect relationship of plant nutrient balance in the productivity of rice - A survey to study the performance of rice in farmer's field.

Collection of plant samples from 36 group farms (*padasekharams)* 12 each from lateritic alluvium, `*kole*' lands and Chittoor black soil and analysed for major, secondary and micro nutrients. The group farms (*padasekharams*) selected are:

Lateritic alluvium	`Kole' land	Chittoor balck soil
1. Wadakkencherry	Pullazhy East	Muttichira-1
2. Alathur	Chettupuzha East	Muttichira-2
3. Kumbalakode	Pullazhy West	Anakkad
4. Alathur-Vannur	Elthuruthu East	Karippali
5. Alathur	Elthuruthu West	Thottassery
6. Kavassery	Chettupuzha West	Kambilichungam
7. Nellaya	Manakodi East	Valara-1 (Nalleppilly)
8. Mannuthy	Manakodi West	Valara-1
9. ARS Mannuthy	Variyam Padavu	Valara-2
10. Pulinkara	Krishnankottapadavu	Muttimampallam
11. Pattambi	Anchumuripadavu	Korakkad
12. RARS Pattambi	Velathur kole padavu	Kallidichalla

The different soil types are depicted in Fig.3.2. The special features of these soil types are:

1. Lateritic alluvium

These are highly leached soils with a silica sesquioxide ratio of 1.33 and below and account for more than 60 per cent of the rice soils of Kerala. The texture of the soil varied, ranging from sandy clay loam to sandy loam. Organic carbon content ranged from 0.4 to 1.56. The soil is acidic in reaction with pH ranges from 3.5 to 6.6. The special characteristic of this soil is that these soils are poor in fertility status compared to other rice soils of the state due to high iron content ranging from 6-9 per cent as Fe_2O_3 (Hassan, 1978).

N
↑

Fig.3.2a Layout of pot culture study

Laterite soil	`Kole' soil	Chitoor black soil
Wadakkanchery	Pullazhy East	Muttichira
Alathur North	Chettupuzha East	Muttichira
Kumblakode	Pullazhy West	Anakkad
Alathur-Vannoor	Elthuruthu East	Karippali
Alathur South	Elthuruthu West	Thottassery
Kavassery	Chettupuzha West	Kambilichungam
Nellaya	Manakodi East	Valara - 1 (Nallepilly)
Mannuthy	Manakodi West	Valara - 1
ARS, Mannuthy	Variyam padavu	Valara - 2
Pulinkara - Chalakudy	Krishankotta padavu	Muttimampallam
Pattambi	Anchumuri padavu	Korakkadu
RARS, Pattambi	Velathur kole	Kallidichalla

N
↑

Fig.3.2b Layout of experimental plots in Experiment III

← 5.1 m →

DSR D_{30} M_0	DSR D_{30} M_5	DSR D_{30} M_0	DSR D_{15} M_{10}	DSR D_{15} M_5	DSR D_{15} M_0	↑ 4 m ↓
TPR D_{30} M_5	TPR D_{30} M_0	TPR D_{30} M_{10}	TPR D_{15} M_{10}	TPR D_{15} M_0	TPR D_{15} M_5	R_1
WSR D_{30} M_0	WSR D_{30} M_5	WSR D_{30} M_{10}	WSR D_{15} M_{10}	WSR D_{15} M_5	WSR D_{15} M_0	

WSR D_{30} M_0	WSR D_{30} M_{10}	WSR D_{30} M_5	WSR D_{15} M_5	WSR D_{15} M_{10}	WSR D_{15} M_0	
DSR D_{30} M_0	DSR D_{30} M_5	DSR D_{30} M_{10}	DSR D_{15} M_0	DSR D_{15} M_{10}	DSR D_{15} M_5	R_2
TPR D_{30} M_{10}	TPR D_{30} M_0	TPR D_{30} M_5	TPR D_{15} M_{10}	TPR D_{15} M_0	TPR D_{15} M_5	

TPR D_{30} M_{10}	TPR D_{30} M_5	TPR D_{30} M_0	TPR D_{15} M_0	TPR D_{15} M_5	TPR D_{15} M_{10}	
WSR D_{30} M_5	WSR D_{30} M_{10}	WSR D_{30} M_0	WSR D_{15} M_{10}	WSR D_{15} M_5	WSR D_{15} M_0	R_3
DSR D_{30} M_{10}	DSR D_{30} M_5	DSR D_{30} M_0	DSR D_{15} M_{10}	DSR D_{15} M_5	DSR D_{15} M_5	

DSR - Dry seeded rice
WSR - Wet seeded rice
TPR - Transplanted rice

M_0, M_5, M_{10} - levels of FYM (0, 5, 10 kg ha^{-1})
D_{15}, D_{30} - Depth of digging (15 cm and 30 cm)

N ↑

Fig.3.2c Layout of experimental plots in Experiment IV

← 5.1 m →

↑ 4 m ↓

R_1	R_2	R_2
WSR D_{15} M_0	TPR D_{15} M_0	WSR D_{15} M_0
WSR D_{15} M_{10}	WSR D_{15} M_{10}	WSR D_{15} M_{10}
WSR D_{15} M_5	TPR D_{15} M_{10}	WSR D_{15} M_5
TPR D_{15} M_5	WSR D_{15} M_5	TPR D_{15} M_5
TPR D_{15} M_{10}	WSR D_{15} M_0	TPR D_{15} M_0
TPR D_{15} M_{10}	TPR D_{15} M_5	TPR D_{15} M_{10}
TPR D_{15} M_0	WSR D_{30} M_{10}	TPR D_{30} M_{10}
TPR D_{30} M_5	WSR D_{30} M_5	WSR D_{30} M_0
TPR D_{30} M_{10}	TPR D_{30} M_5	WSR D_{30} M_{10}
WSR D_{30} M_5	TPR D_{30} M_{10}	TPR D_{30} M_5
WSR D_{30} M_0	WSR D_{30} M_0	TPR D_{30} M_0
WSR D_{30} M_{10}	TPR D_{30} M_0	WSR D_{30} M_0

WSR - Wet seeded rice

TPR - Transplanted rice

D - Depth of digging (15 and 30 cm)

M - Farm yard manure (0, 5 and 10 t ha^{-1})

N ↑

Fig.3.2d Layout of experimental plots is Experiment V

← 5.1 m →

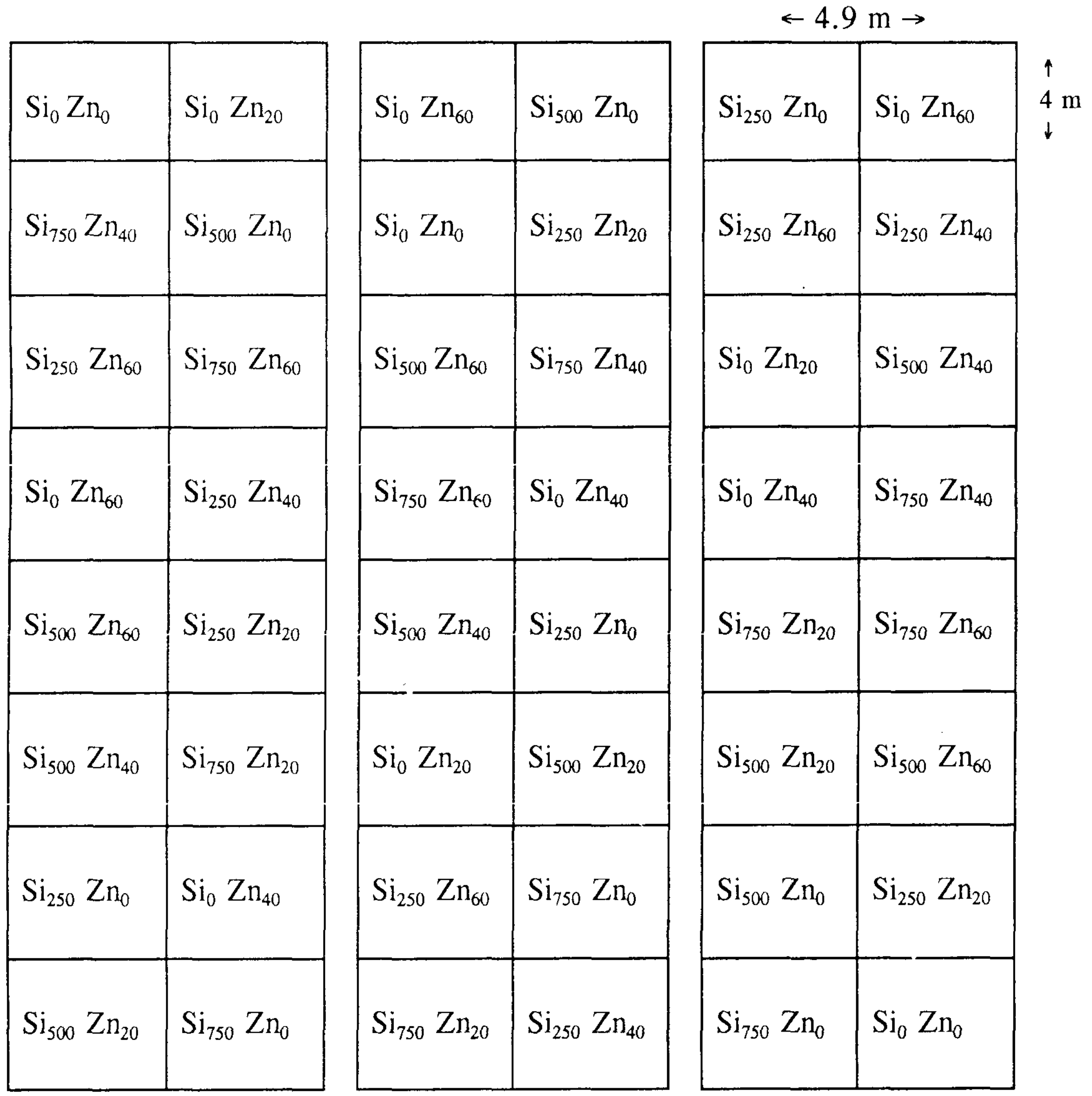
↑ 4 m ↓

$K_0L_0S_{100}$	$K_{60}L_{150}S_0$	$K_0L_0S_0$	$K_{60}L_0S_{100}$	$K_{60}L_0S_{200}$	$K_{180}L_{150}S_0$
$K_0L_0S_0$	$K_{60}L_0S_0$	$K_{60}L_{150}S_0$	$K_{60}L_0S_{200}$	$K_{60}L_{150}S_0$	$K_{180}L_{150}S_{100}$
$K_0L_0S_{200}$	$K_{60}L_0S_{200}$	$K_{120}L_{150}$	$K_0L_0S_{100}$	$K_{60}L_0S_{100}$	$K_{60}L_{150}S_{200}$
$K_0L_{150}S_{100}$	$K_{60}L_{150}S_{100}$	$K_{180}L_{150}S_{200}$	$K_0L_0S_{200}$	$K_0L_0S_{200}$	$K_{60}L_{150}S_{100}$
$K_0L_{150}S_{200}$	$K_{60}L_{150}$	$K_{180}L_0S_{200}$	$K_{180}L_0S_{100}$	$K_0L_0S_{100}$	$K_{60}L_0S_0$
$K_0L_{150}S_0$	$K_{60}L_0$	$K_0L_{150}S_{200}$	$K_0L_{150}S_0$	$K_{180}L_0S_{200}$	$K_0L_0S_0$
$K_{120}L_0S_{100}$	$K_{180}L_{150}S_{100}$	$K_0L_{150}S_{100}$	$K_{180}L_0S_0$	$K_{180}L_0S_{100}$	$K_{180}L_0S_0$
$K_{120}L_{150}S_0$	$K_{180}L_{150}S_{100}$	$K_{120}L_0S_{200}$	$K_{60}L_0S_{200}$	$K_{180}L_{150}S_{150}$	$K_{120}L_0S_{200}$
$K_{120}L_{150}S_{200}$	$K_{180}L_0S_0$	$K_{120}L_0S_{100}$	$K_{60}L_0S_{100}$	$K_{120}L_{150}S_{200}$	$K_0L_{50}S_{200}$
$K_{120}L_0S_0$	$K_{180}L_{150}S_{200}$	$K_{60}L_{150}S_{100}$	$K_{120}L_0S_0$	$K_{120}L_{150}S_{100}$	$K_0L_{150}S_0$
$K_{120}L_0S_{200}$	$K_{180}L_0S_{100}$	$K_{60}L_{150}S_{200}$	$K_{180}L_{150}S_0$	$K_{120}L_0S_0$	$K_{120}L_0S_{100}$
$K_{120}L_{150}S_{100}$	$K_{180}L_0S_{200}$	$K_{60}L_0S_0$	$K_{180}L_{150}S_{100}$	$K_{120}L_{150}S_0$	$K_0L_{150}S_{100}$

K_0, K_{60}, K_{120}, K_{180} - K levels (0, 60, 120, and 180 kg ha^{-1})
L_0, L_{150} - L levels (0 and 150 kg lime ha^{-1})
S_0, S_{100}, S_{200} - S levels (0, 100 and 200 kg ha^{-1})

N ↑

Fig.3.2e Layout of experimental plots is Experiment VI



Si_0 Zn_0	Si_0 Zn_{20}	Si_0 Zn_{60}	Si_{500} Zn_0	Si_{250} Zn_0	Si_0 Zn_{60}
Si_{750} Zn_{40}	Si_{500} Zn_0	Si_0 Zn_0	Si_{250} Zn_{20}	Si_{250} Zn_{60}	Si_{250} Zn_{40}
Si_{250} Zn_{60}	Si_{750} Zn_{60}	Si_{500} Zn_{60}	Si_{750} Zn_{40}	Si_0 Zn_{20}	Si_{500} Zn_{40}
Si_0 Zn_{60}	Si_{250} Zn_{40}	Si_{750} Zn_{60}	Si_0 Zn_{40}	Si_0 Zn_{40}	Si_{750} Zn_{40}
Si_{500} Zn_{60}	Si_{250} Zn_{20}	Si_{500} Zn_{40}	Si_{250} Zn_0	Si_{750} Zn_{20}	Si_{750} Zn_{60}
Si_{500} Zn_{40}	Si_{750} Zn_{20}	Si_0 Zn_{20}	Si_{500} Zn_{20}	Si_{500} Zn_{20}	Si_{500} Zn_{60}
Si_{250} Zn_0	Si_0 Zn_{40}	Si_{250} Zn_{60}	Si_{750} Zn_0	Si_{500} Zn_0	Si_{250} Zn_{20}
Si_{500} Zn_{20}	Si_{750} Zn_0	Si_{750} Zn_{20}	Si_{250} Zn_{40}	Si_{750} Zn_0	Si_0 Zn_0

Si_0, Si_{250}, Si_{500}, Si_{750} - silica levels (0, 250, 500 and 750 kg ha^{-1})
Zn_0, Zn_{20}, Zn_{40}, Zn_{60} - zinc levels (0, 20, 40 and 60 kg ha^{-1})

N
↑

Fig.3.2f Layout of experimental plots is Experiment VII

← 4.9 m →

↑ 4 m ↓

$K_0S_0L_0Si_0$	$K_0S_0L_0Si_{250}$	$K_{0S0}L_{150}Si_0$	$K_{120}S_{100}L_0Si_0$
$K_0S_{100}L_0Si_{250}$	$K_0S_0L_0Si_0$	$K_0S_0L_{150}Si_{250}$	$K_{120}S_{100}L_0Si_{250}$
$K_0S_{100}L_{150}Si_0$	$K_0S_0L_{150}Si_0$	$K_{120}S_{100}L_0Si_0$	$K_{120}S_{100}L_{150}Si_{250}$
$K_{120}S_{100}L_{150}Si_{250}$	$K_0S_0L_{150}Si_{250}$	$K_{120}S_{100}L_0Si_{250}$	$K_{120}S_{100}L_{150}Si_0$
$K_{120}S_{100}L_{150}Si_0$	$K_{120}S_0L_0Si_0$	$K_{120}S_{100}L_{150}Si_0$	$K_{120}S_0L_0Si_{250}$
$K_0S_0L_0Si_{250}$	$K_{120}S_0L_0Si_{250}$	$K_{120}S_{100}L_{150}Si_{250}$	$K_{120}S_0L_0Si_0$
$K_0S_{100}L_0Si_0$	$K_{120}S_0L_{150}Si_{250}$	$K_0S_0L_0Si_0$	$K_{120}S_0L_{150}Si_{250}$
$K_0S_0L_{150}Si_0$	$K_{120}S_0L_{150}Si_0$	$K_0S_0L_0Si_{250}$	$K_{120}S_0L_{150}Si_0$
$K_{120}S_0L_0Si_0$	$K_{120}S_{100}L_0Si_{250}$	$K_0S_{100}L_{150}Si_0$	$K_0S_0L_0Si_{250}$
$K_{120}S_{100}L_0Si_0$	$K_{120}S_{100}L_{150}Si_{250}$	$K_0S_{100}L_{150}Si_{250}$	$K_0S_0L_0Si_0$
$K_0S_{100}L_0Si_{250}$	$K_0S_{100}L_0Si_{250}$	$K_0S_{100}L_0Si_0$	$K_0S_0L_{150}Si_{250}$
$K_{120}S_0L_0Si_{250}$	$K_0S_{100}L_{150}Si_{250}$	$K_0S_{100}L_0Si_{250}$	$K_0S_0L_{150}Si_0$
$K_{120}S_0L_0Si_{250}$	$K_0S_{100}L_0Si_0$	$K_{120}S_0L_{150}Si_0$	$K_0S_{100}L_0Si_{250}$
$K_{120}S_0L_{150}Si_0$	$K_0S_{100}L_{150}Si_0$	$K_{120}S_0L_{150}Si_{250}$	$K_0S_{100}L_0Si_0$
$K_0S_{100}L_{150}Si_0$	$K_{120}S_{100}L_0Si_0$	$K_{120}S_0L_0Si_0$	$K_0S_{100}L_{150}Si_0$
$K_0S_0L_{150}Si_{250}$	$K_{120}S_{100}L_{150}Si_0$	$K_{120}S_0L_0Si_{250}$	$K_0S_{100}L_{150}Si_{250}$
POP	POP	POP	POP
R1	R2	R1	R2

← Continuous submergence (W_0) →

← Irrigation 3 days after disappearance of ponded water (W_1) →

K - Potassium (0 and 120 kg ha^{-1})
Si - Silica (0 and 250 kg ha^{-1})
POP - Package of Practice
L - Calcium (0 and 150 kg lime ha^{-1})
S - Sulphur (0 and 100 kg ha^{-1})

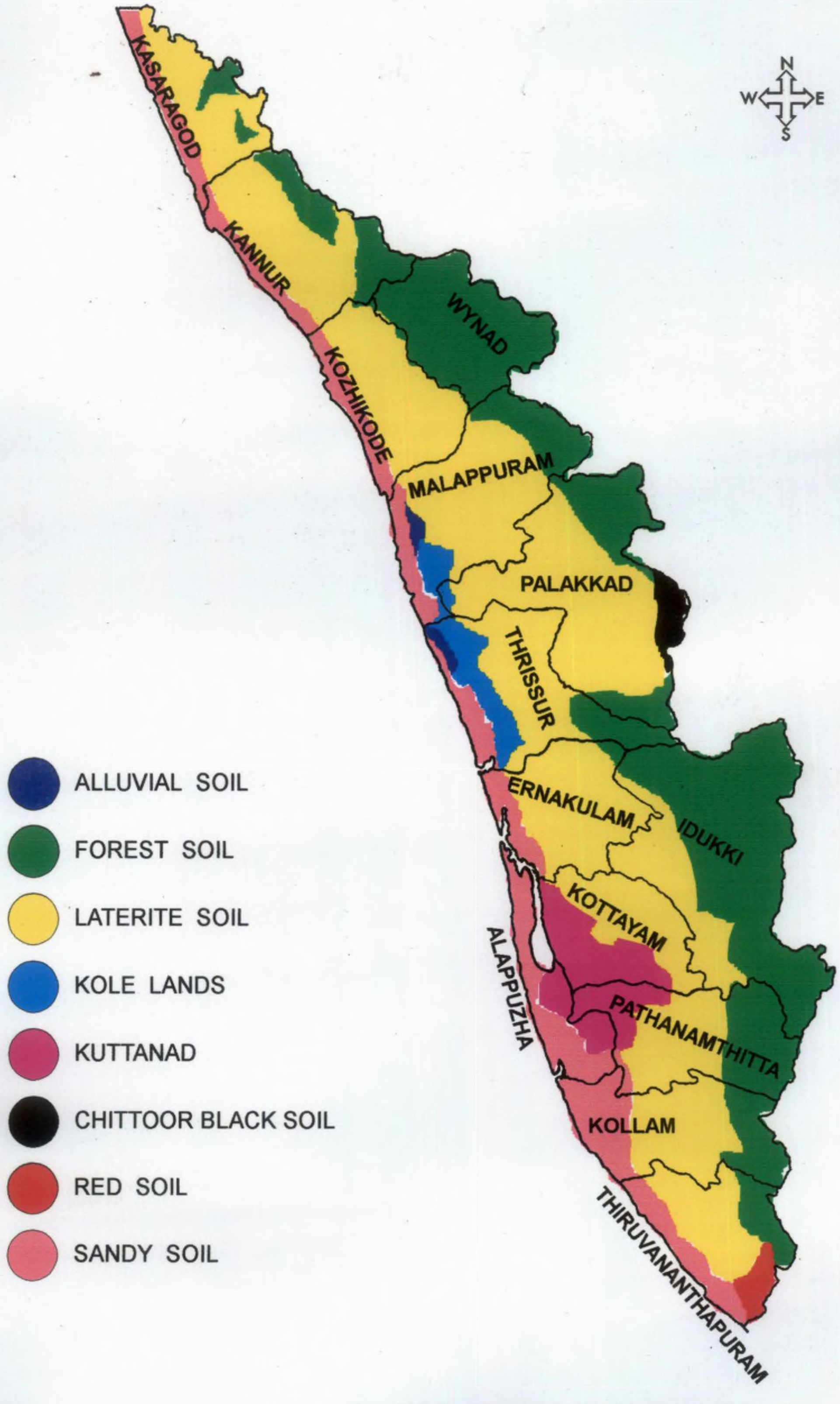


Fig. 3.3. SOIL MAP OF KERALA

Table 3.2 Basic experimental details

Experiment No.	Title	Design	No. of replication	Spacing	Plot size (sqm)	
					Gross	Net
III	Effect of crop management on iron absorption, nutrient balance and productivity of rice	Factorial RBD				
	[First crop (May-Sept.)]	"	3	15 cm x 10 cm	20.4 (5.1m x 4m)	16.2 (4.5m x 3.6m)
IV	Effect of crop management on iron absorption, nutrient balance and productivity of rice	"	3	15 cm x 10 cm	20.4 (5.1m x 4m)	16.2 (4.5m x 3.6m)
	[Second crop (Oct. - Feb.)]					
V	Effect of K, Ca and S management on nutrient balance, iron absorption and productivity of rice	"	3	15 cm x 10 cm	19.8 (4.9 m x 4m)	15.66 (4.35m x 3.6m)
VI	Modifying influences of silica and Zn on the nutrient balance, iron absorption and productivity of rice	"	3	15cm x 10cm	19.8 (4.9 m x 4m)	15.66 (4.35m x 3.6m)
VII	Maximum yield trial	"	2	15cm x 10cm	19.8 (4.9 m x 4m)	15.66 (4.35m x 3.6m)

Table 3.3 Details of treatments of the experiment

	Experiment III Kharif (Virippu) (May - Sept.)	Experiment IV Rabi (Mundakan) (Oct. - Feb.)	Experiment V	Experiment VI	Experiment VII
1. Treatments	*Method of establishment - 3*	*Method of establishment - 2*	*Potassium - 4*	*Silica - 4*	*Potassium - 2*
	1. Dry seeding (DSR) 2. Wet seeding (WSR) 3. Transplanting (TPR)	1. Wet seeding (WSR) 2. Transplanting (TPR)	1. 0 kg ha^{-1} (K_0) 2. 60 kg ha^{-1} (K_{60}) 3. 120 kg ha^{-1} (K_{120}) 4. 180 kg ha^{-1} (K_{180})	0, 250, 500 and 750 kg ha^{-1} (ie. Si_0, Si_{250}, Si_{500} and Si_{750} respectively)	0 and 120 kg ha^{-1} (K_0 and K_{120})
	Method of Land preparation - 2	*Method of land preparation - 2*	*Calcium - 2*	*Zinc - 4*	*Calcium - 2*
	1. Shallow digging - 15 cm (D_{15}) 2. Deep digging - 30 cm (D_{30})	1. Shallow digging - 15 cm (D_{15}) 2. Deep digging - 30 cm (D_{30})	1. 0 kg ha^{-1} (L_0) 2. 1/4 lime requirement - 150 kg ha^{-1} (L_{150})	0, 20, 40 and 60 kg ha^{-1} (ie. Zn_0, Zn_{20}, Zn_{40} and Zn_{60} respectively)	0 and 1/4 lime requirement (L_0 and L_{150})
	Application of organic manure - 3	*Application of organic manure - 3*	*Sulphur - 3*		*Silica - 2*
	0, 5 and 10 t ha^{-1} (ie. M_0, M_5 and M_{10} respectively)	1. 0 t ha^{-1} (M_0) 2. 5 t ha^{-1} (M_5) 3. 10 t ha^{-1} (M_{10})	0, 100 and 200 kg ha^{-1} (ie. S_0, S_{100} and S_{200} respectively)		0 and 250 kg ha^{-1} (Si_0 and Si_{250})
2. Total number of treatments	3x2x3 = 18	2x2x3 = 12	4x2x3 = 24	4x4 = 16	Moisture regimes - 2
3. Total number of plots	54	36	72	48	Continuous submergence (W_0) and irrigation at 3 days after disappearance of ponded water (W_1). (2x2x2x2)=32 64

Table 3.4 Sources of nutrient and its content

Nutrient	Source	Nutrient content (%)
Nitrogen	Urea	46
Phosphorus	Mussorie rock phosphate	22
Potassium	Muriate of potash	60
Calcium	$CaCo_3$	85
Sulphur	Elemental sulphur	90
Zinc	Zinc sulphate	20
Silica	Sodium silicate	45

2. `Kole' lands

The `kole' lands which forms the rice granary of Trichur and Malapuram districts comprise a unique ecosystem in Kerala. The texture of the soil varies, ranging from sandy loam to clay. Organic matter content of the upper layer varied from 2.07 to 4.16 per cent while in the sub surface it was 1.37 to 9.7 per cent and even go upto 28.91 to 69.9 per cent. Soils are in general acidic with pH ranging from 2.6 to 6.3 and EC varies from 0.16 to 15 ds m^{-1}. The CEC of the soil varied from 12.6 to 48.6 c mol kg^{-1}. The sedementary nature of the deposits indicates the presence of 2 : 1 type of clay.

3. Chittoor black soil

Located in patches in Chittoor taluk of Palghat district. The soil is balck in colour and is the extension of the black soils of Decan Plateau. The soils were sandy clay loam to sandy loam in texture with a pH ranging from 6.3 to 8.3. Organic carbon content ranged from 0.30 to 1.5 per cent. Soils are low to high in available N and P but low in available potassium. Calcium dominated among the exchangeable cations, saturating about 20 per cent of the exchange complex. CEC of the soil varied from 7.7 cmol kg^{-1} to 14.6 cmol kg^{-1}.

Experiment II

Cause and effect relationship of plant nutrient balance in the productivity of rice - *Pot culture study*

Soil samples from the above 36 locations were collected and rice raised in them. A surface soil sample (0-15 cm) in bulk were collected, dried and powdered and 20 kg soil was transferred into 30.0 cm dia pot, puddled thoroughly and 2 cm of water was maintained above the surface. Twenty two days old seedlings were planted in each pot and maintained 5 hills/pot. All the pots were manured uniformly.

3.5 Crop culture

General principles of lowland rice culture were followed in the management of all experiments. In all the experiments NPK fertilizers other than the treatments were applied as per the recommendations of KAU (KAU, 1993).

The experimental area was ploughed twice, allowed the weeds to decompose, puddled and levelled. The land was laid out as per designs of the individual experiments with strong bunds of 30 cm x 30 cm with an irrigation cum drainage channel of 30 cm width in between.

Seeds of the rice cv. `Jyothi' was obtained from the Regional Agricultural Research Station, Pattambi. Twenty to twenty five days old seedlings were transplanted from the nursery raised for the purpose.

In Experiment III, for dry sowing during *kharif* (*virippu*), the land was ploughed twice, harrowed and levelled and brought to a weed-free fine tilth. Viable seeds were dibbled at a spacing of 15 cm x 10 cm following a seed rate of 80 kg ha^{-1}. Thinning was done 30 days after seeding retaining 2-3 seedlings per hill. In wet seeding pre-germinated seeds were sown @ 80 kg ha^{-1} over a thin film of water in a well puddled and levelled field. The field was drained 24 hours after seeding. Water was again let in on the fifth day and the depth of water was gradually increased according to the plant growth.

In transplanted crop seedlings were raised in a dry nursery for First (*kharif*) and in a wet nursery for Second (*rabi*) crop. Seedlings of 20-25 days old were transplanted in a well puddled and levelled field at a spacing 15 cm x 10 cm @ 2-3 seedlings/hill.

A basal dose of farm yard manure @ 5 t ha^{-1} was applied in all the experimental plots uniformly before final ploughing and incorporated except in Experiment III and IV wherein organic manure was applied according to the technical programme. A uniform dose of 70:35:35 kg N - P_2O_5 - K_2O ha^{-1} (KAU, 1993) was applied to all the plots except in Experiment V and VII.

The entire phosphorus was applied basally, while two third N and half of K were applied basally and one-third N and half K at panicle initiation stage. In Experiment III, basal dose of N and K were applied 25 DAS in dry sown crop and 10 DAS in wet sown crop in Experiment III and IV.

In Experiment V and VII, K was applied as detailed in Table 3.3. Calcium and sulphur were applied basally in individual plots 10 days prior to planting and well incorporated by digging and levelling the plots.

In Experiment VI, zinc and silica were given on the same day of planting and well incorporated.

During First crop (virippu), the crop was raised as rainfed crop while in Second crop (mundakan) few irrigations were given at the later stages of crop growth. In Experiment VII, the crop was irrigated as per the technical programme.

All the experimental fields were hand weeded twice at 20 and 45 days after planting.

In all the experiments, Metacid was sprayed against rice bug. In Experiment III, Hinosan was sprayed against sheath blight in dry sown situation. No other plant protection measures were undertaken.

Date of sowing and harvesting in the various experiments are tabulated in Table 3.5.

Table 3.5 Sowing and harvesting dates of crops in the experiments

Experiment	Date of sowing/transplanting		Date of harvest	Duration (days)
	Nursery	Main field		
II Pot culture	08-06-95	30-06-95	10-10-95	122
III		09.05.96 (DSR)	20.09.96	134
		19.06.96 (WSR)	05.10.96	108
	10.06.96	04.07.96 (TPR)	05.10.96	117
IV	17.10.95	08.11.95 (TPR)	12.02.96	118
		08.11.95 (WSR)	29.02.96	113
V	08.06.95	30.06.95	11.10.95	123
VI	08.06.95	04.07.95	11.10.95	123
VII	09.10.96	01.11.96	02.02.97	112

TPR - Transplanted rice
WSR - Wet seeded rice
DSR - Dry seeded rice

Experimental crops were harvested when matured. Plants in two border rows on all sides of every plot were harvested and removed first. Net plots were harvested by cutting at the base. Threshing was done on the same day and wet yields were recorded. Moisture percentage of grain and straw were estimated. Dry weight of grain and straw were worked out and recorded at 14 per cent moisutre content.

3.8 Observations

I Plant

A. Biometric observations

i) Height of plants (cm) : At maximum tillering, panicle initiation, flowering and harvesting stage.

ii) Tiller count (Nos./hill) : -do-

iii) Dry matter production (kg ha^{-1}) : At maximum tillering, panicle initiation and harvest

iv) Productive tillers (No./hill) : At harvest

v) Length of panicle (cm) : -do-

vi) Branches per panicle (No.) : -do-

vii) No. of spikelets per panicle : -do-

viii) No. of filled grains per panicle : -do-

ix) No. of unfilled grains per panicle : -do-

x) Grain yield (kg/ha) : -do-

xi) Straw yield (kg/ha) : -do-

xii) Pest and disease incidence :

B. Physiological observations

i) Chlorophyll content : Chlorophyll content of index leaves was estimated colorimetrically in a Spectronic-20 Spectrophotometer (Yoshida *et al.*, 1972) at maximum tillering, panicle initiation and at 50 per cent flowering stage.

ii) Plant sap pH : Plant sap pH was estimated at maximum tillering, panicle initiation and 50 per cent flowering using a pH meter. A 1 : 2.5 leaf sample : water suspension was utilized (Jackson, 1958).

C. Chemical observations

Plant samples were dried in a hot air oven at 60°C ± 5°C, powdered well in a Wiley mill and analysed for nutrient contents by methods given in Table 3.6. Nutrient ratios were also worked out.

D. Other observations

i) Percentage of filled grains : Computed using number of filled grains and total number of grains per panicle

ii) Grain : Straw ratio : Computed from grain and straw yield

iii) Partitioning coefficient : Computed from grain yield and total dry matter accumulated at harvest.

iv) Volume : weight ratio of grains:

v) Nutrient uptake : Computed from nutrient content and dry matter accumulation

II Soil

Physico-chemical characteristics

Soil samples collected from 36 group farms and experimental plots were dried, powdered and passed through 2 mm sieve were used for analysing physico-chemical characteristics of the soil. The methods used for various analysis are given in Table 3.7.

Table 3.6 Methods used for plant chemical analysis

Sl. No.	Nutrient	Method	Reference
1	Nitrogen	Microkjeldhal method	Jackson, 1958
2	Phosphorus	Diacid extract estimated colorimetrically in a spectronic-20 spectrophotometer by Vanadomolybdophosphoric yellow colour method	Jackson, 1958
3	Potassium	Diacid extract method using a flame photometer	Jackson, 1958
4	Calcium	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
5	Magnesium	"	"
6	Sulphur	Turbidimetric method using spectronic-20 spectrophotometer	Hart, 1961
7	Iron	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
8	Manganese	"	"
9	Zinc	"	"
10	Copper	"	"
11	Silica	Gravimetric estimation on wet ashing in a muffle furnace	Yoshida *et al.*, 1972

Table 3.7 Methods used for soil physical and chemical analysis

(a) Physical analsysis

Sl. No.	Character	Method	Reference
1	Particle density	Keen-Raczkowski brass cup method	Piper, 1942
2	Bulk density	"	
3	Pore space	"	
4	Water holding capacity	"	
5	Mechanical composition of soil	International pipette method	Piper, 1942

(b) Chemical analsysis

Sl. No.	Character	Method	Reference
1	Soil reaction (pH)	Soil water suspension of 1 : 2.5 and read in a pH meter	Hesse, 1971
2	Electrical conductivity	"	Jackson, 1958
3	Organic carbon	Walkely-Black Method	Jackson, 1958
4	Total N	Microkjeldhal Method	Jackson, 1958
5	Total P	Nitric-perchloric acid digest extract (2 : 1) estimated colorimeterically in a spectronic-20 spectrophotometer by yellow colour method	Hesse, 1971
6	Total K	Diacid digest extract method using flame photometer	Hesse, 1971

Table 3.7 contd....

7	Total Ca	Diacid extract method using Atomic Absorption Spectrophotometer	Jackson, 1958
8	Total Mg	"	"
9	Total S	"	"
10	Total Fe	"	"
11	Total Mn	"	"
12	Total Zn	"	"
13	Total Cu	"	"
14	Available N	Alkaline permanganate method	Subbiah and Asija, 1956
15	Available P_2O_5	Ascorbic acid reduced molybdophosphoric blue color method	Watanabe and Olsen, 1965
16	Available K_2O	Neutral normal NH_4AC extract method using Flame photometer	Jackson, 1958
17	Exchangeable Ca	NN NH_4AC extract method using Atomic Absorption Spectrophotometry	Jackson, 1958
18	Exchangeable Mg	"	"
19	Available S	Turbidimetric method	Chesnin and Yien, 1951
20	Available Fe	DTPA extract method using Atomic Absorption Spectrophotometry	Lindsay and Vorvell, 1978
21	Available Mn	"	"
22	Available Zn	"	"
23	Available Cu	"	"

3.9 Statistical analysis

Sampling unit:

Ten hills per plot selected at random were used as observational plants for recording biometric observations and chemical analysis. Five other hills were separately selected and used for estimation of chlorophyll and leaf sap pH.

Statistical analysis was done as per design adopted in each experiment using the analysis of varience technique (Panse and Sukhatme, 1978).

In experiment VII each situation was considered as separate experiment in RBD and analysed accordingly. Yield and nutrient uptake were analysed as per hectare basis. Path coefficient and multiple regression analysis (Singh and Choudhary, 1977) were also done to work out the relationship between yield and yield attributes, nutrients and nutrient ratios and yield and weather parameters. MSTATC were used for computation.

Results

RESULTS

Yield as a biometric expression is a function of the metabolic processes regulated and mediated by nutritional elements as well as their interactions. Six experiments and a survey were conducted in the first and second crop seasons in sequence in the project entitled "Nutritional balance analysis for productivity improvement of rice in iron rich lateritic alluvium" at Agricultural Research Station, Mannuthy during 1995-1997. Variabilities serve to identify the cause and effect relationship in any process and as such variabilities induced by various treatment effects in the morphological, physiological and nutritional context through the various phases of rice growth has been presented. Variabilities in content of 11 elements as well as their balances were also studied and the results are presented below:

4.1. EXPERIMENT I

The experiment entitled "cause and effect relationship of plant nutrient balance in the productivity of rice" studied the direct and interactive influences of nutrients on growth and yield process of rice under different rice growing situations viz., laterite soil, `kole' land and Chittoor black soil to study the performance of rice in farmer's field.

4.1.1 Productivity of rice as influenced by different soil groups - Farmer's field

Data on the yield of grain and straw recorded in the 36 farmer's plots is presented in Table 4.1.1 and Fig. 4.1.1, 4.1.2, 4.1.3 and 4.1.4. It may be seen that the yield of grain and straw ranged between 2800 to 9000 kg and 3100 to 13000 kg ha^{-1} respectively across the 36 plots distributed at the rate of 12 each in laterite, `kole' lands and black soils. Soilwise variations for grain was 2860 to 8200 kg ha^{-1} for laterite,

Table 4.1.1 Grain and straw yield of rice-farmer's field

Locations	Grain yield kg ha^{-1}			Straw yield kg ha^{-1}		
	Laterite soil	Kole land	Chittoor black soil	Laterite soil	Kole land	Chittoor black soil
1	8200	6250	5000	7000	7500	9000
2	7000	6250	5500	9000	7500	10000
3	7500	7500	6125	7500	5000	9000
4	5250	5000	7000	6000	5500	12000
5	6000	5000	4500	5000	5500	7000
6	3000	4500	5750	4000	5000	10000
7	3750	5000	6625	5000	5000	13000
8	4680	5500	9000	4200	5000	11500
9	3980	5000	6000	3600	6500	8500
10	3640	5500	5500	3700	6000	9000
11	3215	6250	5375	3100	5000	10000
12	2860	4500	6500	3210	6000	10000
Mean	4923	5521	6073	5109	5792	9917
Yield range	2860-8200	4500-7500	4500-9000	3100-9000	5000-7500	7000-13000

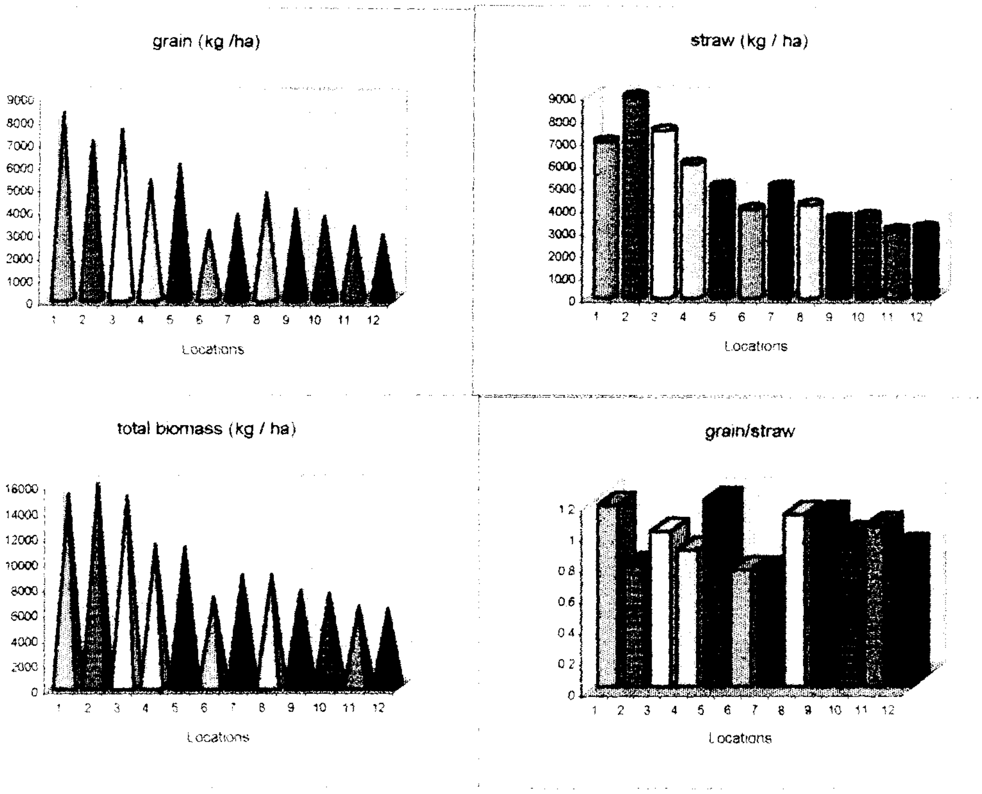


Fig. 4.1.1 Influence of locations on grain, straw and total biomass yield and grain / straw in laterite soil - farmer's field sample

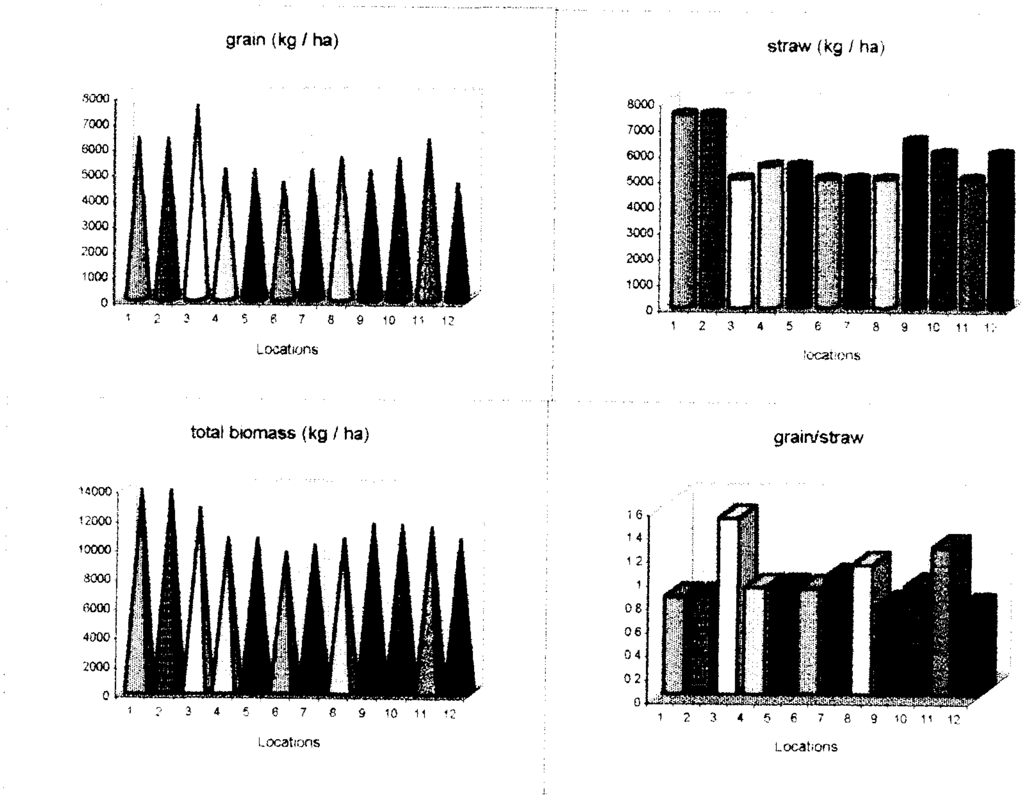


Fig.4.1.2 Influence of locations on grain, straw and total biomass yield and grain / straw in "Kole" land - farmer's field sample

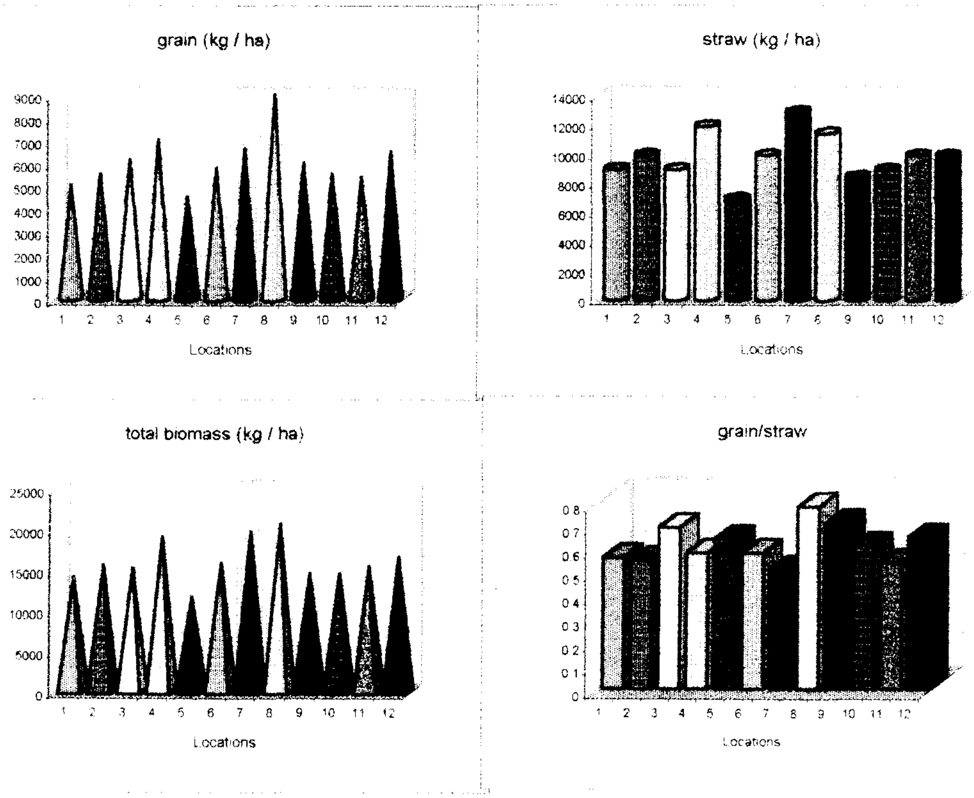


Fig. 4.1.3 Influence of locations on grain, straw and total biomass yield and grain / straw in Chittoor black soil - farmer's field sample

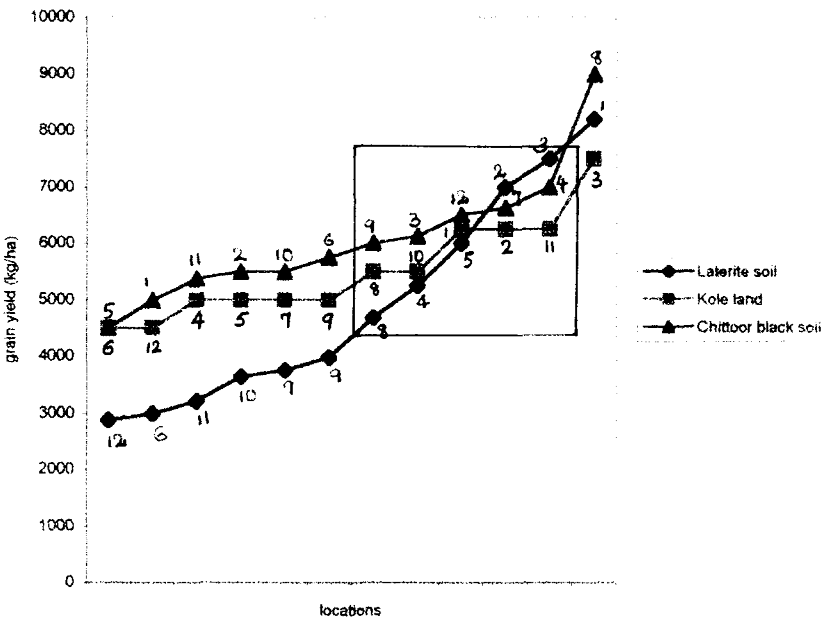


Fig. 4.1.4 Influence of soil situations on grain yield of rice - farmer's field

4500 to 7500 kg ha^{-1} for `kole' lands and 4500 to 9000 kg ha^{-1} for black soils. Corresponding variations for straw were 3100 to 9000 kg, 5000 to 7500 kg and 7000 to 13000 kg ha^{-1} respectively.

A closer perusal of the data showed that the variations were widest in laterite soils and narrowest for `kole' lands.

4.1.2 Nutritional situation as influenced by soil groups

Data on minimum level of individual nutrient element in the leaf at PI stage in the farmers plots as well as the minimum individual levels of the element to produce a yield over 7000 kg ha^{-1} presented in Table 4.1.2. showed that the crop in all the plots had more than the minimal level of major nutrients. Mean contents of nutrients in the plant in laterite soils had a marginal deficiency of Ca and Mg but had excess levels of S and other micronutrients. `Kole' land plants showed a deficiency of Ca though the other elements were in excess. Plants in the black soils showed the least level of micro-elements but maximum amount of Ca. Results showed that deficiency of elements or individual level was not the cause of low yield in any of these soils.

4.1.3 Physical characteristics of the soil groups

Data (Table 4.1.3) showed black soils alone to be near neutral to alkaline. Laterite soils showed wider variations than `kole' soils with a range of 3.58 to 6.11 as against 4.63 to 6.67 in `kole' soils. `Kole' soils showed lowest electrical conductivity. Data on mechanical composition of `kole' land soil recorded mean higher values of silt and clay and lower levels of sand. Laterite and black soils were similar and recorded a very high proportion of sand.

4.1.4 Chemical properties of soil groups

The range of available and total contents of nutrient elements studied are presented in Table 4.1.4. A perusal of the data on the range of available quantities of

Table 4.1.2 Nutritional situation in the field and rice productivity

Leaf nutrient composition at PI stage - Farmer's field

Elements	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Minimum level for >7000 kg grain ha^{-1}	1.66	0.1	1.60	0.04	0.09	1608	325	254	21	5

Minimum nutrient level in the leaf at PI stage

Laterite soil	1.98	0.15	1.60	0.04	0.07	1739	400	187	23	5
Kole land	1.58	0.21	1.55	0.04	0.09	1824	344	368	24	3
Chittoor black soil	1.75	0.10	1.60	0.15	0.09	1314	311	152	17	3

Yield range : 2860 - 9000 kg ha^{-1}

Table 4.1.3 Range of physical characteristics of soil groups - Farmer's field

Characters	Laterite soil	Kole lands	Chittoor black soil
pH	3.58 - 6.11	4.63 - 6.67	6.44 - 7.82
Electrical conductivity (dsm^{-1})	0.10 - 0.98	0.23 - 1.05	0.10 - 0.84
Particle density (g cc^{-1})	2.3 - 2.6	2.1 - 2.50	2.28 - 2.69
Bulk density (g cc^{-1})	1.18 - 1.49	1.11 - 1.34	1.25 - 1.61
Water holding capacity (%)	28.4 - 42.4	43.6 - 53.7	26.5 - 46.04
Porosity (%)	38.9 - 49.7	48.7 - 64.0	41.4 - 48.6
Mechanical composition			
Sand (%)	69.4 - 87.3	43.9 - 80.7	76.0 - 85.7
Silt (%)	0.32 - 11.5	1.86 - 27.0	1.26 - 7.1
Clay (%)	10.3 - 19.4	10.5 - 24.2	10.2 - 18.6

Table 4.1.4 Range of chemical properties of soil groups - Farmers field

Properties	Laterite soil	Kole lands	Chittoor black soil
Available nutrients			
N (kg ha^{-1})	806 - 2800	1882 - 4838	381 - 1344
P (kg ha^{-1})	3.7 - 18.6	2.14 - 4.14	1.8 - 14.0
K (kg ha^{-1})	85.0 - 139.0	94.1 - 152.3	80.6 - 108.0
Ca (kg ha^{-1})	51.3 - 237.5	98.8 - 362.5	197.5 - 1963.0
Mg (kg ha^{-1})	30.0 - 421.3	78.8 - 313.8	275.0 - 673.0
S (kg ha^{-1})	87.9 - 879.0	366.1 - 1069	103.0 - 248.9
Fe (kg ha^{-1})	604 - 1498	372 - 2401	260 - 858
Mn (kg ha^{-1})	29.1 - 152.3	24.6 - 197.0	85.1 - 587.0
Zn (ppm)	1.00 - 2.32	0.92 - 3.6	0.52 - 1.84
Cu (ppm)	2.0 - 13.8	4.04 - 8.5	3.0 - 6.1
Total nutrients			
OC (%)	0.39 - 1.48	1.24 - 2.69	0.36 - 1.28
P (kg ha^{-1})	2692 - 9090	6575 - 12457	3703 - 9426
K (kg ha^{-1})	986 - 2330	1332 - 6660	627 - 1837
Ca (kg ha^{-1})	268 - 1436	436 - 1286	1422 - 5600
Mg (kg ha^{-1})	524 - 1615	1418 - 9960	739 - 1579
S (kg ha^{-1})	102 - 838	395 - 1069	102 - 425
Fe (kg ha^{-1})	605 - 1722	372 - 2401	305 - 858
Mn (kg ha^{-1})	29 - 152	25.0 - 273.3	85.1 - 586.9
Zn (kg ha^{-1})	1.0 - 2.32	0.92 - 3.6	0.52 - 2.36
Cu (kg ha^{-1})	2.2 - 13.8	4.2 - 8.2	2.5 - 6.08

nutrients will show that laterite soils recorded mean higher and lower values of N, P and K, black soils recorded mean higher and lower values of Ca and Mg and `kole' land soils showed mean lower and higher values of S. `Kole' land soils also recorded the highest value of Fe while highest value of the Mn was recorded in black soils and Cu in laterite soils.

The data on total nutrient status of the soil groups showed that `kole' lands had mean higher value and range of N, P, K, Mg, S and Fe. Black soils had higher values of Ca and Mn.

4.1.5 Influence of soil groups on range of plant nutrient content in different parts of rice

4.1.5.1 Root nutrient contents

Highest mean nutrient content of K, S, Fe and Mn was recorded in `kole' land and Ca and Mg in black soils. Highest values of Zn and Cu were recorded in laterite soils (Table 4.1.5). `Kole' land soils had the lowest root N content.

4.1.5.2 Culm nutrient contents

As against the content in the root, highest values of N, P, K and Fe were recorded in kole lands and Mn in black soils. Zinc and Cu contents were lowest in the culm of the plants in black soils (Table 4.1.5).

4.1.5.3 Leaf nutrient contents

Data on the leaf nutrient contents at PI stage (Table 4.1.5) showed that plants in the laterite soils recorded the highest contents of K, Mg, S, Fe, Mn and Cu and mean Ca and Mg contents were in plants in the black soils. Comparison of lowest values of the elements showed that N, K, S and Fe were higher in laterite soils. Phosphorus and Mn were higher in plants of `kole' land soils and Ca in plants grown in black soils.

Table 4.1.5 Range of plant nutrient content in different parts of rice at PI stage - Farmer's field

	Soil groups								
	Root			Culm			Leaf		
	Laterite	Kole land	Chittoor black	Laterite	Kole land	Chittoor black	Laterite	Kole land	Chittoor black
N (%)	1.05 - 1.84	0.35 - 1.05	0.88 - 1.84	0.88 - 1.75	0.61 - 2.45	0.79 - 1.93	1.98 - 3.68	1.23 - 3.40	1.75 - 4.29
P (%)	0.13 - 0.30	0.13 - 0.28	0.15 - 0.28	0.11 - 0.35	0.17 - 0.37	0.14 - 0.31	0.15 - 0.28	0.21 - 0.31	0.10 - 0.27
K (%)	0.3 - 1.3	0.7 - 1.50	0.45 - 1.20	1.60 - 4.5	1.55 - 3.8	1.75 - 3.65	1.60 - 3.4	1.55 - 2.80	1.60 - 2.45
Ca (%)	0.02 - 0.052	0.014 - 0.098	0.066 - 0.673	0.017 - 0.051	0.013 - 0.022	0.012 - 0.26	0.042 - 0.297	0.044 - 0.25	0.15 - 0.69
Mg(%)	0.03 - 0.12	0.044 - 0.14	0.09 - 0.63	0.06 - 0.11	0.08 - 0.11	0.06 - 0.18	0.07 - 0.27	0.09 - 0.15	0.09 - 0.24
S (ppm)	1850 - 4498	3040 - 5178	2739 - 4825	1399 - 2105	1844 - 2334	1386 - 2347	1739 - 3086	1634 - 3007	1314 - 2210
Fe (ppm)	18700 - 53275	33275 - 84725	23175 - 69925	400 - 1681	379 - 2070	395 - 1822	400 - 2111	344 - 914	311 - 1331
Mn (ppm)	89 - 642	187 - 1045	156 - 573	193 - 686	349 - 898	204 - 1147	187 - 981	272 - 782	152 - 593
Zn (ppm)	33 - 106	39 - 87	36 - 96	30 - 71	27 - 70	19 - 31	23 - 33	24 - 34	17 - 27
Cu (ppm)	11 - 94	10 - 73	15 - 33	2 - 10	2 - 6	2 - 5	5 - 10	3 - 9	3 - 7

4.1.6 Interrelation of rice yield with available and total nutrient content of the soil

4.1.6.1 Interrelation of available soil nutrients with yields of rice

The data presented in Table 4.1.6 . showed significant positive or negative relationship of available soil nutrients with yields of rice. Grain yield was not significantly related with the available nutrients. Except N and Ca content all other elements showed a negative relation with yield. Straw yield and total biomass were positively related with available Ca and Mn content of the soil. Significant negative correlation was observed between straw yield and N, K and Fe content of the soil.

4.1.6.2 Interrelation of total nutrient content of soil with yield of rice

The data presented in Table 4.1.6. showed that as in the case of available nutrients, grain yield was not significantly correlated with the total nutrient content of soil. Almost all the elements showed a positive relation with grain yield except in the case of total Fe content which was negatively related with yield.

Straw yield and total biomass production were significantly related with total nutrient content. A significant positive correlation was obtained between Ca, Mg, S and Mn content with straw and total biomass and Fe and Zn recorded a significant negative relation with these factors.

4.1.7 Correlation between nutrient content of rice in farmer's field and yields of rice

4.1.7.1. Root nutrient content with yields of rice

The data on nutrient content of rice root with yields of rice is presented in Table 4.1.7.

Table 4.1.6 Inter-relations of available and total elemental composition of soil with yield of rice

Elemental composition		Grain yield	Straw yield	Total biomass
Available	N	0.013	-0.399*	-0.273
	P	-0.197	0.110	0.003
	K	-0.122	-0.386*	-0.321
	Ca	0.223	0.660**	0.560**
	Mg	-0.303	-0.177	-0.242
	S	0.159	-0.117	-0.023
	Fe	-0.120	-0.351**	-0.296
	Mn	0.123	0.452**	0.369*
	Zn	-0.144	-0.349**	-0.304
	Cu	-0.035	-0.295	-0.197
Total				
	Oc	0.074	-0.263	-0.159
	P	0.325	0.098	0.194
	K	0.170	-0.309	-0.155
	Ca	0.228	0.628**	0.535**
	Mg	0.170	0.590**	0.486**
	S	0.251	0.707**	0.600**
	Fe	-0.004	-0.349*	-0.251
	Mn	0.129	0.395**	0.331**
	Zn	0.017	-0.346**	-0.240
	Cu	0.090	-0.304	-0.183

Table 4.1.7 Correlation coefficients of root nutrient content and yield of rice - Farmer's field

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Yield
N	1.000										
P	0.144	1.000									
K	-0.234	0.129	1.000								
Ca	0.279	0.142	-0.034	1.000							
Mg	0.257	0.176	-0.041	0.978**	1.000						
S	-0.304	0.174	0.563**	0.160	0.151	1.000					
Fe	-0.216	0.253	0.293	-0.203	-0.214	0.001	1.000				
Mn	-0.292	0.111	0.083	-0.072	-0.091	0.392**	0.102	1.000			
Zn	-0.155	-0.036	0.295	-0.106	-0.119	0.283	-0.001	-0.066	1.000		
Cu	-0.137	0.038	0.002	-0.231	-0.138	0.061	-0.046	-0.219	0.540**	1.000	
Grain yield	0.027	0.176	0.334**	0.181	0.229	0.477**	-0.313	0.148	0.454**	0.292	1.000
Straw yield	0.374	0.185	0.154	0.471**	0.501*	0.372*	-0.315*	0.010	0.088	0.015	1.000
Total biomass	0.277	0.199	0.237	0.405**	0.445*	0.447*	-0.344*	0.063	0.236	0.123	1.000

Pooled analysis of the data on nutrient content of rice under three situations showed that the content of each element in the plant is highly correlated with the presence of other elements. Calcium content of root had a significant positive correlation with Mg content, K related with S, S related with Mg and Zn was related with Cu content.

Significant positive correlation was obtained in grain yield with K, Ca, Mg, S and Zn content of root. Straw yield was positively related with Ca and Mg content and the relation with Fe was negative in both cases.

4.1.7.2 Culm nutrient content and yields of rice

The data are presented in Table 4.1.8. It was observed that P content was positively related with Ca and Fe content; K was related with Cu; Ca with Mg and Fe positively and negatively with S and Zn; Mg had a negative relation with Zn and Mn with Cu content and the relations were significant.

Grain yield was significantly correlated only with Mg content of leaf. Straw yield and total biomass were positively related with Ca and Mg content and the relation was negative with P and Zn content of culm at PI and the relations were highly significant.

4.1.7.3 Leaf nutrient content and yield of rice

From the data presented in Table 4.1.9. it was observed that the content of elements in leaf was highly related with the content of other elements. Phosphorus was negatively related with Ca; calcium was positively related with Mg and negatively with S, Zn and Cu; S was positively related with Zn and Cu content; Iron was positively related with Zn and Zn content was highly correlated with Cu content of leaf.

Table 4.1.8 Inter-relation of culm nutrient content and yield - Farmer's field

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Yield
N	1.000										
P	0.011	1.000									
K	0.022	0.049	1.000								
Ca	0.240	-0.364**	-0.139	1.000							
Mg	0.193	-0.121	0.007	0.723**	1.000						
S	-0.197	0.227	0.229	-0.334*	-0.012	1.000					
Fe	-0.018	-0.315*	0.244	0.450**	0.300	-0.044	1.000				
Mn	-0.069	0.115	0.088	-0.082	0.073	0.304	0.218	1.000			
Zn	-0.015	0.298	0.144	-0.438*	-0.343*	0.293	-0.085	0.315	1.000		
Cu	0.042	0.085	0.489**	-0.002	0.056	0.230	0.201	0.353**	0.291	1.000	
Grain yield	0.162	-0.241	0.040	0.305	0.335*	-0.036	0.005	0.041	-0.1000	0.119	1.000
Straw yield	0.202	-0.319*	0.052	0.626**	0.628**	-0.124	0.216	-0.030	-0.484**	0.037	1.000
Total biomass	0.205	-0.320*	0.053	0.563**	0.573**	-0.102	0.156	-0.006	-0.383*	0.072	1.000

Table 4.1.9 Inter-relation of leaf nutrient content and yield of rice - Farme'r field

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Yield
N	1.000										
P	-0.290	1.000									
K	-0.222	0.298	1.000								
Ca	0.221	-0.325*	-0.104	1.000							
Mg	-0.045	-0.205	0.131	0.642**	1.000						
S	0.014	0.168	0.104	-0.384*	0.076	1.000					
Fe	0.294	-0.064	-0.201	0.032	0.017	0.215	1.000				
Mn	-0.073	-0.135	-0.113	-0.092	0.111	0.152	0.204	1.000			
Zn	-0.166	0.293*	0.095	-0.609**	-0.117	0.586**	0.246**	0.225	1.000		
Cu	0.121	-0.037	0.008	-0.393*	-0.159	0.446**	0.089	0.106	0.456**	1.000	
Grain yield	0.277	-0.377*	-0.236	0.355*	0.194	-0.111	-0.175	-0.189	-0.377*	0.083	1.000
Straw yield	0.218	-0.322*	-0.319*	0.619**	0.268	-0.425**	-0.050	-0.308	-0.636**	-0.289	1.000
Total biomass	0.261	-0.380*	-0.318*	0.577**	0.265	-0.347*	-0.102	-0.292	-0.957**	-0.238	1.000

Grain yield was significantly correlated with Ca, P and Zn content and the relationship was positive with Ca and negative with the others.

As in the case of root and culm, grain yield and total biomass recorded a significant positive correlation with Ca. The correlation of P, K, S, Fe, Mn, Zn and Cu were negative and were highly significant (except for Fe and Cu) with straw and total biomass yield.

4.1.8 Interrelation of nutrient content and yield under different rice growing situations

The data on correlation of rice yields with nutrient content of root, culm and leaf are presented in Table 4.1.10.

A perusal of the data revealed that behaviour of plant nutrient content in influencing the yield of rice varied with the situations.

4.1.8.1 Laterite soil

It may be seen that the relation of rice yields with nutrients content of rice root was positively related with all elements except N and Fe. Grain yield showed a significant positive correlation with Mg, S and Cu contents. Significant positive correlation was obtained between straw yield and Mg, Zn and Cu. Total biomass was positively related with Mg, S, Zn and Cu. The relation of Fe was negative with the yields.

No significant correlation was observed between culm and leaf nutrient contents and yields of rice.

4.1.8.2 `Kole' land

In `kole' land, the relation of nutrient content of rice root with grain yield was exactly the reverse of that observed in laterite soil. Grain yield showed a significant

Table 4.1.10 Correlation coefficient of plant nutrient content and yield under different soil groups - Farmers field

		Laterite soil			Kole land			Chittoor black soil		
		Grain yield	Straw yield	Total biomass	Grain yield	Sstraw yield	Total biomass	Grain yield	Straw yield	Total biomass
Root	N	-0.168	-0.126	-0.151	0.367	0.546	0.607**	-0.032	0.115	0.059
	P	0.460	0.292	0.388	-0.088	-0.086	-0.155	-0.285	-0.350	-0.350
	K	0.257	0.086	0.176	0.129	0.351	0.321	0.658**	0.451	0.583**
	Cu	0.122	0.075	0.101	0.038	-0.456	-0.286	-0.004	-0.096	-0.063
	Mg	0.837**	0.856**	0.874**	0.151	-0.403	-0.177	-0.099	-0.114	-0.136
	S	0.585**	0.486	0.552	-0.039	0.337	0.204	0.561**	0.495	0.567**
	Fe	-0.585**	-0.561**	-0.592**	0.135	0.101	0.156	-0.650**	-0.681**	-0.725**
	Mn	0.374	0.173	0.626**	-0.180	-0.145	-0.215	0.044	-0.172	-0.089
	Zn	0.512	0.719**	0.893**	0.612**	0.220	0.543	0.731**	0.504	0.650**
	Cu	0.848**	0.881**	0.437	-0.216	0.125	-0.054	-0.468	0.361	-0.394
Culm at PI										
	N	0.361	0.484	0.437	-0.037	0.085	0.034	0.310	0.072	0.185
	P	0.041	0.152	0.100	-0.080	-0.520	-0.405	-0.645**	-0.459	-0.587
	K	0.107	0.345	0.236	-0.052	0.677**	0.494	0.190	0.283	0.266
	Ca	-0.125	-0.270	-0.204	0.030	0.344	0.263	0.413	0.399	0.440
	Mg	0.496	0.438	0.484	0.049	0.127	0.118	0.085	0.348	0.260
	S	0.223	0.330	0.286	-0.243	0.182	-0.038	-0.178	0.371	0.156
	Fe	-0.266	-0.098	-0.188	0.420	0.897**	0.880**	-0.081	0.106	0.031
	Mn	0.426	0.558*	0.508	-0.019	0.153	0.091	-0.473	-0.434	-0.489
	Zn	0.181	0.390	0.296	0.429	-0.115	0.197	-0.323	0.101	-0.081
	Cu	0.336	0.516	0.441	0.037	0.153	0.128	0.249	0.450	0.398
Leaf at PI										
	N	0.206	0.148	0.183	0.189	0.516	0.472	-0.619**	0.148	0.373
	P	-0.258	-0.215	-0.244	-0.036	-0.059	-0.063	-0.558**	-0.062	-0.288
	K	-0.033	-0.311	-0.179	-0.307	-0.133	-0.289	-0.407	-0.482	-0.490
	Ca	0.240	0.074	0.161	-0.031	0.190	0.109	0.388	0.397	0.427
	Mg	0.366	0.098	0.197	-0.117	0.127	0.011	0.048	0.146	0.114
	S	0.124	0.019	0.073	0.208	0.185	0.259	-0.023	-0.006	-0.016
	Fe	-0.180	0.153	-0.012	-0.172	0.126	-0.025	0.114	-0.076	0.003
	Mn	-0.107	-0.158	-0.137	-0.285	0.293	0.016	-0.144	-0.019	-0.076
	Zn	-0.375	-0.243	-0.319	-0.268	0.024	-0.156	0.104	0.112	0.118
	Cu	0.352	0.250	0.311	0.052	0.017	0.045	-0.172	-0.122	-0.155

positive correlation with Zn content and straw yield with N content only. Total biomass was significantly related with these two elements.

Differential response was observed between yields of rice and nutrient content of culm and leaf. The data revealed a significant positive correlation between straw yield and K and Fe contents, and total biomass and Fe content.

Grain yield was not significantly related with the nutrient contents though the relations were negative.

4.1.8.3 Chittoor black soil

A perusal of the data further revealed that grain and straw yields and the total biomass were positively correlated with K, S and Zn contents of roots and negatively with other elements. Similar was the relationship with straw and total biomass yield. In straw the relation was significant only with Fe while in total biomass the relation was significant and positive with K, S and Zn and negative with Fe content.

It may be observed that grain yield was negatively related with culm P content and negatively related with leaf N and P content and the influence was highly significant. Other elements did not have any significant relation with the yields.

4.1.9 Direct and indirect effect of elements on crop productivity

Data on the direct and indirect influences of elements on yield of grain, straw and total biomass are presented in Table 4.1.10.

The results showed that residue value had been very high in the case of grain, straw and total biomass which showed that the influence of individual elements as such and by themselves is unreliable and should not be taken as a method to evaluate nutritional relations to productivity.

Table 4.1.11 Path coefficient - available soil nutrients with grain and straw yield and total biomass - Farmer's field

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Residue
Grain											
N	0.045	0.0018	-0.0049	-0.106	0.021	0.185	-0.032	0.013	-0.151	0.043	
P	-0.021	-0.0038	0.0006	0.048	-0.143	-0.135	0.020	-0.007	0.073	-0.030	
K	0.016	0.0002	-0.0136	-0.065	-0.045	0.028	-0.019	0.005	-0.044	0.016	
Ca	-0.017	-0.0006	0.0031	0.286	0.014	-0.103	0.029	-0.024	0.083	-0.048	
Mg	-0.003	-0.0020	-0.0021	-0.015	-0.276	-0.056	0.011	0.003	0.012	0.024	
S	0.028	0.0017	-0.0013	-0.099	0.052	0.298	-0.020	0.008	-0.143	0.036	
Fe	0.021	0.0011	-0.0038	-0.120	0.044	0.087	-0.069	0.018	-0.162	0.064	
Mn	-0.015	-0.0006	0.0019	0.182	0.020	-0.066	0.032	-0.038	0.085	-0.079	
Zn	0.025	0.0010	-0.0022	-0.087	0.012	0.155	-0.040	0.012	-0.274	0.055	
Cu	0.011	0.0006	-0.0012	-0.079	-0.038	0.060	-0.025	0.017	-0.086	0.175	0.753
Straw											
N	-0.202	-0.034	-0.064	-0.238	0.006	0.228	0.057	0.015	-0.137	-0.022	
P	0.094	0.073	0.007	0.107	-0.042	-0.167	-0.036	-0.008	0.066	0.015	
K	-0.072	-0.003	-0.198	-0.146	-0.013	0.034	0.035	0.006	-0.040	-0.008	
Ca	0.075	0.012	0.041	0.641	0.004	-0.128	-0.052	-0.028	0.075	0.025	

Contd....

Table 4.1.11 contd...

Mg	0.015	0.038	-0.029	-0.033	-0.082	-0.069	-0.020	0.003	0.011	-0.012	
S	-0.125	-0.033	-0.017	-0.223	0.015	0.367	0.036	0.010	-0.130	-0.018	
Fe	-0.094	-0.022	-0.051	-0.270	0.013	0.108	0.123	0.021	-0.147	-0.033	
Mn	0.067	0.013	0.025	0.407	0.006	-0.081	-0.057	-0.045	0.077	0.041	
Zn	-0.111	-0.019	-0.029	-0.195	0.004	0.191	0.072	0.014	-0.249	-0.028	
Cu	-0.050	-0.013	-0.016	-0.177	0.011	0.075	0.045	0.020	-0.078	-0.090	0.396
Total biomass											
N	-0.127	-0.025	-0.048	-0.210	0.012	0.233	0.028	0.015	-0.155	0.001	
P	0.059	0.050	0.006	0.095	-0.082	-0.170	-0.018	-0.008	0.075	-0.001	
K	-0.046	-0.002	-0.132	-0.129	-0.027	0.035	0.017	0.006	-0.045	0.0003	
Ca	0.047	0.008	0.030	0.566	0.009	-0.130	-0.026	-0.029	0.085	-0.001	
Mg	0.010	0.026	-0.022	-0.029	-0.163	-0.070	-0.010	0.003	0.013	0.0004	
S	-0.018	-0.023	-0.012	-0.197	0.031	0.375	0.018	0.010	-0.147	0.0010	
Fe	-0.061	-0.015	-0.038	-0.238	0.026	0.110	0.061	0.021	-0.166	0.0010	
Mn	-0.028	0.009	0.018	0.360	0.012	-0.083	-0.028	-0.046	0.087	-0.0013	
Zn	0.036	-0.013	-0.021	-0.172	0.007	0.196	0.036	0.014	-0.282	0.0009	
Cu	0.022	-0.009	-0.012	-0.156	-0.023	0.076	0.022	0.021	-0.088	0.003	0.525

4.2 EXPERIMENT II

The experiment entitled "cause and effect relationship of plant nutrient balance on the productivity of rice" - A pot culture study - studied the information on relative nutrient relations in the three soil plant systems and their potential capabilities and weaknesses in relation to rice productivity.

4.2.1 Grain and straw yield of rice as influenced by soil situations

Data on the yield of grain and straw are presented in Table 4.2.1 and Fig. 4.2.1, 4.2.2 and 4.2.3. It can be seen that the yield of grain and straw manifested extreme variations within and across the soil types. Thus grain yield varied between 58.1 and 142.1 g and the straw varied from 88.0 to 120.8 g per pot in laterite soil. The respective range of variation in grain and straw worked out to 144.5 and 47.5 per cent. Corresponding range of variation in grain and straw in `kole' lands were 164.8 and 75.0 and in black soils 166.0 and 84.6 per cent.

Data on the range of growth and yield attributes presented in Table 4.2.2 indicated extreme variability and range in all the attributes. Progressive variation in tiller counts in the lower range varied from 6.2 to 14.3 and in the high range from 15.2 to 27.3 in the laterite soil. Corresponding figures for `kole' lands and black soils were 6.0 to 12.0 and 23.0 to 30.4 as well as 5.6 to 8.7 and 21.7 to 23.3 respectively.

Among the yield attributes panicle weight showed the maximum extent of 150 per cent variation in laterite soil and panicles per hill 38.5 per cent variation. As against this the corresponding variations were 147.9 and 164.4 per cent in `kole' lands and 70.3 and 200 per cent in black soils. Similar was the variation in thousand grain weight also.

Table 4.2.1 Grain and straw yield of rice - Pot culture study

Locations	Grain yield g pot^{-1}			Straw yield g pot^{-1}		
	Laterite soil	Kole land	Chittoor black soil	Laterite soil	Kole land	Chittoor black soil
1	141.4	119.5	63.0	110.0	118.8	79.2
2	128.2	115.1	89.6	118.8	118.8	79.2
3	142.1	50.6	118.2	110.0	83.6	88.0
4	120.0	52.0	122.8	123.2	92.4	105.6
5	125.6	93.2	57.1	123.2	123.2	57.2
6	104.3	59.7	92.5	88.0	74.8	79.2
7	114.5	59.9	107.1	110.0	70.4	70.4
8	109.9	116.7	151.9	101.2	136.4	101.2
9	107.3	113.5	116.8	96.8	96.8	88.0
10	119.5	82.0	84.6	123.8	123.2	101.2
11	82.6	79.4	71.0	88.0	101.2	79.2
12	58.1	134.0	116.6	129.8	114.4	88.0

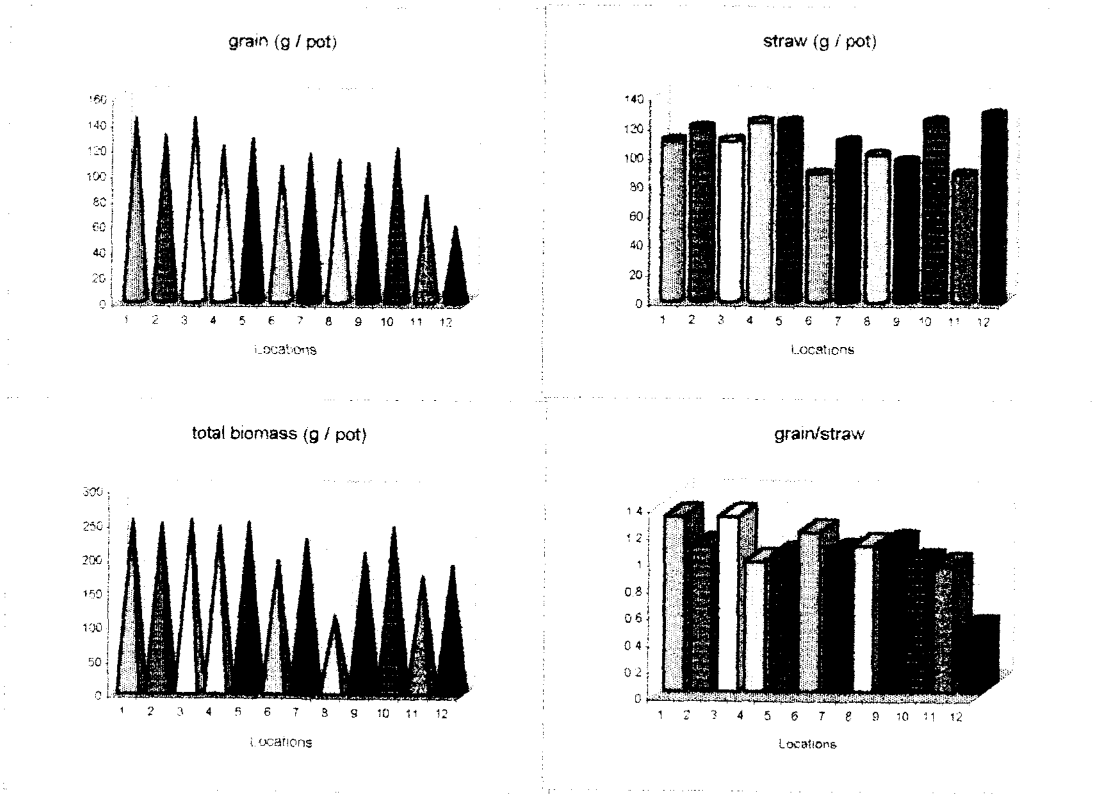


Fig.4.2.1 Influence of locations on grain, straw and total biomass yield and grain / straw in laterite soil - pot culture study

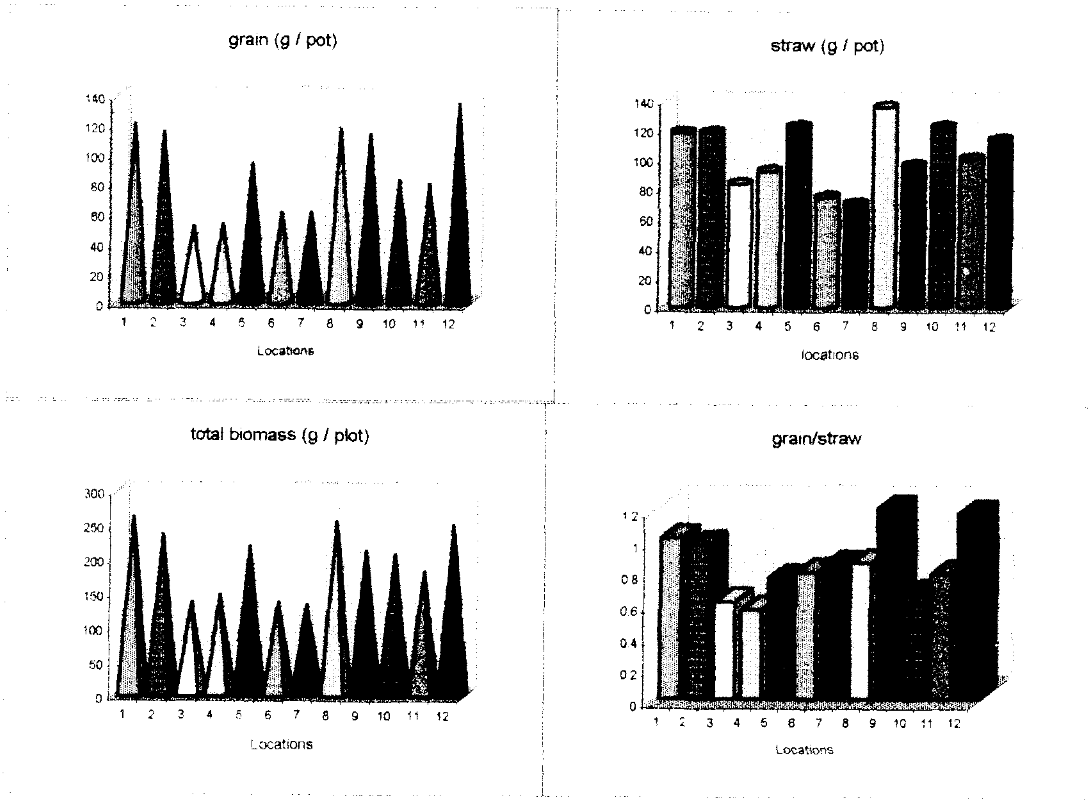
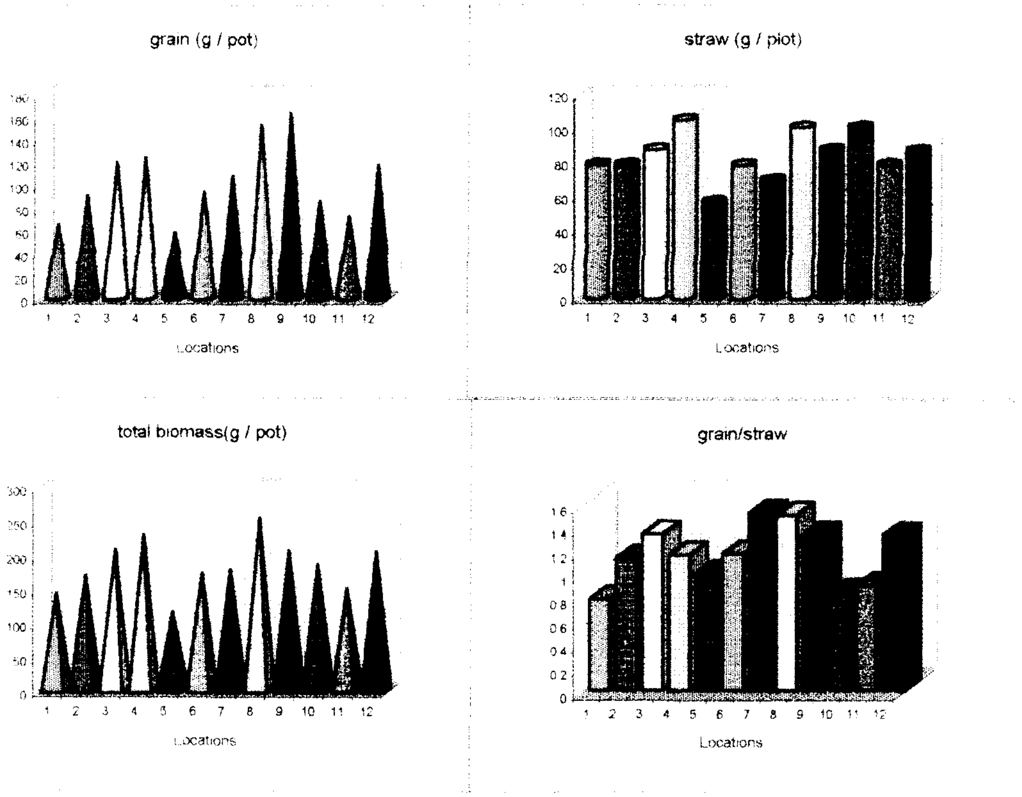


Fig. 4.2.2 Influence of locations on grain, straw and total biomass yield and grain / straw in "Kole" land - pot culture study



grain (g / pot)

straw (g / piot)

total biomass(g / pot)

grain/straw

Fig. 4.2.3 Influence of locations on grain, straw and total biomass yield and grain / straw in Chittoor black soil - pot culture study

Table 4.2.2 Range of growth and yield attributes of rice - Pot culture study

Characters	Laterite soil	Kole lands	Chittoor black soil
Tillers/hill at MT	6.2 - 15.2	6.0 - 27.2	5.6 - 23.2
Tillers/hill at PI	7.8 - 17.6	5.8 - 30.4	7.4 - 22.0
Tillers/hill at Flg.	14.3 - 27.3	12.0 - 28.0	8.7 - 23.3
Tillers/hill at harvest	13.7 - 19.0	8.7 - 23.0	7.7 - 21.7
Chlorophyll `a' boot leaf	1.55 - 2.27	1.33 - 2.07	1.40 - 2.47
Chlorophyll `b' boot leaf	0.98 - 2.05	0.77 - 1.86	0.88 - 1.80
Total chlorophyll - boot leaf	2.17 - 4.32	2.77 - 3.88	2.38 - 3.85
Leaf sap pH	6.15 - 6.40	6.20 - 6.50	5.95 - 6.35
Yield attributes and yield			
Panicles/hill	13.0 - 18.0	8.7 - 23.0	7.0 - 21.0
Panicle weight (g/10 panicle)	12.8 - 32.0	11.7 - 29.0	17.5 - 29.8
Filled grains/panicle	55.6 - 103.2	57.4 - 119.4	65.8 - 101.6
Total grains/panicle	70.4 - 133.2	84.0 - 153.4	84.0 - 121.4
1000 grain weight (g)	23.9 - 31.2	26.4 - 30.7	26.5 - 31.1
Percentage filling	68.2 - 89.7	61.6 - 86.3	65.3 - 88.0
Grain yield (g/pot)	58.1 - 142.1	50.6 - 134.0	57.1 - 151.9
Straw yield (g/pot)	88.0 - 129.8	70.4 - 123.2	57.2 - 105.6
Total biomass (g/pot)	111.1 - 252.1	130.3 - 253.0	142.2 - 253.1
Grain/straw	0.48 - 1.29	0.56 - 1.20	0.80 - 1.52

MT - Maximum tillering; PI - Panicle initiation; Flg. - Flowering

Data in Table 4.2.3 show the range of nutrient contents in the various parts of the plant in the three soil groups. It can be seen that the lowest root contents of S were in the `kole' lands and Fe, Zn and Cu in the black soils. There was only marginal variations between soil types in respect of lower levels of other elements. Highest content of N, S, Zn and Cu were in `kole' lands; P was highest in laterite soils and Ca, Fe and Mn were highest in the root in black soils.

Data on the culm content of elements showed that N, P, K, S, Mg, Fe and Zn were highest in `kole' soils plants, Ca in black soil plants and Mn and Cu in rice plants in laterite soils. Lower contents in the culm did not vary much in the different soil groups.

Leaves of rice plant in laterite soil recorded highest contents of Fe, Mn, Zn and Cu whereas highest leaf contents of N, P and K were in the `kole' lands and the highest Ca contents were in the crop in black soils. Among the lowest levels, laterite soil gave the highest content of P, K, Mg, Mn, Zn and Cu. Leaf N content in laterite soil alone was the lowest.

Lowest level of all the elements except Ca, Fe and Zn were observed in black soil, lowest Ca and Fe were observed in laterite soils and lowest Zn was in kole soils.

4.2.2 Interrelations of growth and physiologic attributes with yield of rice

Data presented in Table 4.2.4 showed that among the morphological attributes, panicles per hill, grains per panicle and thousand grain weight alone showed simple correlation with yield. In addition, tillers per hill at flowering and harvest showed a positive relation to total biomass.

Straw yield showed significant correlation only with total grains per panicle.

able 4.2.3 Range of nutrient content in different parts of rice - Pot culture study

	Soil groups											
	Root			Culm			Leaf			Boot leaf		
	Laterite	Kole land	Chittoor black	Laterite	Kole land	Chittoor black	Laterite	Kole land	Chittoor black	Laterite	Kole land	Chittoor black
N (%)	0.80 - 1.4	1.01 - 2.53	0.94 - 1.83	1.22 - 2.4	1.1 - 2.68	1.34 - 2.60	1.75 - 3.64	1.97 - 4.61	1.87 - 4.62	2.27 - 4.04	2.17 - 3.50	1.90 - 3.97
P (%)	0.15 - 0.37	0.16 - 0.29	0.17 - 0.30	0.29 - 0.46	0.28 - 0.49	0.23 - 0.46	0.27 - 0.35	0.16 - 0.38	0.22 - 0.34	0.21 - 0.27	0.20 - 0.28	0.19 - 0.27
K (%)	0.85 - 1.55	0.75 - 1.40	0.75 - 1.60	3.2 - 4.65	3.1 - 4.85	2.85 - 4.45	2.40 - 3.60	2.30 - 3.65	2.30 - 3.60	1.70 - 2.30	1.45 - 2.25	1.45 - 2.05
Ca (%)	0.02 - 0.159	0.019 - 0.271	0.021 - 0.36	0.014 - 0.023	0.014 - 0.032	0.016 - 0.038	0.052 - 0.161	0.068 - 0.219	0.057 - 0.35	0.10 - 0.36	0.135 - 0.377	0.104 - 0.33
Mg (%)	0.061 -0.181	0.054 - 0.25	0.05 - 0.28	0.09 - 0.18	0.123 - 0.211	0.12 - 0.17	0.101 - 0.169	0.08 - 0.22	0.076 - 0.202	0.104 - 0.18	0.13 - 0.23	0.012 - 0.23
S (ppm)	1314 - 2033	896 - 3131	1164 - 2857	1654 - 2550	1281 - 2935	1190 - 2510	1477 - 2622	1582 - 2615	1589 - 2661	1713 - 2635	1765 - 3079	1713 - 2693
Fe (ppm)	14675 - 42950	13075 - 50225	9675 - 55750	303 - 1024	414 - 2865	356 - 886	483 - 1911	327 - 1188	514 - 1481	216 - 486	310 - 641	248 - 435
Mn (ppm)	98 - 392	123 - 518	101 - 545	307 - 1018	288 - 931	199 - 867	481 - 1452	283 - 1260	266 - 1405	434 - 1312	445 - 2899	165 - 1145
Zn (ppm)	22 - 50	23 - 110	19 - 38	45 - 112	46 - 131	33 - 72	21 - 35	19 - 32	17 - 29	64 - 274	50 - 298	56 - 170
Cu (ppm)	13 - 39	12 - 46	8 - 34	8 - 18	5 - 16	5 - 12	9 - 18	6 - 12	6 - 17	7 - 13	7 - 17	5 - 10

Table 4.2.4 Inter-relation of growth attributes, physiologic attributes and yield attributes with yield of rice - Pot culture study

Attributes	Pot culture study		
	Grain yield	Straw yield	Total biomass
Tillers/hill at MT	0.107	-0.167	0.051
Tillers/hill at PI	0.090	-0.074	0.011
Tillers/hill at Flg	0.195	0.230	0.408**
Tillers/hill at Harvest	0.238	0.257	0.351*
Panicles/hill	0.461**	0.031	0.476**
Chlorophyll `a'	0.210	-0.233	0.272
Chlorophyll `b'	0.301	-0.303	0.376*
Leaf sap pH	-0.226	0.056	-0.090
Chlorophyll `a'/Chlorophyll ratio	-0.161	0.165	-0.146
Shoot dry weight at PI	-0.072	0.122	-0.021
Root dry weight at PI	0.066	0.291	0.139
Total dry weight at PI	-0.144	-0.202	-0.133
Filled grains/pacnile	0.246	0.260	0.161
Total grains/panicle	0.382**	0.324**	0.400**
1000 grain weight	0.328*	0.063	0.208

Correlation matrix of elements in the root as well as their relationship to yield (Table 4.2.5) showed that no element exerted any influence on yield. Root content of Ca was found related with Mg and Mn positively and with Cu negatively. Sulphur was positively related with K, Cu and Fe. Phosphorus also found to be related with Mn.

Culm content of S (Table 4.2.6) was related positively with Zn, Mn, Fe, K, Ca and Mg. Calcium and Fe were negatively related with yield of grain. Mn, Cu and Zn also were positively related.

Sulphur content of the leaf (Table 4.2.7) again was positively and significantly related with Mg, Mn, Zn and Cu contents. Copper content was positively related with Zn content also. Phosphorus content was positively influenced by Zn and K. Thus the results showed that contents of all elements except N and Ca were positively and significantly related.

Data on the significant interrelationships among boot leaf contents of elements are presented in Table 4.2.8. Here again S content was positively related with P, K, Ca, Mg, Fe, Mn and Cu contents and through P to Zn content also.

4.2.3 Interrelations of nutrient content of different plant parts with productivity of rice

4.2.3.1 Laterite soil

Data presented in Table 4.2.9 showed that in laterite soil N and Mn content of the leaf and Mg and Cu content of the culm showed positive relationship with yield of grain. Potassium and Cu content of the culm and boot leaf showed negative relation with yield of grain.

Straw yield was found correlated significantly with N content of the root as well as with P and Fe content of the culm.

Table 4.2.5 Inter-relation of root nutrient content and yield of rice - pot culture study

	Root at PI stage										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Yield
N	1.000										
P	0.217	1.000									
K	-0.020	-0.094	1.000								
Ca	0.117	0.180	-0.174	1.000							
Mg	0.050	0.248	0.039	0.817**	1.000						
S	0.194	-0.137	0.358**	-0.269	-0.304	1.000					
Fe	-0.613	0.075	0.135	-0.209	-0.142	0.549**	1.000				
Mn	-0.018	0.480**	-0.072	0.157**	0.460**	-0.197	-0.054	1.000			
Zn	-0.004	0.218	-0.013	0.091	0.225	-0.054	-0.113	0.119	1.000		
Cu	-0.008	0.041	0.412**	-0.400**	-0.267	0.449**	0.287	-0.245	0.222	1.000	
Grain yield	0.037	0.205	-0.077	-0.037	-0.015	-0.113	-0.009	0.224	-0.192	-0.014	1.000
Straw yield	0.250	0.037	0.137	0.036	0.086	0.037	0.294	-0.056	-0.138	-0.034	1.000
Total biomass	0.150	0.166	0.011	-0.009	0.032	-0.064	0.139	0.133	-0.206	-0.027	1.000

Table 4.2.6 Inter-relation of culm nutrient content and yield of rice - Pot culture study

	Culm at PI stage										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Yield
N	1.000										
P	0.046	1.000									
K	0.213	0.467**	1.000								
Ca	0.088	0.106	0.329**	1.000							
Mg	-0.056	0.139	0.396**	0.375**	1.000						
S	0.176	-0.016	0.657**	0.342**	0.415**	1.000					
Fe	0.263	0.444**	0.549**	0.533**	0.391**	0.337**	1.000				
Mn	-0.175	0.128	0.203	0.300	0.268	0.440**	0.259	1.000			
Zn	0.072	0.251	0.512**	0.208	0.425**	0.610**	0.438**	0.667**	1.000		
Cu	-0.157	-0.265	-0.090	0.065	-0.179	0.195	0.075	0.466**	0.359**	1.000	
Grain yield	0.092	-0.161	-0.088	-0.345**	0.183	-0.012	-0.369**	-0.208	-0.126	-0.148	1.000
Straw yield	0.033	-0.119	0.155	-0.157	0.019	0.279	-0.239	-0.020	-0.137	0.018	1.000
Total biomass	0.082	-0.175	0.013	-0.347**	0.141	0.130	-0.383**	-0.160	-0.159	-0.098	1.000

Table 4.2.7 Inter-relation of leaf nutrient content and yield of rice - pot culture study

	Leaf at PI stage										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Yield
N	1.000										
P	0.161	1.000									
K	0.288	0.266	1.000								
Ca	-0.022	-0.389**	-0.117	1.000							
Mg	0.276	-0.051	0.283**	0.354**	1.000						
S	0.308	-0.018	0.021	0.170	0.336**	1.000					
Fe	0.104	0.127	-0.056	-0.081	0.015	0.171	1.000				
Mn	0.288	-0.108	-0.048	0.224	0.246	0.364**	-0.086	1.000			
Zn	0.114	0.218	0.113	-0.115	0.239	0.436**	0.188	0.271	1.000		
Cu	0.190	0.086	0.022	0.081	0.327**	0.416**	0.272	0.250	0.551**	1.000	
Grain yield	0.192	0.052	-0.109	-0.275	-0.171	-0.042	0.066	0.123	-0.121	0.121	1.000
Straw yield	0.004	-0.097	-0.234	-0.029	-0.077	-0.197	0.164	-0.093	-0.219	-0.005	1.000
Total biomass	0.142	-0.011	-0.194	-0.212	-0.161	-0.127	0.129	0.049	-0.195	0.084	1.000

Table 4.2.8 Inter-relation of boot leaf nutrient content and yield of rice - Pot culture study

	Boot leaf at PI stage										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Yield
N	1.000										
P	0.301	1.000									
K	0.132	0.499**	1.000								
Ca	-0.116	0.235	0.263	1.000							
Mg	-0.044	0.178	0.174	0.629**	1.000						
S	0.172	0.576**	0.457**	0.376**	0.626**	1.000					
Fe	0.013	0.154	0.044	0.151	0.3000	0.366**	1.000				
Mn	-0.145	0.090	-0.002	0.537**	0.737**	0.373**	0.162	1.000			
Zn	-0.045	0.344**	0.181	-0.139	-0.177	0.115	-0.160	-0.094	1.000		
Cu	0.158	0.144	0.246	0.199	0.251	0.433**	0.342**	0.017	-0.139	1.000	
Grain yield	-0.049	0.115	0.219	0.091	-0.126	-0.182	0.034	-0.148	-0.025	-0.109	1.000
Straw yield	0.009	0.047	0.246	0.021	-0.007	0.167	0.002	-0.141	0.138	0.145	1.000
Total biomass	-0.031	0.106	0.288	0.076	-0.094	-0.048	0.026	-0.176	0.050	-0.007	1.000

Table 4.2.9 Inter-relation of nutrient content with yield of rice under different soil groups - pot culture study

		Laterite			Kole lands			Chittoor black soil		
		Grain yield	Straw yield	Total biomass	Grain yield	Straw yield	Total biomass	Grain yield	Straw yield	Total biomass
Root										
	N	0.434	0.529**	0.668**	0.490	0.576**	0.587**	-0.399	-0.145	-0.376
	P	0.300	0.127	0.309	-0.181	0.003	-0.107	0.179	-0.181	0.035
	K	-0.726**	0.029	-0.584**	0.294	0.322	0.324	0.063	0.051	0.085
	Ca	0.243	0.104	0.251	-0.065	-0.088	-0.079	0.022	0.200	0.145
	Mg	-0.037	-0.073	-0.067	-0.123	-0.007	-0.077	0.145	0.272	0.295
	S	-0.074	0.165	0.021	0.157	0.289	0.227	-0.167	-0.236	-0.290
	Fe	0.127	0.167	0.187	-0.083	0.116	0.004	0.050	0.555**	0.394
	Mn	0.094	0.033	0.093	-0.124	-0.209	-0.170	0.711**	0.071	0.642**
	Zn	-0.286	0.109	-0.182	-0.341	-0.251	-0.319	0.573**	-0.236	0.331
	Cu	-0.564**	0.370	-0.281	0.029	-0.086	-0.022	0.255	-0.387	-0.032
Culm										
	N	-0.477	-0.124	-0.454	0.115	-0.065	0.039	0.477	0.244	0.555**
	P	-0.070	0.511**	0.195	-0.138	-0.216	-0.182	-0.219	-0.337	-0.398
	K	0.213	0.266	0.306	0.089	0.047	0.075	-0.500	0.257	-0.256

Contd....

Table 4.2.9 contd....

Ca	-0.139	0.380	0.073	-0.324	-0.476	-0.412	-0.349	0.030	-0.274
Mg	0.587**	0.061	0.513	0.102	0.063	0.090	0.439	0.070	0.414
S	-0.074	-0.100	-0.110	0.428	0.364	0.424	-0.389	0.510	-0.002
Fe	-0.273	0.546**	0.045	-0.385	-0.469	-0.446	-0.309	-0.100	-0.323
Mn	-0.327	-0.128	-0.332	0.038	0.016	0.030	-0.291	-0.002	-0.246
Zn	-0.066	-0.343	-0.223	-0.008	-0.183	-0.088	-0.359	-0.019	-0.313
Cu	0.604**	0.140	-0.428	0.028	-0.138	-0.047	-0.329	-0.046	-0.306
Leaf									
N	0.597**	-0.174	0.406	0.005	0.217	0.103	0.286	-0.048	0.210
P	-0.112	-0.378	-0.279	-0.121	-0.228	-0.177	0.202	0.124	0.249
K	-0.133	-0.034	-0.126	-0.200	-0.089	-0.160	0.108	-0.588*	-0.282
Ca	0.442	-0.061	0.334	-0.394	0.028	-0.222	-0.490	-0.047	-0.441
Mg	0.384	0.453	0.540**	-0.424	-0.050	-0.277	0.140	-0.235	-0.032
S	-0.091	-0.299	-0.222	-0.358	-0.024	-0.225	0.335	-0.314	0.082
Fe	0.012	0.317	0.166	-0.275	0.018	-0.156	-0.249	0.018	-0.198
Mn	0.598**	-0.117	0.434	-0.229	-0.001	-0.138	-0.000	0.323	-0.190
Zn	-0.679**	0.083	-0.519	-0.492	-0.532**	-0.539**	0.557**	-0.072	0.405
Cu	-0.243	0.002	-0.199	-0.332	-0.116	-0.252	0.395	-0.058	0.286

Contd....

Table 4.2.9 contd.....

Boot leaf									
N	-0.294	-0.219	-0.350	-0.065	0.135	0.004	-0.091	-0.058	-0.113
P	-0.114	-0.221	-0.203	0.057	0.193	0.123	0.268	-0.076	0.177
K	-0.663**	-0.115	-0.606**	0.584**	0.457	0.559**	0.350	0.176	0.405
Ca	-0.434	0.044	-0.336	0.004	-0.027	-0.010	0.542**	0.010	0.462
Mg	-0.244	0.212	-0.097	-0.140	-0.177	-0.165	0.225	0.159	0.290
S	-0.354	-0.029	-0.277	-0.046	0.196	0.062	-0.025	0.339	0.194
Fe	0.356	0.241	0.174	0.136	0.201	0.174	0.271	0.161	0.330
Mn	-0.077	0.191	0.031	-0.416	-0.386	-0.426	0.609**	0.251	0.670**
Zn	-0.041	0.477	0.172	-0.172	0.106	-0.054	0.336	-0.173	0.172
Cu	-0.646*	0.372	-0.348	0.156	-0.039	0.076	0.283	0.299	0.110

Total biomass content was found to be positively related with N content of the culm and Mg content of the leaf and significantly and negatively related with K content of root and boot leaf.

4.2.3.2 `kole' lands

It can be seen from the data presented in Table 4.2.9. that K content of boot leaf alone was positively correlated with yield of grain.

Nitrogen content of the root and K content of boot leaf manifested significantly positive and Zn content of leaf showed negative relationship with biomass yield.

Nitrogen content of root had positive and Zn content of the leaf showed negative relationship with straw yield.

4.2.3.3 Black soils

It can be observed from the Table 4.2.9 that Mn content of the root and boot leaf and Zn content of the root and Ca content of the boot leaf showed significant positive relationships with yield of grain. However Zn and Mn content of the culm tended to show negative relationships. Iron content of the root showed significant relationship with straw yield while K showed a positive relationship with straw yield.

Total biomass yield was found to have significant positive relationship with Mn content of the root, Nitrogen content of the culm and Mn content of the boot leaf. Elemental composition of any part other than the above did not manifest any significant relationship.

4.2.4 Requirement of percentage contents and some ratios of nutrients in various parts of plant for rice productivity

Data are presented in Table 4.2.10. It can be seen from the Table 4.2.10 that mean pot yield was the highest in laterite soil (112.8 g) and Chittoor black soils

Table 4.2.10 Minimum nutrient requirement for >120 g grain pot^{-1} and some nutrient ratios - Pot culture study

Soil group	Minimum nutrient content - Root at PI										Nutrient ratio		
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	N/Fe	K/Fe	Ca+M g/K
Laterite	1.01	0.16	0.80	0.03	0.064	1314	14675	98	22	13	0.67	0.54	0.11
Kole land	1.42	0.19	1.10	0.04	0.113	2713	40975	165	37	22	0.35	0.29	0.14
Chittoor black	0.92	0.20	0.75	0.07	0.09	1164	20050	455	32	8	0.46	0.38	0.21
					Culm at PI								
Laterite	1.2	0.30	3.75	0.015	0.092	1732	303	390	45	8	40.0	125.0	0.029
Kole land	1.97	0.4	4.80	0.02	0.146	2877	824	727	93	7	24.6	58.5	0.035
Chittoor black	2.35	0.23	3.25	0.018	0.150	1739	344	211	33	5	69.0	95.6	0.052
					Leaf at PI								
Laterite	2.4	0.28	2.4	0.068	0.101	1915	483	597	22	10	50.0	50.0	0.070
Kole land	1.97	0.16	2.3	0.076	0.142	2131	538	570	19	7	36.4	42.6	0.095
Chittoor black	3.66	0.27	2.55	0.06	0.076	1589	779	266	20	6	46.9	33.0	0.057
					Boot leaf								
Laterite	2.27	0.21	1.7	0.1	0.10	1713	220	438	82	7	103.2	77.3	0.118
Kole land	2.60	0.22	1.95	0.17	0.14	2170	348	495	133	8	52.5	55.7	0.159
Chittoor black	2.35	0.22	1.9	0.24	0.14	2059	272	1120	115	6	86.4	70.4	0.20

Mean grain yield (g pot^{-1}) Laterite : 112.8; Kole land : 89.6; Chittoor black : 99.3

recorded a mean yield of 99.3 gms. `Kole' lands soil gave the mean yield of 89.6 g grain pot^{-1}.

The data showed that 120 g of grain per pot was recorded with varying levels of nutrients in different plant parts.

Thus the lowest level of N, K, Ca, Mg and Cu to produce 120 g grain per plot was in black soils. Phosphorus, Fe, Mn and Zn were lowest in laterite soils and Ca was lowest in kole lands.

A yield above 120 g per pot was produced with varying percentage levels of all the individual elements in the culm also. The data showed that a minimum of 5, 33 and 21 ppm of Cu, Zn and Mn and 0.23 and 3.25 per cent of P and K were enough for a yield above 120 g per pot with black soils. But 2.35 per cent N as against 1.2 per cent N in culm was required. Calcium content was 0.18 per cent here as against 0.02 per cent in kole land soils. Nitrogen levels were very high in black soils compared to laterite and the increase was above 80 per cent.

Rice plant with 1.97 per cent N in the leaf produced 120 g grain per pot in `kole' land soils compared with 2.4 per cent N in laterite and 3.66 per cent in black soils. The 3.66 per cent N plant$^{-1}$ was accompanied by 2.55 per cent K and 779 ppm of Fe. On the other hand 1.97 per cent N in `kole' lands was also associated with 0.076 per cent Ca and 0.142 per cent Mg and 2131 ppm of S.

In the boot leaf a grain yield of 120 g per pot was recorded with 2.27 per cent N. The contents of P, K, Ca, Mg and Fe were also lowest. In pots with black soil 3.66 per cent N was required to produce a comparable yield but was associated with 326 ppm less S and 286 ppm more Fe.

4.3 EXPERIMENT III

The experiment entitled "Effect of crop management on iron absorption, nutrient balance and productivity or rice" studied the relationship of organic manure and digging under three systems viz., dry seeding, wet seeding and transplanting of rice during first crop season (kharif) from May to September.

4.3.1 Main effects

4.3.1.1 System of crop establishment

Data on the effect of cultural management and organic manure on morphophysiologic development of rice are presented in Table 4.3.1a. and 4.3.1b.

4.3.1.1.1 Growth characters

Dry direct seeding registered significant superiority over wet seeding and transplanting in increasing tiller counts at all stages and height after the maximum tillering (MT) stage. The increments in height in direct dry seeding worked out to 20.7 and 17.1 per cent over wet seeding and 27.0 and 19.2 per cent over transplanting at panicle initiation (PI) and flowering stages respectively.

It may be seen that dry seeding had recorded a larger number of roots as well as higher average length of roots. Dry seeding recorded a mean number of 122.7 roots/plant which was 78.3 per cent higher than that of wet seeding which had produced the lowest number of roots. Wet seeding and transplanting did not significantly differ in number of roots. Mean length of roots was also higher in dry seeding and it was significantly superior to transplanting. Dry and wet seeding did not significantly differ in the mean length of roots though it was significantly superior to transplanting. Thus dry and wet seeding recorded a 60.9 and 50 per cent higher mean length of roots compared to transplanting.

Table 4.3.1a Effect of cultural management on growth attributes of rice - First crop (May - Sept.)

Treatments	Growth attributes										
	Plant height (cm)				Tillers/hills (No.)				Root characters/plant		
	MT	PI	Flg.	Harvest	MT	PI	Flg.	Harvest	No. of roots	Max. root length (cm)	Average root length (cm0
System											
DSR	47.9	68.0	87.8	87.0	5.5	10.2	8.5	7.6	122.7	10.3	7.4
WSR	48.4	56.3	74.7	74.0	3.4	4.4	5.0	3.5	67.4	16.1	6.9
TPR	48.6	53.4	73.6	75.0	4.6	5.5	6.0	4.5	68.8	13.0	4.6
CD (0.05)	NS	3.11	2.51	2.96	0.67	0.79	0.75	0.70	11.34	0.879	0.609
Digging											
D_{15}	47.8	60.1	79.2	79.2	4.5	6.7	6.5	5.4	80.0	13.1	6.3
D_{30}	48.8	58.3	78.2	78.4	4.5	6.7	6.5	5.0	92.6	13.2	6.2
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	9.16	NS	NS
FYM											
M_0	45.7	58.8	77.4	75.7	4.1	6.7	6.5	5.0	76.0	11.8	5.9
M_5	49.1	56.7	77.9	79.2	4.8	6.9	6.8	5.6	82.2	13.1	6.2
M_{10}	50.2	62.2	80.7	81.5	4.6	6.5	6.3	5.1	100.6	14.5	6.8
CD (0.05)	2.52	3.11	2.51	2.96	0.67	NS	NS	NS	11.34	0.879	0.609
CV(%)	7.68	7.74	4.69	5.52	22.1	17.38	16.95	19.84	19.30	9.86	14.26

DSR - Dry seeded rice
WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging (15 and 30 cm)
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.3.1a contd...

Treatments	Plant dry weight (g plant^{-1})											
	MT stage				PI stage				Flowering stage			
	Root	Shoot	Total	S/R	Root	Shoot	Total	S/R	Root	Shoot	Total	S/R
System												
DSR	1.6	7.4	8.9	5.2	6.3	17.8	24.3	3.2	7.0	31.1	36.3	4.6
WSR	1.2	3.7	4.9	3.3	1.7	12.4	14.1	7.9	1.0	12.9	14.8	13.7
TPR	1.1	4.3	5.4	4.2	1.4	14.6	16.1	11.6	1.3	17.6	18.9	14.6
CD (0.05)	0.32	0.813	0.97	0.89	1.07	2.83	2.91	2.31	1.61	4.06	6.54	2.6
Digging												
D_{15}	1.3	5.1	6.3	4.3	2.9	15.1	18.0	7.4	2.6	19.0	22.2	11.1
D_{30}	1.3	5.2	6.5	4.2	3.4	14.9	18.3	7.7	3.7	22.0	24.5	10.9
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.97	NS	NS	NS
FYM												
M_0	1.2	4.6	5.9	4.2	3.8	15.0	18.8	6.6	3.4	18.9	23.2	11.3
M_5	1.1	4.9	6.0	4.5	2.6	14.0	16.6	8.7	2.8	19.4	21.9	10.9
M_{10}	1.5	5.8	7.3	4.0	3.0	16.0	19.0	7.4	3.2	23.3	24.8	10.7
CD (0.05)	0.26	0.663	0.79	NS	0.93	NS	NS	2.31	NS	4.06	NS	NS
CV(%)	36.85	23.42	22.45	30.99	53.97	23.34	23.61	26.49	56.33	29.08	30.66	26.49

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.3.1b Effect of cultural management on physiologic characters of rice - First crop (May-Sept.)

Treatments	Physiologic characters											
	Chlorophyll (mg/g fresh sample weight)											
	MT stage			PI stage			Flowering stage			Leaf sap pH		
	Chl.a	Chl.b	Total chl.	Chl.a	Chl.b	Total chl.	Chl.a	Chl.b	Total chl.	MT	PI	Boot leaf
System												
DSR	1.631	1.331	2.989	1.572	1.491	3.007	1.695	1.491	3.180	6.2	6.39	6.23
WSR	1.469	1.233	2.586	1.175	1.159	2.351	1.101	1.339	2.431	5.91	6.11	6.17
TPR	1.475	1.220	2.633	1.359	1.250	2.577	1.177	1.39	2.547	5.91	6.05	6.22
CD (0.05)	NS	NS	0.339	0.196	0.206	0.369	0.132	NS	0.265	0.109	0.017	NS
Digging												
D_{15}	1.542	1.273	2.752	1.352	1.320	2.673	1.308	1.390	2.690	6.06	6.20	6.25
D_{30}	1.508	1.245	2.719	1.385	1.280	2.617	1.340	1.420	2.748	5.94	6.17	6.17
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.089	NS	0.082
FYM												
M_0	1.534	1.261	2.809	1.389	1.433	2.776	1.383	1.433	2.664	5.98	6.18	6.22
M_5	1.548	1.292	2.678	1.361	1.235	2.569	1.360	1.235	2.634	6.08	6.15	6.22
M_{10}	1.492	1.224	2.720	1.356	1.232	2.590	1.460	1.232	2.858	5.95	6.22	6.19
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	15.03	18.12	18.24	21.02	23.37	20.55	14.70	13.58	14.36	2.67	2.57	2.38

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Farm yard manure (0, 5 and 10 t ha^{-1})

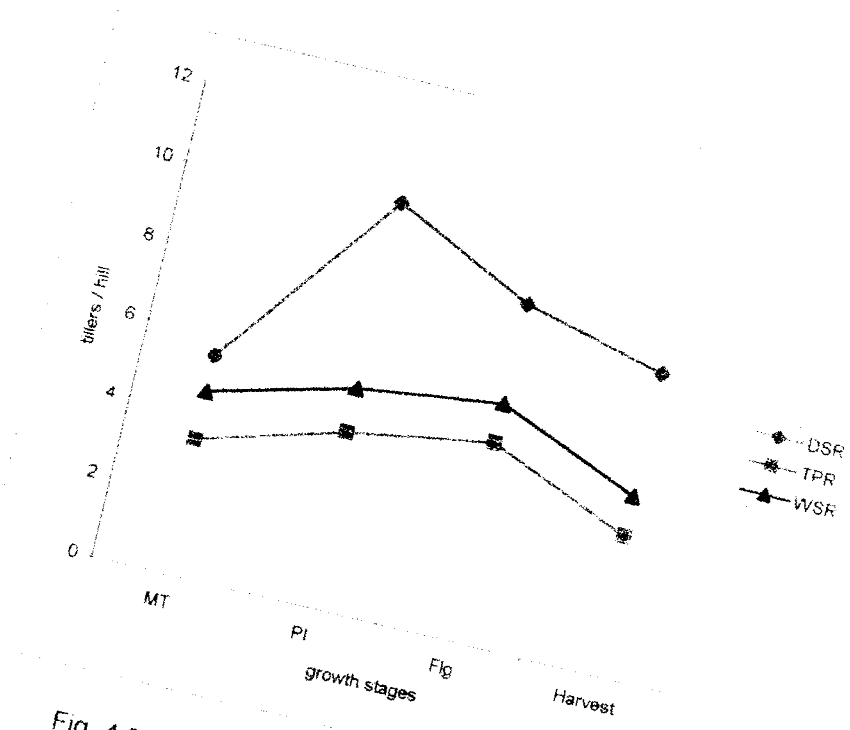


Fig. 4.3.2 Phasic progression in tiller development

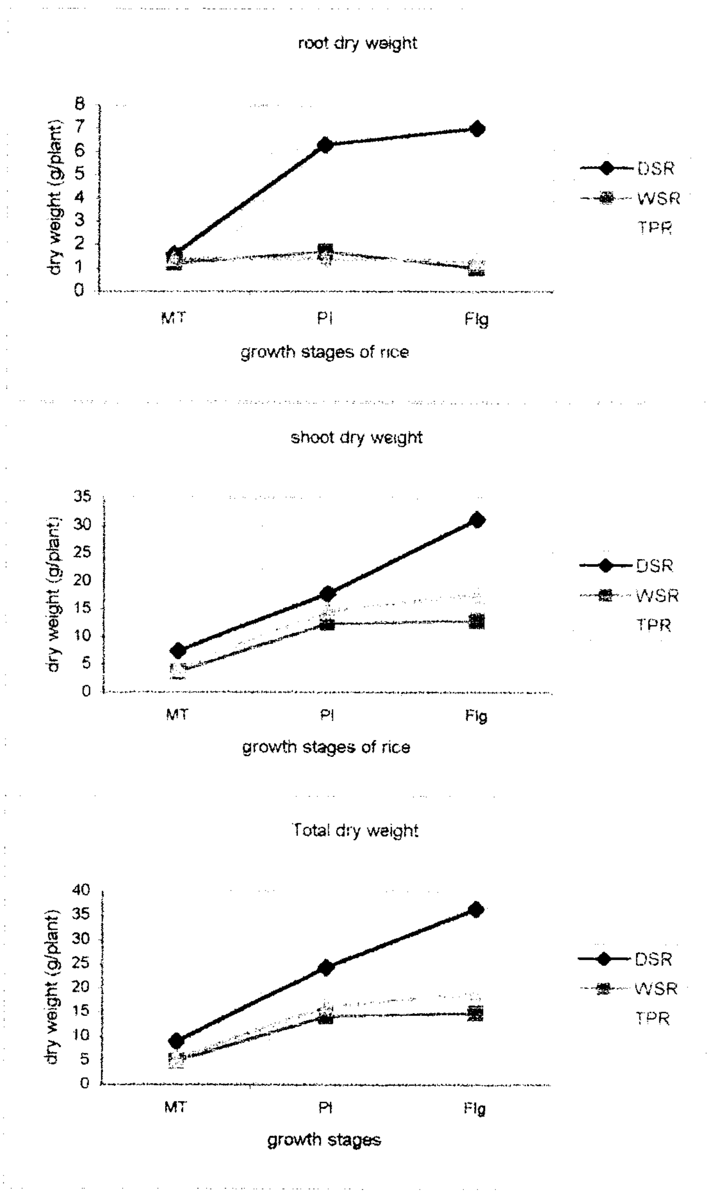


Fig. 4.3.3 Phasic progression in dry matter accumulation under different methods of crop establishment

Direct dry seeding was significantly superior to the other two treatments in increasing the total number of tillers at all stages. The superiority declined in order of wet seeding and transplanting. Thus direct dry seeding recorded 61.8, 132.9, 70.0 and 117.1 per cent more tiller counts over wet seeding and 19.5, 85, 42 and 68.8 per cent over transplanting at MT, PI, flowering and harvest stages respectively. Data showed that irrespective of treatments grand growth phase in rice in first crop season is confined to between MT and flowering.

It may also be seen from the data that the system of cultivation affected the duration and extent of tiller decline (Fig. 4.3.2). Tiller decline which extended from PI to harvest in dry seeding was confined to between flowering and harvest in other treatments. The magnitude of tiller decline was lowest in the transplanted crop. However the early superiority of dry seeding in direct seeding was retained to the end.

Data presented on the weight of shoot, root and their balance at various growth stages showed that dry seeding was markedly superior to the other two methods in total accumulation of both shoot and root at all stages of observation. Moreover, this treatment maintained nearly steady rate till boot leaf stage (Fig.4.3.3). The percentage increase in total dry matter under dry seeding compared to transplanting worked out to 64.8, 50.9 and 92.1 per cent. The increases were 81.6, 82.3 and 145.3 per cent over wet seeding (Plate 1, 2 ,3 and 4).

When the shoot root ratios were compared, though dry seeding registered the widest ratio at MT stage, transplanting recorded the widest ratio both at PI and boot leaf stages.

4.3.1.1.2 Physiological characters

Variation among the method of establishment were reflected in the chlorophyll content and leaf sap pH. Direct dry seeding invariably recorded significantly higher total chlorophyll content at all stages of observation; content of chlorophyll `a' was significant only at PI and boot leaf stages. Wet seeding and transplanting did not significantly differ. Thus the content of total chlorophyll was 13.5, 45.3 and 24.9 per cent more in dry seeding than in transplanting and the corresponding increases in chlorophyll `a' were 10.6, 15.7 and 44 per cent respectively at MT, PI and boot leaf stages (Table 4.3.1b).

A comparative perusal of the content of chlorophyll `a' at MT, PI and boot leaf showed that stability was higher in dry seeding.

Leaf sap pH also recorded significantly higher values in dry seeding at MT and PI with 4.7 and 5.6 per cent higher values over transplanting. Wet seeding and transplanting did not differ significantly.

4.3.1.1.3 Yield attributes and yield

Data (Table 4.3.1c and Fig. 4.3.1) showed that dry seeding significantly increased the number of panicles per hill, number of filled grains and seed weight but did not affect the weight or number of branches of panicle or total number of grains per panicle. It recorded significantly higher number of filled grains. Thus dry seeding recorded an increase of 72.7, 14.3 and 3.8 per cent in respect of number of panicles per hill, number of filled grains per panicle and seed weight over transplanting. Wet seeding resulted in a significantly reduced number of panicles per hill, number of branches per panicle and seed weight.

Dry seeding recorded higher yield of grain and straw of 6496 and 5388 kg ha^{-1} compared to other treatments and the increases were 40.7 and 37.5 per cent over transplanting and 37.8 and 40.4 per cent over wet seeding (Fig. 4.3.2.).

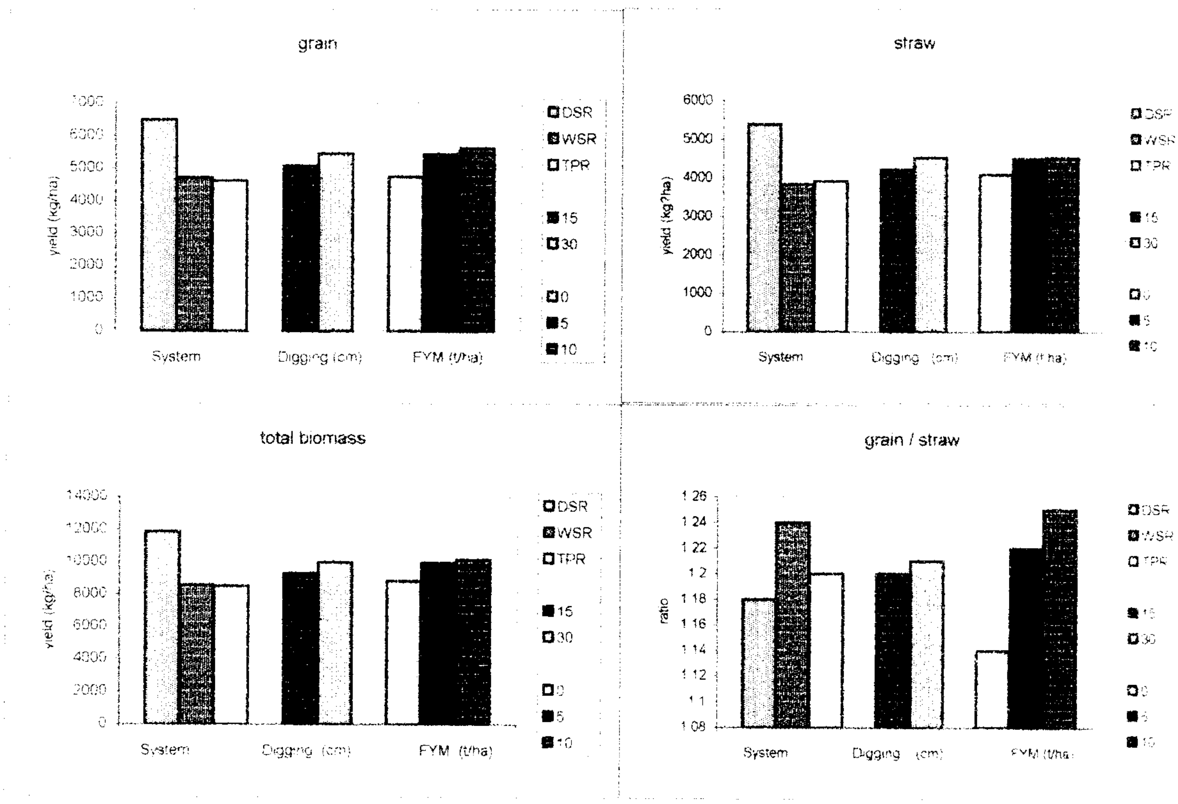


Fig. 4.3.1 Effect of cultural management on grain, straw and total biomass yield and grain / straw - first crop (May - September)

Table 4.3.1c Effect of cultural management on yield attributes and yield of rice - First crop (Mat - Sept.)

Treatments	Yield attributes and yield												
	Panicles/ hill (Nos.)	Panicle wgt/10 panicle (g)	Panicle length (cm)	Branches/ panicle (Nos.)	Filled grains/ panicle (Nos.)	Unfilled grains/ panicle (Nos.)	1000 grain weight. (g)	Percentage filling	Moisture content of grain (%)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total biomass (kg ha^{-1})	Grain/ straw ratio
System													
DSR	7.6	23.7	20.3	8.2	87.9	16.9	32.4	83.4	20.6	6496	5388	11881	1.18
WSR	3.4	22.4	19.7	8.7	83.4	22.0	30.9	79.3	10.8	4715	3837	8582	1.24
TPR	4.4	22.4	20.0	8.2	76.9	29.4	31.2	72.3	13.6	4615	3919	8534	1.20
CD (0.05)	0.78	NS	0.46	0.388	4.26	3.82	0.080	2.35	1.42	425.0	560.0	754.4	NS
Digging													
D_{15}	5.2	23.1	20.1	8.4	82.4	23.7	31.3	77.8	15.1	5086	4222	9308	1.20
D_{30}	5.0	23.6	19.9	8.4	83.0	21.8	31.7	79.0	15.0	5465	4541	10013	1.21
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	347.0	NS	616.0	NS
FYM													
M_0	4.8	21.9	20.1	8.2	79.4	22.9	31.3	77.0	15.5	4748	4101	8851	1.14
M_5	5.6	23.1	19.9	8.5	79.2	22.9	31.5	77.6	14.3	5455	4509	9963	1.22
M_{10}	5.1	23.8	20.1	8.4	89.4	21.4	31.7	80.4	15.2	5623	4532	10155	1.25
CD (0.05)	NS	NS	NS	NS	4.26	NS	NS	2.35	NS	425.0	NS	754.4	NS
CV(%)	22.45	10.09	2.50	5.06	5.68	18.37	3.77	4.42	13.86	8.81	13.98	8.54	14.45

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Farm yard manure (0, 5 and 10 t ha^{-1})

4.3.1.2 Method of land preparation (digging)

Among the 46 morphophysiological parameters used to test the variability in the influence of digging/ploughing at 15 and 30 cm depths only five were significantly affected and they were number of roots/plant at MT, leaf sap pH at MT stage and boot leaf, dry weight of roots at flowering stage, grain yield and total biomass at harvest (Table 4.3.1a; 4.3.1b and 4.3.1c).

Depth of digging significantly influenced only the number of roots. Digging to a depth of 30 cm increased the mean number of roots by 15.8 per cent over digging to a depth of 15 cm. Digging at 30 cm depth registered a lower leaf sap pH of the boot leaf, raised the root dry weight at flowering stage, increased the grain yield by 379 kg ha^{-1} and increased the biomass yield by 705 kg ha^{-1}. All these increases were statistically significant.

4.3.1.3 Farm yard manure/organic manure

Increasing levels of farm yard manure (FYM) significantly increased the height of the rice plants at all stages and tiller counts at MT (Table 4.3.1a). Application of FYM @ 10 t ha^{-1} was superior and increase over control were 8.6, 5.8, 4.3 and 7.7 per cent at MT, PI, flowering and harvest while the increases in tiller counts at MT was 12.2 per cent. Differences in tiller counts on the subsequent stages were not significant.

Increasing levels of FYM increased the number, length and maximum length of roots and the increases were statistically significant. The lowest values of these observations were recorded under control and the increases in number of roots, maximum length of roots and mean length of roots were 8.2, 11.0 and 5.1 per cent when FYM was applied @ 5 t ha^{-1} and 32.4, 22.9 and 15.3 per cent when the level of FYM applied was raised to 10 t ha^{-1}.

Among dry weight of plants as well as its components viz., shoot and root as well as the shoot root ratio, dry weight of shoots at MT and flowering and root weight at MT and PI were affected. Application of FYM at 10 t ha^{-1} increased the shoot and root weight at MT and shoot weight alone at flowering stages. The increasing shoot weight at MT stage and flowering worked out to 26.1 and 23.3 per cent respectively over control.

Chlorophyll content and leaf sap pH at all the three stages of observation remained unaffected.

Among the yield attributes number of filled grains as well as the percentage of filling were significantly affected with 12.6 and 4.4 per cent increases for 10 t ha^{-1} of FYM over control (Table 4.3.1c).

4.3.2 Interaction effects

4.3.2.1 Combined effect of method of crop establishment and depth of digging on morphophysiological characteristics

It can be seen from the Table 4.3.2a that the combined effect of depth of digging and method of crop establishment was highly significant.

Mean number of roots/plant was most influenced by the combined effect while the same had the least effect in wet seeding. Higher depth of digging increased the mean number of roots by 108.3 per cent and the difference was significant. Variation in depth of digging did not have any effect on number of roots both in wet seeding and transplanting.

Data on maximum root length showed that while depth of digging significantly increased the maximum root length in dry seeding, it did not have any effect on the maximum root length under wet seeded and transplanted crop. The increase in maximum root length under dry seeding with 30 cm deep digging worked out to 12.4 per cent over D_{15}.

Table 4.3.2a Interaction effect of crop establishment and digging on growth attributes, physiologic characters and yield attributes and yield of rice - First crop (May-Sept.)

		Root characters at MT									Plant dry weight (g/plant)								
		No. of roots/plant			Max. root length (cm)			Average root length (cm)			Shoot at Flowering			Total dry weight at Flg			Shoot/Root at PI		
System		DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR
Digging	D15	107.3	66.3	66.5	9.7	16.2	13.2	7.0	7.3	4.8	26.7	12.7	17.7	32.1	15.5	19.0	3.5	8.61	10.2
	D30	138.1	68.5	71.0	10.9	15.9	12.8	7.8	6.5	4.4	35.4	13.0	17.5	40.5	14.1	18.8	2.99	7.2	12.9
CD (0.05)			16.03			1.2			NS			5.74			6.88			2.43	

		Chlorophyll (mg/g fresh sample wgt.)									Leaf sap pH					
		Total Chl. at PI			Chl.a at boot leaf			Total Chl. at boot leaf			Maximum Tillering			Panicle initiation		
System		DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR
Digging	D15	3.02	2.37	2.66	3.24	2.44	2.40	1.72	1.09	1.10	6.22	5.96	6.01	6.38	6.12	6.09
	D30	2.99	2.36	2.50	3.12	2.43	2.69	1.67	1.09	1.25	6.14	5.88	5.82	6.41	6.09	6.02
CD (0.05)			0.187			0.169			0.187			0.155			0.152	

	Panicles/hill (No.)			Panicle length (cm)			Filled grains/panicle			Unfilled grains/panicle			Total spikelets/panicle			1000 grain wgt.(g)			Percentage of fillin		
System	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TP
Digging																					
D15	8.4	3.3	4.2	20.2	20.01	20.12	86.8	87.8	72.7	14.21	24.19	32.6	101.3	111.9	104.9	32.2	30.9	30.8	85.7	78.5	69
D30	7.0	3.6	4.5	20.5	19.46	19.89	88.9	79.0	81.1	19.59	19.71	26.2	109.5	98.7	107.4	32.3	30.9	31.5	81.2	80.1	75.
CD (0.05)		1.13			0.481			4.51			4.016			5.89			0.11			3.33	

Shoot dry weight and total dry weight at flowering were significantly affected by the interaction between depth of digging and crop establishment.

Digging deeper to a depth of 30 cm under dry seeding significantly increased the shoot dry weight and total dry weight over digging to a depth of 15 cm and the increases were 33.2 and 26.3 per cent. Digging variable depths did not affect dry weights in wet seeded and transplanted crops. The highest shoot dry weight of 35.55 gm at flowering was 179.0 per cent more than the lowest value for shoot weight recorded in wet seeding method with 15 cm digging. A similar improvement of 104.6 per cent was observed between wet seeding in 30 cm dug plots and dry seeded 15 cm dug plots.

Combined effect of depth of digging and method of crop establishment significantly influenced total chlorophyll at PI and boot leaf, chlorophyll `a' content of boot leaf and leaf sap pH both at MT and PI stages.

It may be seen that highest level of total chlorophyll at PI and maximum chlorophyll `a' content were recorded when dry seeding and digging to a depth of 15 cm were combined. Combined influence of deep digging and wet seeding recorded the lowest content of total chlorophyll at PI and chlorophyll `a' of boot leaf. The increase of total chlorophyll and chlorophyll `a' in dry seeding had worked out to 28.0 and 57.8 per cent over the lowest content recorded.

Combined effect of digging at 15 cm depth and dry seeding recorded the highest leaf sap pH of 6.22 at MT which was significantly superior to those of wet seeding or transplanting irrespective of depth of digging. Depth of digging tended to reduce the leaf sap pH.

At PI stage also the highest leaf sap pH was recorded when dry seeding and digging to a depth of 15 cm were combined and the lowest when the crop was transplanted after digging to a depth of 30 cm.

Interaction effect of digging and crop establishment were significant in respect of panicle length, number of filled and unfilled grains, total spikelets per panicle, percentage of filling and 1000 grain weight.

Dry seeding combined with digging to a depth of 30 cm recorded the longest panicles, maximum number of filled grains per panicle and 1000 grain weight and the wet seeded rice under 30 cm digging recorded the minimum length of panicle, lowest number of unfilled grains per panicle as well as total spikelets per panicle. Transplanting at 30 cm digging recorded the lowest number of filled grains, 1000 grain weight and the lowest percentage of filling. And all the above treatments significantly differed among themselves.

4.3.2.2 Combined effect of depth of digging and level of FYM on morphophysiological characters

Combined effect of 30 cm deep digging and 10 t ha^{-1} FYM recorded the maximum number of 104 roots/plant as against 69 roots in $D_{15}M_0$ treatment and the difference was statistically significant (Table 4.3.2b).

Similarly, maximum root length of 14.7 was recorded at $D_{30}M_{10}$ which was 31.3 per cent more than that under $D_{30}M_0$ and the difference was statistically significant.

Highest content of total chlorophyll at PI was recorded at $D_{15}M_0$ level and lowest at $D_{30}M_5$ level and the influences were statistically significant. At the same level of digging (15 cm) increasing levels of FYM progressively decreased the total chlorophyll content while at 30 cm digging chlorophyll content increased significantly when FYM application level was raised from 5 to 10 t ha^{-1}.

Table 4.3.2b Interaction effect of FYM levels and digging on growth, physiologic attributes and yield attributes and yield of rice - First crop (May-Sept

Levels of FYM	No. of roots/plant at MT			Maximum root length (cm) at MT			Chlorophyll (mg/g fresh sample weight)					
							Total Chlorophyll at PI			Chl. `a' at boot leaf		
	M0	M5	M10	M0	M5	M10	M0	M5	M10	M0	M5	M10
Digging												
D15	69.8	73.8	96.5	12.3	12.5	14.3	2.82	2.69	2.51	1.20	1.28	1.44
D30	82.3	90.6	104.7	11.2	13.6	14.7	2.73	2.45	2.67	1.41	1.26	1.35
CD (0.05)		16.03			1.242			0.187			0.186	

At the boot leaf stage, highest content of chlorophyll `a' was recorded at the combined level of digging to a depth of 15 cm and FYM level of 10 t ha^{-1} which was significantly superior to digging alone.

4.3.2.3 Combined effect of FYM levels and method of crop establishment on morphophysiological characters in rice

It may be seen from Table 4.3.2c that the effect of FYM levels on number of roots varied with the method of crop establishment adopted. In wet seeding and transplanting application of FYM @ 10 t ha^{-1} increased the number of roots by 18.1 and 23.5 per cent over control while the number of roots remained unaffected in dry seeding.

Increasing levels of FYM influenced the maximum root length differently in different methods of crop establishment. The effect was significant at both the incremental levels of FYM in the case of transplanting and the increase with 5 and 10 t ha^{-1} of FYM over control were 28.2 and 49.5 per cent respectively.

In wet seeding the maximum root length significantly increased only when FYM level increased from 5 to 10 t ha^{-1}.

In dry seeding application of 5 t ha^{-1} FYM was required to bring about significant increase in root length over that of control.

Significant interaction was observed due to the interaction effect of organic manure levels and method of crop establishment. The most significant effect was in transplanted crop where the ratio widened from 9.68 to 13.56 when FYM was applied at 5 t ha^{-1}. The lowest shoot-root ratio was observed in dry seeding with no FYM and the widest ratio in transplanted crop with 5 t ha^{-1} FYM.

Table 4.3.2c Interaction effect of crop establishment and levels of FYM on growth attributes, physiologic attributes and yield attributes and yield of rice - First crop (May-Sept.)

		Root characters at MT						Shoot dry weight at Flowering (g/plant)			Total dry weight (g/plant)			Shoot/root at PI		
		No. of roots/plant			Max. root length (cm)											
System		DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR
FYM	M_0	123.1	54.8	50.3	8.9	16.0	10.3	30.69	9.84	16.20	39.05	13.42	17.45	2.64	7.36	9.68
	M_5	117.5	66.9	62.1	10.7	15.3	13.2	27.50	13.05	17.78	32.78	13.99	19.15	3.41	9.02	13.56
	M_{10}	127.5	80.5	93.9	11.3	16.9	15.4	35.18	15.78	18.8	37.12	16.89	20.30	3.69	7.38	11.41
CD (0.05)			19.64			1.52			7.032			8.147			2.973	

		Chlorophyll (mg/g fresh sample wgt.)									Leaf sap pH					
		Total Chl. at PI			Chl.a at boot leaf			Total Chl. boot leaf			Maximum Tillering			Panicle initiation		
System		DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR
FYM	M_0	2.95	2.71	2.67	1.71	1.15	1.05	3.16	2.36	2.47	6.18	5.95	5.81	6.39	6.12	6.04
	M_5	2.79	2.35	2.56	1.70	1.02	1.09	3.22	2.29	2.38	6.19	5.90	6.14	6.37	6.10	5.98
	M_{10}	3.29	1.99	2.50	1.68	1.23	1.29	3.16	2.65	2.77	6.18	5.90	5.78	6.42	6.10	6.14
CD (0.05)			0.229			0.229			0.229			0.155			0.186	

		Panicle length (cm)			Filled grains/panicle			Unfilled grains/panicle			Total spikelet/panicle			Percentage of filling		
System		DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR
FYM	M_0	20.38	19.62	20.27	80.37	81.12	77.0	20.22	21.83	26.77	100.9	102.9	103.8	79.7	78.9	74.4
	M_5	20.23	19.48	19.88	86.02	79.20	72.5	16.72	23.18	31.88	102.1	102.4	104.5	84.5	77.6	69.1
	M_{10}	20.42	20.10	19.87	97.17	89.9	81.2	13.77	20.83	29.55	113.1	110.7	110.3	86.2	81.4	73.6
CD (0.05)			0.589			5.529			4.016			7.22			4.09	

FYM - Farm yard manure DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice

In the case of shoot weight transplanting registered smaller response both in quantity and rate of increase. Quantitatively the response was higher for dry seeding and in rate wet seeding was better. Highest shoot dry weight was recorded at 10 t ha^{-1} of FYM in dry seeded crop and the lowest for wet seeded crop with no FYM. The increase in shoot weight over the latter was 257.5 per cent at flowering stage.

The data showed that the total chlorophyll content at PI and chlorophyll `a' content of the boot leaf were differentially affected. At PI stage increasing levels of FYM increased the chlorophyll content in dry seeded crop, while the reverse trend was observed in wet seeding and transplanting. The highest content of chlorophyll was recorded in dry seeded crop with 10 t ha^{-1} of FYM, which was superior to all other treatments combinations. The lowest content of total chlorophyll was recorded in wet seeded plots receiving 10 t ha^{-1} FYM. Increasing levels of FYM significantly reduced the total chlorophyll content in wet seeded plots.

An exactly opposite trend was observed in the case of chlorophyll `a' of the boot leaf at flowering. Increasing levels of FYM tended to reduce chlorophyll `a' in dry seeded plots and increased it in wet seeded and transplanted plots. Highest content of chlorophyll `a' was recorded in DSR M_0 and lowest in WSR M_5 and the differences were statistically significant.

Data on the combined effect of FYM and crop establishment showed that leaf sap pH at MT was affected significantly only in transplanted crop. A leaf sap pH of 6.14 at MT was significantly reduced to 5.78.

At PI stage, the overall level of leaf sap pH was higher than the MT stage. The highest leaf sap pH was recorded in dry seeded crop receiving 10 t ha^{-1} FYM and the lowest value of 6.10 in wet seeded crop receiving 5 and 10 t ha^{-1} of FYM.

Shoot root ratio at PI widened from dry seeding to transplanting with wet seeding in between both under two depths of digging and the variations were significant. Thus the widest ratio of shoot/root was recorded in the transplanted crop with 30 cm deep digging and the narrowest ratio was in dry seeding with 30 cm digging.

4.3.2.4. Combined effect of method of crop establishment, digging and FYM level on morphophysiological attributes and yield attributes and yield of rice

Data on the combined effect of method of crop establishment, digging and FYM level are presented in Table 4.3.2d.

It was seen that the combined effect of these three factors were most pronounced in the case of dry seeding. The maximum number of 142 roots/plant at MT stage of the crop was recorded when digging to a depth of 30 cm, dry seeding and FYM 10 t ha^{-1} were combined. The lowest number of 48.9 roots were recorded under transplanting combined with 15 cm digging and no organic manures followed by 50.2 when the land was dug to 15 cm and the crop was transplanted with 5 t ha^{-1} FYM application. The increases over transplanting treatments were 190.8 and 183.3 per cent respectively for D_{30} DSR M_{10}.

A closer scrutiny of the data also showed that root production was less responsive in transplanted crop than in wet seeded crop and that the harmful effects of wet seeding and transplanting could be significantly overcome by application of 10 t ha^{-1} of FYM.

However, with regard to the maximum length of root recorded, wet seeding combined with digging to a depth of 15 cm gave the longest root which was

Table 4.3.2d Interaction effect of method of crop establishment digging and level of FYM on root characters of rice at MT - First crop (May-Sept.)

Treatments	No. of roots/plant at MT			Maximum root length (cm)			Average root length (cm)		
	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
DSR D_{15}	109.0	100.1	112.8	8.3	10.4	10.5	6.9	7.0	7.0
DSR D_{30}	137.0	135.0	142.2	9.6	11.1	12.0	6.7	8.5	8.1
WSR D_{15}	51.5	71.0	76.3	17.7	14.1	17.0	7.9	7.2	6.7
WSR D_{30}	58.0	62.8	84.6	14.4	16.4	16.8	6.1	5.6	8.0
TPR D_{15}	48.9	50.2	100.5	11.0	13.2	15.5	3.5	4.1	6.7
TPR D_{30}	51.7	74.1	87.3	9.6	13.2	15.5	4.0	4.9	4.2
CD (0.05)		27.46			2.153			0.483	

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice

102.4 per cent more than that under dry seeding combined with 15 cm deep digging and no manure which gave the shortest roots. The variation among these treatments were significantly different.

Average length of roots was maximum in dry seeded plots combined with digging to a depth of 30 cm and 5 t ha^{-1} FYM application and the lowest length of 3.5 cm was recorded in transplanted plots with a minimum digging of 15 cm. It can be seen that there was a generalised decrease in root length from dry seeding to transplanting with wet seeding in between.

4.3.3 Effect of cultural management on elemental composition of rice

4.3.3.1 Main effects

4.3.3.1.1 Elemental composition of root at MT stage

Data on elemental composition of root is presented in Table 4.3.3a and Fig. 4.3.4.

a. Method of crop establishment

It was observed that method of crop establishment significantly influenced the elemental composition of root at MT stage.

Transplanting recorded the highest content of P and Fe which was significantly superior to dry seeding and the increases were 24.7 and 300.3 per cent.

Wet seeding gave the highest content of K and Mn and the increases were 81.2 and 63.9 per cent over dry seeding.

Dry seeding recorded the maximum percentage content of Mg, Zn and Cu in roots and they were significantly higher than that at transplanting which recorded the lowest contents.

able 4.3.3a Effect of cultural management on elemental composition of root at maximum tillering stage - 1st crop (May-Sept.)

Treatment	Root at Maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
DSR	1.095	0.186	0.883	0.033	0.094	2787	10619	227	86.8	27.7
WSR	1.098	0.209	1.600	0.028	0.080	2908	28979	372	61.3	22.4
TPR	1.185	0.232	1.562	0.024	0.056	3032	42504	184	72.3	15.0
CD(0.05)	NS	0.027	0.280	NS	0.015	NS	5699	56.44	8.45	5.74
Digging										
D15	1.176	0.211	1.411	0.027	0.075	2901	26366	264	76.2	20.6
D30	1.076	0.206	1.286	0.030	0.079	2917	28368	258	70.7	22.7
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FYM										
M0	1.192	0.203	1.450	0.029	0.078	2941	26010	248	77.1	22.9
M5	1.104	0.220	1.279	0.028	0.072	2872	27183	249	66.7	20.2
M10	1.082	0.204	1.317	0.029	0.081	2914	28909	287	76.7	22.0
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	8.45	NS
CV (%)	18.73	17.37	24.11	46.83	21.58	11.59	24.17	25.09	13.35	30.76

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure (0, 5 and 10 t ha^{-1})

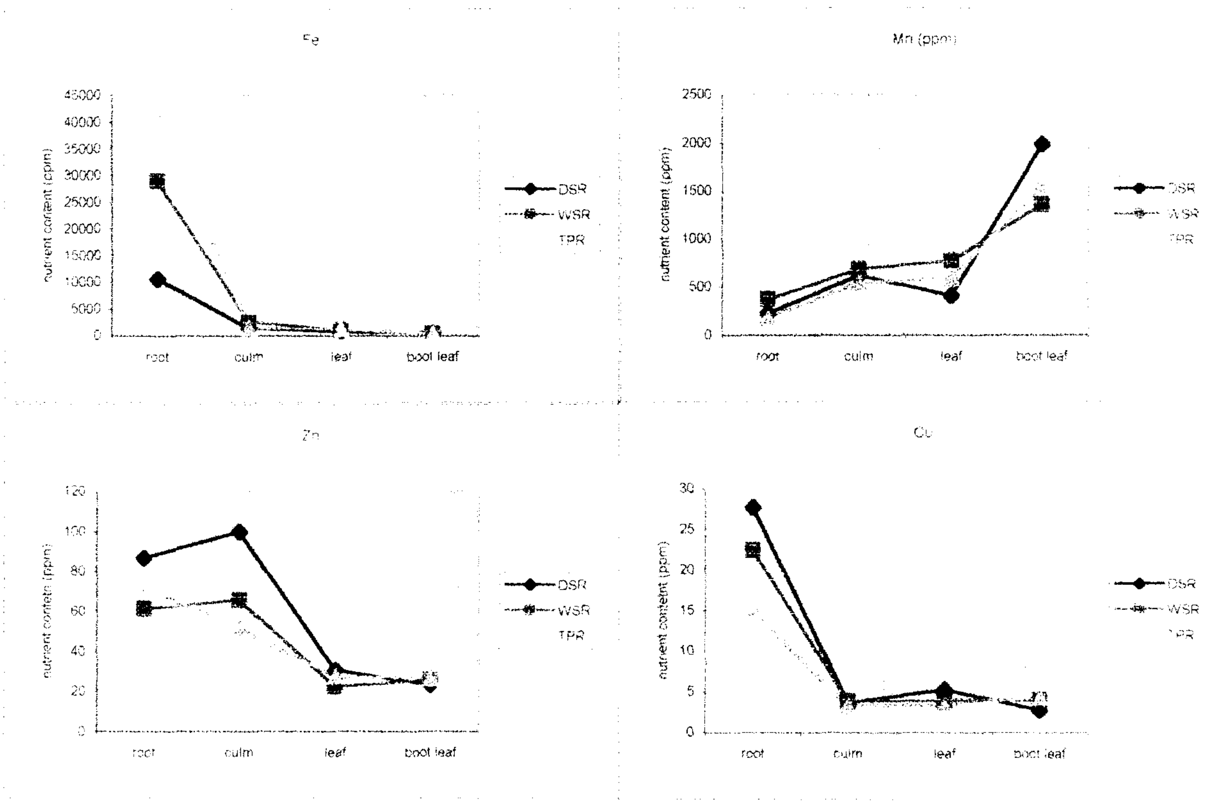


Fig. 4.3.4 Phasic progression in Fe, Mn, Zn and Cu content under different methods of crop establishment

b. Depth of digging

Digging did not affect the elemental composition of root at MT stage.

c. Farm yard manure/organic manure

Organic manure affected the Zn content of the root significantly. Wet seeding gave the lowest level of 66.7 ppm which was significantly inferior to both dry seeding and transplanting.

4.3.3.1.2 Elemental composition of root at PI stage

a. Method of crop establishment

Data presented in Table 4.3.3b. showed that dry seeding gave the highest root N content of 1.12 per cent which was 41.4 and 44.3 per cent more than wet seeding and transplanting respectively.

Wet seeding recorded the highest level of Ca and Mn content of the root which was 32.0 and 65.0 per cent more than dry seeding and transplanting respectively.

Transplanting registered the highest root content of S, Fe and Zn and the content were significantly higher than that under dry seeding by 22.6, 18.8 and 35.2 per cent.

Depth of digging and FYM levels did not have any significant effect on the root elemental composition.

4.3.3.1.3 Elemental composition of shoot at MT stage

a. Method of crop establishment

Data on the shoot elemental composition presented in Table 4.3.3c. showed that dry seeding gave higher content of all the elements except Fe and Mn in the shoot at MT stage compared to wet seeding and transplanting and the differences were statistically significant. The content of N, Ca, Mg, S and Cu were 56.2, 31.5, 104.5, 10.3 and 6.5 per cent higher than that at wet seeding and 77.5, 68.0, 158.6, 16.9 and 27.8 per cent more than that at transplanting.

able 4.3.3b Effect of cultural management on elemental composition of root at panicle initiation stage - 1st crop (May-Sept.)

Treatment	Root at panicle initiation									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
DSR	1.117	0.208	0.842	0.025	0.049	2217	43613	179	48.0	13.9
WSR	0.790	0.214	0.683	0.033	0.056	2142	46917	269	50.9	12.5
TPR	0.774	0.199	0.650	0.020	0.047	2719	51833	184	64.9	12.0
CD(0.05)	0.125	NS	NS	0.007	NS	372.1	5776.6	11.0	10.39	NS
Digging										
D15	0.857	0.211	0.892	0.026	0.053	2352	47513	191	54.6	13.6
D30	0.931	0.203	0.558	0.025	0.048	2366	47394	231	54.6	12.0
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FYM										
M0	0.841	0.208	0.542	0.023	0.046	2270	49660	182	51.0	11.8
M5	0.927	0.206	0.654	0.025	0.055	2491	45813	214	57.3	13.7
M10	0.913	0.207	0.979	0.030	0.051	2316	46890	237	55.5	12.9
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	16.11	7.73	12.6	29.17	19.15	18.71	14.13	37.23	22.09	33.96

SR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
S - Non significant M - Manure (0, 5 and 10 t ha^{-1})

Table 4.3.3c Effect of cultural management on elemental composition of shoot at maximum tillering stage - 1st crop (May-Sept.)

Treatment	Shoot at Maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
DSR	2.863	0.254	2.629	0.163	0.225	2621	1929	484	40.4	5.75
WSR	1.833	0.287	3.204	0.124	0.110	2376	1503	504	38.4	5.40
TPR	1.613	0.280	2.862	0.097	0.087	2242	2403	361	32.3	4.5
CD(0.05)	0.386	NS	NS	0.038	0.027	180.1	547.4	106.1	NS	0.995
Digging										
D_{15}	2.161	0.280	2.761	0.116	0.132	2481	1928	416	38.3	5.3
D_{30}	2.047	0.267	3.036	0.140	0.149	2345	1962	483	35.8	5.1
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FYM										
M_0	2.230	0.275	2.775	0.129	0.120	2348	2111	461	41.9	5.3
M_5	1.904	0.282	3.029	0.125	0.146	2495	1928	486	37.8	5.25
M_{10}	2.177	0.265	2.892	0.130	0.156	2396	1794	403	31.4	5.08
CD(0.05)	NS	NS	NS	NS	0.027	NS	NS	NS	NS	NS
CV (%)	21.3	15.83	20.64	31.4	20.03	8.66	32.67	27.04	32.3	22.38

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure (0, 5 and 10 t ha^{-1})

Transplanting recorded the highest content of Fe and wet seeding recorded maximum Mn content in the shoot at MT stage.

b. Depth of digging

Depth of digging did not have any significant effect on the elemental composition of shoot at MT.

c. FYM/Organic manure

Increasing levels of FYM significantly affected only the Mg content of the shoot. Highest Mg content was recorded in 10 t ha^{-1} of FYM. The increase was significant and worked out to 30.0 per cent over control.

4.3.3.1.4 Elemental composition of culm at PI stage

a. Method of crop establishment

Data on the main effects of treatments on the elemental composition of culm at PI stage are presented in Table 4.3.3d and Fig. 4.3.4.

a. Method of crop establishment

It may be seen that significant variation due to treatment effect on elemental composition was found only in the case of Mg, S and Zn. Dry seeding recorded significantly higher levels of these elements over transplanting and the increases were 47.6, 18.0 and 95.3 per cent respectively. In wet seeding and transplanting culms did not significantly differ in elemental composition.

b. Depth of digging

Shallow digging recorded significantly higher level of K in the leaf over digging to a depth of 30 cm and the increase was 9.8 per cent. No other element was significantly affected.

Table 4.3.3d Effect of cultural management on elemental composition of culm at PI - 1st crop (May-Sept.)

Treatment	Culm at Panicle Initiation Stage									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
DSR	1.203	0.274	2.600	0.037	0.121	1971	1375	617	99.8	3.7
WSR	0.891	0.273	2.667	0.029	0.086	1767	2643	687	65.6	3.9
TPR	0.955	0.278	2.512	0.036	0.082	1671	1464	549	51.1	3.3
CD(0.05)	NS	NS	NS	NS	0.019	243.4	NS	NS	22.83	NS
Digging										
D15	1.061	0.279	2.714	0.036	0.101	1861	1679	620	78.3	3.5
D30	0.972	0.273	2.472	0.032	0.091	1745	1963	615	65.9	3.7
CD(0.05)	NS	NS	0.196	NS	NS	NS	NS	NS	NS	NS
FYM										
M0	0.940	0.264	2.333	0.034	0.097	1768	2698	620	77.9	3.7
M5	1.066	0.286	2.662	0.030	0.099	1845	1545	663	70.3	3.5
M10	1.043	0.276	2.783	0.039	0.093	1797	1220	570	68.3	3.7
CD(0.05)	NS	NS	0.241	NS	NS	NS	NS	NS	NS	NS
CV (%)	31.83	11.13	10.80	42.51	21.93	15.67	126.6	26.91	36.73	35.04

DSR - Dry seeded rice
WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging (15 and 30 cm)
NS - Non significant
M - Manure (0, 5 and 10 t ha^{-1})

c. FYM

Increasing levels of FYM significantly affected only K content only of the culm. Application of FYM @ 10 t ha^{-1} increased the K content by 19.3 per cent.

4.3.3.1.5 Elemental composition of leaf at PI stage

a. Method of crop establishment

It can be seen from the Table 4.1.3e. that the leaf at PI stage in dry seeding recorded the highest level of N, P, Mg, S, Zn and Cu and it was significantly superior to both the other systems. The increases over wet seeding were 22.3, 11.3, 40.59, 18.3, 19.6 and 32.5 per cent and corresponding increases over transplanting were 33.1, 6.3, 43.4, 15.6, 30.5 and 55.9 per cent respectively.

The data further showed that wet seeding recorded the highest content of Mn and it was significantly superior to dry seeding and transplanting.

b. Depth of digging

Depth of digging did not show any significant effect on the elemental composition of leaf.

c. Levels of FYM/Organic manure

FYM applied at 10 t ha^{-1} (Table 4.3.1e) significantly reduced the Mg content of the leaf and the reduction worked out to 11.9 per cent over no FYM.

4.3.3.1.6 Elemental composition of the boot leaf

a. Method of crop establishment

Data presented in Table 4.1.3f. revealed that different systems of crop establishment differently affected the elemental composition of the boot leaf. Dry seeding recorded significantly higher contents of Ca, Fe and Mn over wet seeding and transplanting. The increases were 141.9, 50.7 and 46.4 per cent over wet seeding and 115.2, 42.4 and 27.6 per cent over transplanting respectively.

Table 4.3.3e Effect of cultural management on elemental composition of leaf at PI stage - 1st crop (May-Sept.)

Treatment	Leaf at Panicle Initiation stage									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
DSR	2.101	0.236	2.292	0.247	0.142	2144	791	415	30.5	5.3
WSR	1.718	0.212	1.996	0.236	0.101	1813	1123	774	22.5	4.0
TPR	1.578	0.222	2.212	0.253	0.099	1854	1341	596	27.6	3.4
CD(0.05)	0.305	0.015	NS	NS	0.013	164.8	NS	105.73	2.45	0.81
Digging										
D15	1.786	0.226	2.200	0.234	0.114	2003	1177	610	28.4	4.2
D30	1.812	0.221	2.133	0.258	0.114	1871	993	579	27.3	4.2
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FYM										
M0	1.799	0.225	2.221	0.257	0.118	1936	1301	627	27.3	4.3
M5	1.847	0.224	2.204	0.242	0.119	1978	1126	589	27.4	4.0
M10	1.751	0.220	2.075	0.239	0.104	1898	829	569	28.8	4.3
CD(0.05)	NS	NS	NS	NS	0.013	NS	NS	NS	NS	NS
CV (%)	19.63	8.61	15.83	20.94	13.29	9.88	56.9	20.64	10.21	22.25

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure (0, 5 and 10 t ha^{-1})

Table 4.3.3f Effect of cultural management on elemental composition of boot leaf - 1st crop (May-Sept.)

Treatment	Boot leaf									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
DSR	1.927	0.157	1.292	0.525	0.066	1702	568	1989	23.3	2.8
WSR	2.004	0.187	1.446	0.217	0.133	1830	377	1360	25.7	4.0
TPR	2.092	0.199	1.754	0.244	0.123	1739	399	1559	26.4	4.3
CD(0.05)	NS	0.027	0.245	0.047	0.027	NS	93.01	161.3	NS	1.01
Digging										
D15	2.061	0.173	1.606	0.319	0.100	1719	445	1532	25.6	3.4
D30	1.955	0.188	1.389	0.338	0.114	1795	450	1740	24.6	3.9
CD(0.05)	NS	NS	0.204	NS	NS	NS	NS	131.7	NS	NS
FYM										
M0	1.927	0.176	1.505	0.319	0.106	1751	423	1592	24.5	4.0
M5	1.957	0.180	1.529	0.362	0.109	1719	498	1692	23.8	3.3
M10	2.139	0.186	1.458	0.305	0.106	1801	422	1623	27.1	3.8
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	11.94	14.75	19.06	1724	31.56	14.71	24.14	11.45	24.00	32.40

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure : (0, 5 and 10 t ha^{-1})

Transplanting recorded the highest content of P, K and Cu and the contents were significantly superior to dry seeding. The K content of the transplanted crop was significantly superior to wet seeding also.

Wet seeding recorded the highest level of Mg in the boot leaf and was significantly superior to dry seeding. The increase over dry seeding was worked out to 101.5 per cent.

b. Depth of digging

Digging to a depth of 30 cm significantly reduced the K content and increased Mn content of the boot leaf over shallow digging and the percentage changes were 13.5 and 13.6 per cent respectively.

c. Levels of FYM/Organic manure

Increasing levels of FYM did not have any significant effect on the boot leaf composition.

4.3.3.1.7 Elemental composition of grain

a. Method of crop establishment

System of establishment significantly affected the P, K, S and Mn content of the grain (Table 4.3.3g).

Dry seeding increased the grain content of P by 15.6 per cent over transplanting and the increase was significant. Wet seeding and transplanting were on par.

Transplanting gave a significantly higher content of K, S and Mn in the grain over dry seeding and the increases were 18.4, 9.6 and 66.9 per cent. It was also noted that the grain content of K and Mn in the transplanted crop was significantly higher than the wet seeded crop and the significant increases were 14.9 and 29.5 per cent.

Table 4.3.3g Effect of cultural management on elemental composition of grain - 1st crop (May-Sept.)

Treatment	Grain										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Sio$_2$ (%)
System											
DSR	1.290	0.267	0.429	0.005	0.057	1312	171.8	61	21.3	2.8	11.1
WSR	1.221	0.247	0.442	0.005	0.053	1371	94.5	78	19.0	2.8	12.4
TPR	1.161	0.231	0.508	0.005	0.057	1438	78.8	101	23.4	3.2	12.1
CD(0.05)	NS	0.027	0.054	NS	NS	71.0	NS	14.4	NS	NS	NS
Digging											
D15	1.206	0.251	0.458	0.005	0.055	1338	89.0	80	20.1	2.7	12.6
D30	1.242	0.245	0.461	0.005	0.056	1409	141.1	80	22.4	3.2	11.2
CD(0.05)	NS	NS	NS	NS	NS	57.9	NS	NS	NS	NS	NS
FYM											
M0	1.231	0.245	0.462	0.005	0.056	1348	168.9	81	20.0	2.8	13.2
M5	1.206	0.250	0.471	0.005	0.056	1398	83.8	76	21.9	3.0	10.3
M10	1.235	0.249	0.446	0.005	0.055	1348	92.5	82	21.8	2.9	12.3
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	13.78	11.98	14.51	19.64	10.17	6.00	150.35	20.96	20.6	32.47	25.30

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure (0, 5 and 10 t ha^{-1})

b. Depth of digging

The data in Table 4.3.3g. showed that digging to a depth of 30 cm increased the seed S content by 5.3 per cent. Other elements were not affected.

c. Levels of FYM/Organic manure

Variation in the level of FYM did not significantly affect the content of any element in the grain.

4.3.3.1.8 Elemental composition of straw

a. Method of crop establishment

From the Table 4.3.3h. it can be seen that dry seeding recorded significantly higher content of N, P, S and Fe in straw over both wet seeding and transplanting. The increases were 30.4, 13.5, 7.4 and 100.7 per cent over wet seeding and 26.2, 12.0, 6.4 and 90.9 per cent over transplanting.

Transplanting gave the highest content of Mn in the straw and the content was on par with wet seeding but was superior to dry seeding and the increase worked out to 59.0 per cent.

Depth of digging and organic manure did not significantly affect the elemental composition of straw.

4.3.4 Interaction effects

4.3.4.1. Interaction effects on elemental composition of root at MT

a. Method of crop establishment x FYM

The data presented in Table 4.3.4a. showed that application of FYM at 10 t ha^{-1} while significantly increasing the Zn content of the root in dry seeded crop reduced it in the transplanted crop and the respective variations worked out to 21.4 and 26.5 per cent. It is also evident that wet seeded crop failed significantly to match the Zn content with dry seeded or transplanted crop.

Table 4.3.3h Effect of cultural management on elemental composition of straw - 1st crop (May-Sept.)

Treatment	Straw										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	SiO_2 (%)
System											
DSR	1.046	0.168	2.929	0.187	0.084	1434	586	940	57.2	4.3	22.5
WSR	0.802	0.148	2.471	0.198	0.099	1335	292	1444	54.5	4.3	20.1
TPR	0.829	0.150	2.725	0.186	0.086	1347	307	1495	42.9	3.8	23.1
CD(0.05)	0.123	0.009	NS	NS	NS	63.2	116.4	204.9	NS	NS	NS
Digging											
D15	0.877	0.157	2.728	0.175	0.087	1377	355	1198	52.9	3.9	23.0
D30	0.908	0.153	2.689	0.206	0.092	1367	334	1388	50.1	4.3	20.8
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	167.3	NS	NS	NS
FYM											
M0	0.950	0.153	2.583	0.196	0.084	1399	367	1330	57.0	4.0	22.1
M5	0.787	0.146	2.658	0.196	0.091	1369	367	1284	50.8	4.08	20.1
M10	0.941	0.166	2.883	0.179	0.094	1348	451	1264	46.8	4.30	23.6
CD(0.05)	0.123	0.009	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	15.82	11.57	15.83	25.09	23.10	5.35	34.20	18.39	42.99	27.60	35.04

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure (0, 5 and 10 t ha^{-1})

Table 4.3.4a Interaction effect of cultural management on elemental composition of root and shoot at MT stage - 1st crop (May-Sept.)

I Method of crop establishment x FYM

	Root at MT		
	Zn (ppm)		
	DSR	WSR	TPR
M_0	84.0	62.3	85.0
M_5	73.0	57.5	69.5
M_{10}	102.3	64.3	62.5
CD (0.05)	14.64		

II Method of crop establishment x digging

	Shoot at MT stage								
	Mg (%)			S (ppm)			Cu (ppm)		
	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR
D_{15}	0.194	0.253	0.113	2556	2536	2350	5.7	6.3	4.0
D_{30}	0.107	0.089	0.084	2687	2216	2132	5.8	4.5	5.0
CD (0.05)		0.038			254.6			1.42	

III Depth of digging x FYM

	Shoot at MT stage		
	Mg (%)		
	M_0	M_5	M_{10}
D_{15}	0.118	0.116	0.162
D_{30}	0.123	0.176	0.149
CD (0.05)		0.038	

4.3.4.2 Interaction effects on elemental composition of shoot at MT

a. Method of crop establishment x Digging

It may be seen from the Table that digging to a depth of 30 cm significantly reduced the Mg content in all the methods by 44.8, 65.8 and 25.7 per cent in the order of DSR, WSR and TPR respectively over dry seeding. It can also be seen that the variation was from 0.084 to 0.253 in the Mg content of the root under the different treatment combinations.

Within the different depths of digging, deeper digging reduced the Mg content significantly in WSR and TPR over dry seeding whereas in shallow digging WSR gave the highest Mg content which was significantly superior by 30.4 and 123.9 per cent over DSR and TPR respectively.

In the case of S, dry seeded and wet seeded crops were on par but transplanting was inferior in shallow digging. In deep digging DSR was superior to both WSR and TPR and the increases worked out to 21.3 and 26.0 per cent respectively.

Data further showed that wet seeding combined with shallow digging gave the highest Cu content and shallow digging combined with transplanting gave the lowest content.

b. Depth of digging x FYM

It can be seen from the Table 4.3.4a. that 10 t ha^{-1} of FYM was required under shallow digging as against 5 t ha^{-1} in deep digging to bring about a significant improvement in the Mg status of the shoot at MT stage.

4.3.4.3 Interaction effects on elemental composition of root at PI

a. Method of crop establishment x Digging

It can be seen from the data in Table (4.3.4b) that shallow digging combined with wet seeding gave higher P content in the root which was significantly superior to

Table 4.3.4b Interaction effect of cultural management on elemental composition of root, culm and leaf at PI stage - 1st crop (May-Sept.)

I Method of crop establishment x FYM

	Leaf at PI stage		
	Mn (ppm)		
	DSR	WSR	TPR
M_0	366	712	804
M_5	392	801	573
M_{10}	487	809	410
CD (0.05)		183.1	

II Method of crop establishment x digging

	Root at PI			Culm at PI			Leaf at PI stage					
	P (%)			K (%)			Mn (ppm)			Zn (ppm)		
	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR	DSR	WSR	TPR
D_{15}	0.202	0.225	0.206	2.892	2.800	2.450	387	873	572	32.8	24.5	27.8
D_{30}	0.214	0.202	0.192	2.308	2.533	2.575	443	674	619	28.2	26.5	27.3
CD (0.05)		0.0186			0.340			149.5			3.46	

III Depth of digging x FYM

	Root at PI		
	Mg (%)		
	M_0	M_5	M_{10}
D_{15}	0.046	0.064	0.049
D_{30}	0.046	0.047	0.052
CD (0.05)		0.013	

shallow digging accompanied by dry seeding or transplanting. In the case of deep digging P content of the root was highest in dry seeded crop and the increase was significant compared to transplanting.

b. Depth of digging x FYM

Maximum root content of Mg was observed in $D_{15} M_5$ treatment combination which was significantly superior to all others except $D_{30} M_{10}$ which was on par with the former.

4.3.4.4 Interaction effects on elemental composition of culm at PI

a. Method of crop establishment x Digging

Efficiency of different methods of crop establishment significantly differed when depth of digging was shallow in affecting K content of the culm (Table 4.3.4b). Dry seeding combined with shallow digging gave a significantly higher content of K over transplanting and the increase worked out to 18.0 per cent. It was also be noted that deep digging irrespective of method of crop establishment registered only lower content of K in the culm.

4.3.4.5 Interaction effect on elemental composition of leaf at PI

a. Method of crop establishment x digging

It can be observed from Table 4.3.4b. that shallow digging combined with wet seeding gave the highest Mn content of the leaf at PI which was significantly superior to all other treatment combinations. Dry seeding recorded a lower Mn content compared to wet seeding and transplanting at both the depth of digging. Transplanting showed a reduction in Mn content over that of wet seeded crop but was significant only in respect of shallow dug plots.

Maximum Zn content of the leaf was recorded by D_{15}DSR combination which was significantly superior to all other treatment combinations. Deep digging methods did not significantly differ in affecting the Zn content.

b. Method of crop establishment x FYM

It can be seen (Table 4.3.4b) that increasing levels of FYM while increasing the Mn content in dry and wet seeded crops, decreased it in transplanted crop and the decrease was statistically significant.

4.3.4.6 Interaction effects on elemental composition of boot leaf

It was observed (Table 4.3.4c) that under shallow digging transplanted crop gave the highest K content which was significantly superior to wet and dry seeded rice, though the latter did not significantly differ and the increase was 63.0 and 30.6 per cent respectively. Methods of crop establishment did not significantly differ when the land was dug deep.

4.3.4.7 Interaction effects on elemental composition of grain

First order interaction effects did not significantly affect the elemental composition of grain.

4.3.4.8 Interaction effects on elemental composition of straw

a. Method of crop establishment x Digging

It may be seen from the Table 4.3.4c. that under shallow digging dry seeding and transplanting recorded significantly higher content of K over wet seeding and the increases were 25.6 and 32.9 per cent respectively. Transplanting gave the highest K content under shallow digging. But under deep digging transplanting gave the lowest K content. Dry seeding was significantly superior to transplanting and the difference was 23.8 per cent.

Table 4.3.4c Interaction effect of cultural management on elemental composition of boot leaf and straw - 1st crop (May-Sept.)

I Method of crop establishment x digging

	Boot leaf K (%)			Straw K (%)		
	DSR	WSR	TPR	DSR	WSR	TPR
D_{15}	1.242	1.550	2.025	2.867	2.283	3.033
D_{30}	1.342	1.342	1.483	2.992	2.658	2.417
CD (0.05)		0.347			0.556	

II Depth of digging x FYM

	Straw					
	K (%)			Cu (ppm)		
	M_0	M_5	M_{10}	M_0	M_5	M_{10}
D_{15}	2.500	2.483	3.200	3.5	3.3	4.8
D_{30}	2.667	2.833	2.567	4.5	4.8	3.7
CD (0.05)		0.556			1.38	

b. Depth of digging x FYM

Application of FYM at 10 t ha^{-1} significantly increased the K content of straw over control when the soil was dug to a depth of 30 cm.

4.3.5 Second order interaction effects

4.3.5.1 Root at MT stage

Significant interactions due to combined effect of depth of digging, system of crop establishment and levels of FYM were observed in the K and Fe content of root at MT stage and the data are presented in Table 4.3.5.

The data showed that maximum content of 1.5 per cent K in the dry seeded crop was obtained when the plots were not deeply dug and fertilizer was not applied. Increasing levels of FYM both in shallow and deep dug plots recorded very low K content.

In wet seeded plots the average K content was higher but the treatments failed to bring about any significant variation. In transplanted crop shallow digging accompanied by 5 t ha^{-1} of FYM gave the highest content of K which significantly superior to what was observed in the treatment receiving deep digging and 5 t ha^{-1} of FYM. It was also seen from the data that root content of K ranged from 0.65 per cent in DSR $D_{30}M_{10}$ to 1.9 per cent in TPR $D_{15}M_5$.

It can be seen from the Table 4.3.5 that significant variations due to interactions on Fe content were evident in three planes. Transplanting the crop combined with shallow digging significantly increased the Fe content when 5 t ha^{-1} of FYM was applied and the increase was 58.5 per cent over TPR $D_{15}M_0$. Deep digging and transplanting also significantly increased the Fe content of the root by 47.6 per cent over shallow digging and was aggravated further by application of 10 t ha^{-1} of FYM

Table 4.3.5 Combined effect of method of crop establishment, digging and FYM on elemental composition of rice

	Root at MT						Shoot at MT		
	K (%)			Fe (ppm)			Mg (%)		
	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
DSR D_{15}	1.535	0.850	0.700	10500	10063	11313	0.179	0.131	0.273
DSR D_{30}	1.250	0.925	0.650	10538	11875	9425	0.183	0.348	0.234
WSR D_{15}	1.375	1.575	1.825	35075	20187	30365	0.094	0.119	0.127
WSR D_{30}	1.825	1.250	1.750	25875	34587	27787	0.102	0.093	0.128
TPR D_{15}	1.475	1.900	1.475	29913	47425	42463	0.081	0.98	0.087
TPR D_{30}	1.850	1.175	1.500	44163	38963	52100	0.083	0.086	0.084
CD(0.05)		0.686			13958			0.065	

	Leaf at PI						Boot leaf					
	S (ppm)			Mn (ppm)			N (%)			Cu (ppm)		
	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
DSR D_{15}	1556	1668	1576	456.0	368.5	336.0	1.880	1.935	2.005	2.0	3.0	2.0
DSR D_{30}	1694	1749	1971	276.0	416.0	638.0	1.885	2.060	1.750	2.5	2.0	5.0
WSR D_{15}	1877	1546	1749	728.0	803.0	1088.0	1.895	1.840	1.945	4.5	3.0	3.5
WSR D_{30}	1752	1916	2141	696.0	798.5	528.5	2.360	1.490	2.495	4.5	4.0	4.5
TPR D_{15}	1821	1824	1854	731.5	558.5	427.5	1.795	2.450	2.755	4.0	4.0	5.0
TPR D_{30}	1808	1615	1513	876.0	587.5	393.0	1.750	1.970	1.835	6.5	3.5	2.50
CD (0.05)		269.5			259.0			0.503			2.50	

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice when the root content of Fe was 74.2 per cent higher than in TPR $D_{15}M_0$. Another important observation from the data has been that dry seeding, irrespective of depth and FYM levels, recorded the lowest root Fe content and all these treatment combinations were significantly inferior to wet seeding and transplanting. The magnitude of the effect is evident from a comparison of root content of Fe in DSR D_{30} M_{10} and TPR D_{30} M_{10} where the latter was 452.8 per cent higher than the former.

4.3.5.2 Shoot at MT stage

It can be observed from the data (Table 4.3.5) that maximum Mg content of the shoot at MT stage (0.348%) was found in DSR D_{30} M_5 treatment, which was significantly superior to all other treatment combinations. The range in Mg content was from 0.081 to 0.384 per cent in WSR $D_{15}M_0$ and DSR D_{30} M_5. It is also evident from the data that at FYM, 5 t ha^{-1} the tendency for lowest Mg content was observed which rose at 10 t ha^{-1} FYM.

4.3.5.3 Leaf at PI stage

Data are presented in Table 4.3.5. Significant influence on the S content of the leaf was evident at the FYM level of 10 t ha^{-1} only. Maximum S content was observed in WSR D_{30} M_{10} which significantly superior to DSR $D_{15}M_{10}$ and DSR $D_{15}M_0$.

Data on the Mn content of the leaf showed that in dry seeded crop shallow digging combined with increasing levels of FYM decreased the Mn content whereas in deep digging in dry seeded as well as shallow dug wet seeded crops, the Mn content significantly increased with increasing levels of FYM. However, in transplanted crop, irrespective of depth of digging, FYM tended to decrease the Mn content.

4.3.5.4 Elemental composition of boot leaf

Combined effects of depth of digging, method of crop establishment and FYM on the N and Cu content of boot leaf is presented in Table 4.3.5.

The data showed that transplanting combined with shallow digging and 10 t ha^{-1} FYM recorded the highest N content of the boot leaf followed by WSR D_{30} M_{10} and the former was significantly superior to all combinations in dry seeded crops and the increases in N content in the treatment over DSR D_{15} M_{10} and DSR $D_{30}M_5$ were 37.4 and 33.7 per cent respectively.

Data on the Cu content of boot leaf showed that the highest content of 6.5 ppm was recorded in transplanted crop combined with deep digging alone which was significantly superior to all treatments combining dry seeding and 5 t ha^{-1} of FYM. Wet seeding without FYM, irrespective of depth of digging, also was significantly superior to corresponding dry seeding treatments.

4.3.5.5 Straw

Combined effect of method of crop establishment, depth of digging and FYM levels on K content of straw is presented in Table 4.3.5.

The data showed that the highest content of K in the straw was recorded at TPR D_{15} M_{10} which was significantly superior to all the treatment combinations of wet seeding and transplanting. A perusal of the data also showed that dry seeding or wet seeding treatments differed among themselves in the K content.

4.3.6 Effect of cultural management on nutrient uptake by grain and straw

4.3.6.1 Grain

4.3.6.1.1 Main effects of treatments on nutrient uptake

a. Method of crop establishment

Data are presented in Table 4.3.6a. It was noted that method of crop establishment significantly affected the uptake of all nutrients by grain. Dry seeding registered the maximum uptake of all elements except Mn in the grain and it was

Table 4.3.6a Effect of cultural management on nutrient uptake by grain - 1st crop (May-Sept.)

Treatment	Grain (kg ha^{-1})										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO_2
System											
DSR	84.14	17.38	28.05	0.309	3.72	8.58	0.575	0.390	0.138	0.018	738.2
WSR	58.15	12.00	21.21	0.222	2.59	6.64	0.461	0.376	0.093	0.013	630.3
TPR	56.03	11.11	24.76	0.237	2.72	7.00	0.380	0.496	0.124	0.015	588.5
CD(0.05)	10.88	1.78	4.492	0.039	0.368	0.696	0.077	0.081	0.038	0.0038	NS
Digging											
D15	62.78	13.14	23.67	0.251	2.89	6.93	0.458	0.402	0.106	0.014	680.0
D30	69.78	13.86	25.67	0.262	3.13	7.89	0.486	0.439	0.131	0.018	625.0
CD(0.05)	NS	NS	NS	NS	NS	0.568	NS	NS	NS	0.00023	NS
FYM											
M0	59.15	11.70	22.07	0.253	2.63	6.64	0.410	0.382	0.096	0.014	630.7
M5	68.52	14.45	26.72	0.261	3.23	7.90	0.477	0.422	0.134	0.017	614.1
M10	70.65	14.35	25.23	0.255	3.17	7.68	0.529	0.458	0.125	0.017	712.6
CD(0.05)	10.88	1.78	NS	NS	0.368	0.696	0.077	NS	NS	NS	NS
CV (%)	19.12	15.27	21.14	17.51	14.21	10.91	18.43	22.90	32.93	28.78	34.19

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure (0, 5 and 10 t ha^{-1})

superior to both wet seeding and transplanting in the case of N, P, Ca, Mg, S and Fe and the increases were 44.7, 44.8, 39.2, 43.6, 29.2 and 24.7 per cent over wet seeding and 50.2, 56.4, 30.4, 36.8, 22.6 and 51.3 per cent over transplanting. The variation in the case of silica was not significant. Transplanting recorded a significantly higher content of Mn and Zn over wet seeding and in the increases were 31.9 and 33.3 per cent which were statistically significant. The increased uptake of K, Ca, Mg, S and Cu in the grain of the transplanted crop was not significant. Similar was the case with the higher contents of N, P and Fe in wet seeded crop.

b. Depth of digging

Variation in depth of digging significantly affected only the S content. Deep digging (30 cm) significantly increased the S content over shallow digging and the increase was 13.9 per cent.

c. Level of FYM/Organic manure

Application of 10 t ha^{-1} of FYM significantly increased the N, P, Mg, S and Fe content over control and the increases were 19.4, 22.6, 20.5, 15.7 and 29.0 per cent respectively. Five and 10 t ha^{-1} level of FYM did not differ between themselves in affecting the grain content of elements except in the case of Fe and Mn. Iron and Mn content in the grain was significantly higher in transplanted crop and it was significantly higher over wet seeding and the increases were 29.0 and 19.9 per cent over dry seeding and 10.9 and 7.1 per cent over wet seeding.

Magnesium and S contents were highest in the grain in wet seeded crop and they were significantly higher than that in dry seeded crop.

4.3.6.2 Straw

Data on the effect of method of crop establishment, depth of digging and FYM on the elemental composition of straw are given in Table 4.3.6b.

Table 4.3.6b Effect of cultural management on nutrient uptake by straw - 1st crop (May-Sept.)

Treatment	Straw (kg ha^{-1})										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO_2
System											
DSR	57.54	9.27	163.12	9.86	4.61	7.78	3.24	5.18	0.307	0.023	1228.7
WSR	31.23	5.77	88.15	5.88	3.92	5.19	1.17	5.53	0.203	0.017	794.1
TPR	37.82	6.28	104.55	5.80	3.53	5.44	1.97	6.02	0.182	0.019	923.8
CD(0.05)	10.79	1.24	34.38	0.696	0.805	0.729	1.18	NS	0.082	NS	337.2
Digging											
D15	41.77	7.09	116.8	5.46	3.84	6.01	2.13	5.02	0.239	0.017	983.7
D30	42.63	7.13	120.4	8.90	4.20	6.26	2.13	6.14	0.223	0.023	980.8
CD(0.05)	NS	NS	NS	0.568	NS	NS	NS	0.970	NS	NS	NS
FYM											
M0	41.04	6.44	105.46	7.04	3.44	5.87	2.37	5.36	0.236	0.017	932.0
M5	37.24	6.97	128.66	7.45	4.23	6.34	1.82	5.83	0.239	0.023	955.2
M10	48.31	7.91	121.70	7.06	4.40	6.21	2.20	5.54	0.217	0.019	1059.4
CD(0.05)	NS	1.24	NS	NS	0.805	NS	NS	NS	NS	NS	NS
CV (%)	29.71	20.27	33.65	40.08	23.27	15.11	64.60	24.73	40.08	48.82	39.89

DSR - Dry seeded rice WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging (15 and 30 cm)
NS - Non significant M - Manure (0, 5 and 10 t ha^{-1})

a. Method of crop establishment

Dry seeding significantly increased the N, P, K, Ca, S, Fe, Zn and silica content of the straw over wet seeding and transplanting and the increases were 84.2, 60.7, 85.1, 67.7, 49.9, 176.9, 51.2 and 54.7 per cent over wet seeding and 52.4, 47.6, 56.0, 70.0, 43.0, 64.5, 68.7 and 33.0 per cent over transplanting.

b. Depth of digging

Depth of digging did not significantly affect the elemental composition of the straw.

c. Level of FYM/Organic manure

Increasing levels of FYM significantly affected only the P and Mg contents of the straw. Farm yard manure at 10 t ha^{-1} level increased the P and Mg content by 22.8 and 27.9 per cent over control. There was no difference between wet seeding and transplanting in P and Mg content.

The interaction effect of depth of digging, method of crop establishment and level of FYM did not significantly influence the nutrient uptake by grain and straw.

4.3.7 Correlation between root characters and biometric differentials with yield of rice

The data presented in Table 4.3.7 showed a significant positive correlation between root characters and biometric differentials with yield of rice. Maximum correlation was recorded by number of roots/plants with grain yield, straw yield and total biomass followed by difference in total dry weight between flowering and PI stage. The differences in root dry weight between PI and MT stage and flowering and PI stage, shoot dry weight differences between flowering and PI stage, total dry weight difference between PI and MT stage and average root length were also highly correlated

Table 4.3.7 Interaction between root characters, root iron content and some biometric differentials with yield (1st crop - May - Sept.)

Root and biometric characters	Yield			Root iron content
	Grain	Straw	Total	
Shoot dry weight (PI - MT)	0.203	0.186	0.206	-
Root dry weight (PI - MT)	0.625**	0.631**	0.665**	-
Total dry weight (PI - MT stage)	0.422**	0.412	0.442**	-
Shoot dry weight (Flg - PI)	0.609**	0.539**	0.610**	-
Root dry weight (Flg - PI)	0.463**	0.494**	0.506**	-
Total dry weight (Flg - PI)	0.629**	0.577**	0.640**	-
Root Nos/plant	0.748**	0.676**	0.757**	-0.607**
Average root length (cm)	0.402	0.358**	0.404**	-0.565**

with grain yield, straw yield and total biomass. No significant correlation was observed in the case of shoot dry weight difference between PI and MT stage.

4.3.8 Nutrient ratios

4.3.8.1 Effect of cultural management on nutrient ratios of shoot at MT stage

Data presented in Table 4.3.8a. show that dry seeding recorded wider ratios of N/P, N/K, N/Mg, N/S, N/Fe and N/Mn among N relationships, narrow P/Ca, P/Mg, P/S, P/Zn and P/Cu among the P relations and narrow K/Ca, K/Mg, K/Fe, K/Mn, K/S and K/Zn among the K relations.

Between digging to a depth of 15 and 30 cms, significant influence on N based ratios was observed only in N/Mg and N/Mn ratios. K/S ratio widened and S/Mn ratio narrowed down significantly. Phosphorus based ratios were not affected at all.

FYM levels significantly affected only N/Mg and N/S ratios. At 5 t FYM ha^{-1} level of application both ratios were reduced.

4.3.8.2 Effect of cultural management on nutrient ratios of leaf at PI stage

Data presented in Table 4.3.8b. showed that dry seeding registered significantly wider ratios of N/P, N/K, N/Ca, N/Fe, N/Mn, P/Ca, P/Mn, P/Fe, K/Fe, K/Mn and K/Ca and P/Mg and K/Mg ratios were narrow in dry seeding.

Treatment differences in depth of digging did not significantly affect the ratios. Organic manure/FYM levels affected only the P/Zn ratio. Application of 10 t ha^{-1} of FYM narrowed down the ratio significantly.

4.3.8.3 Effect of cultural management on nutrient ratios of boot leaf

Main effect of treatment on the ratios with different elements with N, P and K is presented in Table 4.3.8c.

Table 4.3.8a Effect of cultural management on nutrient ratios of shoot at MT stage - first crop (May-Sept.)

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu
System																	
DSR	11.4	1.2	17.9	14.4	11.0	17.7	67.5	767	5005	0.104	1.64	1.28	0.97	1.57	6.11	66.2	451
WSR	6.4	0.58	17.9	16.8	7.7	13.1	39.4	539	3504	0.09	2.75	2.68	1.22	2.03	6.12	83.5	550
TPR	6.0	0.60	18.8	18.8	7.3	7.1	49.0	516	3921	0.10	3.23	3.29	1.26	1.21	8.36	87.0	681
CD (0.05)	1.76	0.31	NS	3.5	1.53	5.39	17.7	184.1	995	NS	1.04	0.49	0.17	0.53	NS	12.9	152
Digging																	
D_{15}	8.0	0.85	20.5	18.1	8.8	13.0	59.9	623	4292	0.104	2.83	2.51	1.13	1.64	7.64	78.7	578
D_{30}	7.8	0.74	15.9	15.2	8.5	12.2	44.0	592	3996	0.09	2.28	2.33	1.17	1.57	6.09	79.1	544
CD (0.05)	NS	NS	NS	2.8	NS	NS	14.5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FYM																	
M_0	8.6	0.92	20.3	19.1	9.4	11.2	56.4	587	4189	0.103	2.75	2.64	1.18	1.40	6.91	70.7	527
M_5	6.8	0.66	15.6	14.9	7.5	11.0	41.5	534	3928	0.095	2.62	2.54	1.16	1.64	6.40	81.3	621
M_{10}	8.4	0.81	18.6	15.9	9.1	15.7	57.9	702	4314	0.095	2.29	2.07	1.12	1.78	7.28	84.7	534
CD (0.05)	NS	NS	NS	3.5	1.53	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	25.8	45.3	45.4	24.1	20.54	49.6	39.8	35.2	27.9	21.2	47.3	23.9	17.4	38.4	38.5	19.0	31.4

WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.3.8a contd...

	K/Ca	K/Mg	K/S	K/Fe	K/Mn	K/Zn	K/Cu	S/Fe	S/Mn	S/Cu	Mn/Fe	Mn/ Zn	$\frac{Ca+Mg}{K}$	$\frac{Ca+Mg+Fe}{P+K+S}$	$\frac{Ca+Mg+Fe+k}{P+S}$	$\frac{Ca+Mg+Fe+K}{N+P+S}$
System																
DSR	17.0	12.8	10.0	16.5	61.7	683	4757	1.63	6.1	69.1	0.28	13.0	0.16	0.196	6.2	0.98
WSR	29.8	29.9	13.7	23.0	68.4	964	6171	1.7	5.0	69.4	0.36	14.0	0.07	0.104	6.9	1.60
TPR	33.6	33.9	12.9	12.4	86.2	889	6819	0.97	6.8	70.7	0.16	11.3	0.07	0.130	6.5	1.62
CD (0.05)	10.8	5.51	2.27	6.34	NS	196	1512	0.54	1.57	NS	0.09	NS	0.04	0.04	NS	0.25
Digging																
D_{15}	28.6	25.1	11.2	16.1	73.7	776	5665	1.46	6.6	70.2	0.25	11.8	0.10	0.143	6.1	1.28
D_{30}	25.0	26.0	13.2	18.5	70.4	914	6162	1.40	5.3	69.3	0.29	13.9	0.10	0.145	7.0	1.53
CD (0.05)	NS	NS	1.85	NS	NS	NS	NS	NS	1.28	NS	NS	NS	NS	NS	0.85	0.21
FYM																
M_0	27.4	27.1	12.0	14.3	69.7	729	5279	1.18	5.6	61.0	0.24	11.7	0.10	0.15	6.4	1.31
M_5	28.0	27.0	12.4	18.2	68.4	875	6537	1.48	5.7	70.9	0.29	14.0	0.09	0.13	6.6	1.58
M_{10}	25.0	22.5	12.2	12.3	78.1	931	5925	1.64	6.5	77.3	0.27	12.9	0.11	0.15	6.7	1.31
CD (0.05)	NS	NS	NS	NS	NS	196	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.25
CV (%)	46.9	25.0	21.6	42.8	37.3	26.9	29.7	43.8	30.6	25.5	40.9	34.5	40.9	33.9	15.0	-

SR - Wet seeded rice

S - Non significant

TPR - Transplanted rice

M - Farm yard manure (0, 5 and 10 t ha^{-1})

D - Depth of digging

.e 4.3.8b Effect of cultural management on nutrient ratios of leaf at PI stage - first crop (May-Sept.)

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu
tem																	
R	9.0	0.94	9.0	15.0	9.9	28.5	57.8	699	4148	0.105	1.03	1.70	1.1	3.2	6.5	77.7	460
;R	8.2	0.88	7.4	17.4	9.6	20.4	23.6	691	4661	0.108	0.91	2.16	1.19	2.6	2.9	84.2	547
R	7.1	0.73	6.3	16.5	8.5	13.7	29.2	575	4848	0.102	0.89	2.3	1.20	1.9	4.1	81.0	677
(0.05)	1.56	0.18	1.8	NS	NS	7.6	12.7	NS	NS	NS	NS	0.28	NS	0.76	1.3	5.93	98.2
gging																	
	7.9	0.83	7.9	16.1	8.9	19.1	36.7	638	4362	0.105	1.01	2.1	1.13	2.4	4.5	80.8	559
,	8.3	0.87	7.2	16.4	9.8	22.6	37.0	672	4610	0.105	0.88	2.0	1.20	2.7	4.5	81.1	564
) (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
'M																	
)	8.0	0.83	7.2	15.8	9.5	18.4	35.7	670	4229	0.104	0.92	2.0	1.20	2.3	4.3	83.6	535
;	8.3	0.85	8.0	15.9	9.4	21.0	37.4	684	4858	0.103	0.97	1.9	1.14	2.6	4.6	82.5	597
10	8.0	0.86	7.5	17.2	9.2	23.3	37.4	612	4371	0.108	0.93	2.2	1.16	2.8	4.7	76.7	552
) (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	5.93	NS
V (%)	22.4	24.7	27.6	20.5	21.6	42.5	40.1	23.8	26.8	14.0	22.6	16.2	13.3	34.7	33.5	8.51	20.32

R - Wet seeded rice

\- Non significant

TPR - Transplanted rice

M - Farm yard manure (0, 5 and 10 t ha^{-1})

D - Depth of digging

le 4.3.8c Effect of cultural management on nutrient ratios of boot leaf at PI stage - first crop (May-Sept.)

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu
stem																	
SR	12.4	1.50	3.7	34.2	11.5	35.4	9.9	850	7988	0.123	0.304	2.74	0.93	2.9	0.81	68.6	631
SR	10.8	1.43	9.8	16.3	11.2	55.3	15.1	835	5284	0.131	0.929	1.55	1.03	5.2	1.41	75.9	483
PR	10.7	1.24	9.0	18.0	12.3	53.6	13.9	814	5665	0.119	0.847	1.69	1.18	5.1	1.31	78.4	562
D (0.05)	1.6	0.22	1.94	9.65	NS	9.04	1.97	NS	1632	NS	0.22	0.75	NS	0.88	0.25	NS	NS
igging																	
$_{15}$	12.0	1.35	8.1	25.3	12.2	50.1	14.0	838	6586	0.112	0.7	2.07	1.01	4.3	1.19	69.9	540
$_{30}$	10.6	1.43	7.0	20.3	11.1	46.1	11.9	828	6039	0.137	0.69	1.90	1.08	4.5	1.15	78.7	578
D (0.05)	1.3	NS	NS	NS	NS	NS	1.60	NS	NS	0.014	NS	NS	NS	NS	NS	NS	NS
YM																	
$_0$	11.1	1.37	7.7	23.9	11.1	49.5	12.9	816	5746	0.122	0.73	2.09	1.01	4.6	1.20	73.4	505
$_5$	11.0	1.31	6.0	20.6	11.8	41.1	11.9	863	6742	0.121	0.57	1.85	1.08	3.9	1.10	78.7	612
M_{10}	11.8	1.50	8.9	24.0	12.0	53.7	14.1	820	6449	0.130	0.78	2.02	1.05	4.7	1.23	70.8	559
CD (0.05)	NS	NS	1.9	NS	NS	9.04	1.97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	16.6	18.8	29.9	49.2	20.5	21.8	17.6	27.4	30.0	16.5	373	43.8	327	23.2	24.2	23.9	37.7

SR - Wet seeded rice

S - Non significant

TPR - Transplanted rice

M - Farm yard manure (0, 5 and 10 t ha^{-1})

D - Depth of digging

Ratios of elements with N showed that N/P, N/K, N/Mg and N/Cu ratios significantly widened due to dry seeding compared to those in transplanting and N/Fe and N/Mn ratios narrowed down.

Among the P based ratios, P/K, P/S, P/Zn and P/Cu were not significantly affected and all the other ratios narrowed down significantly over transplanting.

Among the K based ratios K/Zn and K/Cu alone were not significantly affected and all the other ratios narrowed down significantly. Mn/Zn, $\frac{Ca+Mg}{K}$, $\frac{Ca+Mg+Fe}{P+K+S}$ widened in dryseeding compared to transplanting.

Variations in depth of digging affected only N/Mn, K/Ca, K/Mn and $\frac{Ca+Mg+Fe+K}{P+S}$ significantly. Deeper digging narrowed down all the three ratios.

Increasing levels of FYM affected only the N/Ca, N/Fe and N/Mn relations significantly. FYM applied at 10 t ha^{-1} widened the ratios as compared to 5 t ha^{-1} level.

4.3.9.1 Interrelation of leaf and boot leaf ratios with yield and physiological attributes

Correlation coefficients of leaf and boot leaf ratios with physiological attributes and yield are presented in Table 4.3.9.

It was seen from the data that the ratios N/Fe, N/Mn and N/Zn were positively related with all physiological parameters and grain and straw yields of rice and were negatively correlated with total biomass production. The relation of N/Fe ratio was significant with chlorophyll `a' at MT and boot leaf total chlorophyll at MT, leaf sap pH of boot leaf and grain and straw yield of rice. Total biomass showed a significant negative relation.

Table 4.3.9 Correlation coefficients of nutrient ratios of leaf and boot leaf with physiologic attributes and yields of rice - First crop (May - Sept.)

Attributes	Leaf			Boot leaf		
	N/Fe	N/Mn	N/Zn	N/Fe	N/Mn	N/Zn
Chl. \`a' at MT	0.358**	0.332**	0.188	-0.166	-0.066	0.311
Chl. \`b' at MT	0.257	0.283	0.143	-0.120	-0.011	0.163
Total Chl. at MT	0.403**	0.332**	0.147	-0.101	-0.008	0.211
Chl. \`a' at PI	0.115	0.001	0.002	-0.276	-0.130	-0.251
Chl. \`a' at PI	0.074	0.193	0.097	-0.233	-0.215	0.027
Total Chl. \`a' PI	0.113	0.054	0.052	-0.203	-0.152	-0.106
Chl. \`a' at boot leaf	0.370**	0.674**	0.153	-0.393**	-0.255	0.085
Chl. \`b' at boot leaf	0.114	0.445**	0.097	-0.011	0.067	0.178
Total Chl. at boot leaf	0.311	0.629**	0.152	-0.274	-0.154	-0.156
Leaf sap pH at MT	0.281	0.313	0.169	-0.271	-0.128	-0.015
Leaf sap pH at PI	0.311	0.394**	0.330**	-0.293	-0.234	-0.044
Leaf sap pH at boot leaf	0.403*	0.332**	0.147	-0.108	-0.088	-0.211
Grain yield	0.543**	0.654**	0.184	-0.546**	-0.409**	0.031
Straw yield	0.579**	0.539**	0.215	-0.583**	-0.409**	0.076

The significant positive correlation observed in N/Mn ratio was with chlorophyll `a' and total chlorophyll at MT, chlorophyll `a', `b' and total chlorophyll at boot leaf, leaf sap pH of leaf at PI and at boot leaf and with grain and straw yields. N/Zn ratio recorded significant positive correlation with leaf sap pH of leaf at PI stage only.

In the case of boot leaf, a reverse trend was observed in the relation between nutrient ratios, physiological attributes and yields of rice. All the three ratios viz., N/Fe, N/Mn and N/Zn showed negative relationship with all the physiological attributes and yield and relation was significant in the case of N/Fe with chlorophyll `a' at boot leaf and N/Fe and N/Mn with grain and straw yields. Contrarily total biomass showed a significant positive relationship with N/Fe ratio of boot leaf.

4.3.9.2 Interrelations of leaf sap pH with chlorophyll content and yield of rice

Chlorophyll `a' `b' and total chlorophyll content of leaf at MT at PI and boot leaf were positively related with leaf sap pH at all stages except chlorophyll content of leaf at MT with boot leaf sap pH (Table 4.3.10).

At maximum tillering stage, the leaf sap pH was significantly correlated with chlorophyll `a' content of all the three stages and total chlorophyll at MT stage and boot leaf stage. The leaf sap pH of leaf at PI stage was significantly correlated with chlorophyll `a' at MT stage and chlorophyll `a', `b' and total chlorophyll of boot leaf. The boot leaf sap pH showed significant correlation only with chlorophyll `b' and total chlorophyll of leaf at PI stage.

With regard to yield, grain and straw yields recorded a significant positive relationship with leaf sap pH at all the three stages. The relation of leaf sap pH with total biomass was negative at all stages though the relation was not statistically significant.

Table 4.3.10 Inter-relations between physiologic attributes and yield of rice - First crop

Physilogic attributes	Leaf sap pH			Yield	
	MT	PI	Boot leaf	Grain	Straw
Chl. \`a' at MT	0.363*	0.326*	-0.064	0.440*	0.467**
Chl. \`b' at MT	0.185	0.201	-0.121	0.349*	0.304
Chl. at MT	0.360*	0.292	-0.049	0.453**	0.456**
Chl. \`a' at PI	0.343*	0.204	0.311	0.203	0.373*
Chl. \`b' at PI	0.270	0.112	0.359*	0.190	0.245
Total Chl. \`a' PI	0.270	0.112	0.359*	0.165	0.229
Chl. \`a' at boot leaf	0.435*	0.657**	0.227	0.740**	0.642**
Chl. \`b' at boot leaf	0.085	0.491**	0.134	0.387*	0.267
Total Chl. at boot leaf	0.304	0.652**	0.201	0.648**	0.543**
Leaf sap pH at MT	-	-	-	0.485**	0.514**
Leaf sap pH at PI	-	-	-	0.501**	0.581**
Leaf sap pH at boot leaf	-	-	-	0.453**	0.456**

Table 4.3.11 Inter-relations of nutrient ratios of leaf and boot leaf of rice - First crop

Physilogic attributes		Leaf			Boot leaf		
		N/Fe	N/Mn	N/Zn	N/Fe	N/Mn	N/Zn
Leaf	N/Fe	1.00					
	N/Mn	0.293	1.00				
	N/Zn	0.333*	0.294	1.000			
Boot leaf	N/Fe	-0.210	-0.365*	-0.165	1.000		
	N/Mn	-0.120	-0.277	-0.160	0.765**	1.000	
	N/Zn	0.239	0.244	0.065	0.207	0.329*	1.000

Plate 1 Progressional root damage in dry seeded rice

1. Maximum tillering stage
2. Panicle initiation stage
3. Boot leaf stage


DSR
1
2
3

Plate 2 Progressional root damage in wet seeded rice

1. Maximum tillering stage
2. Panicle initiation stage
3. Boot leaf stage

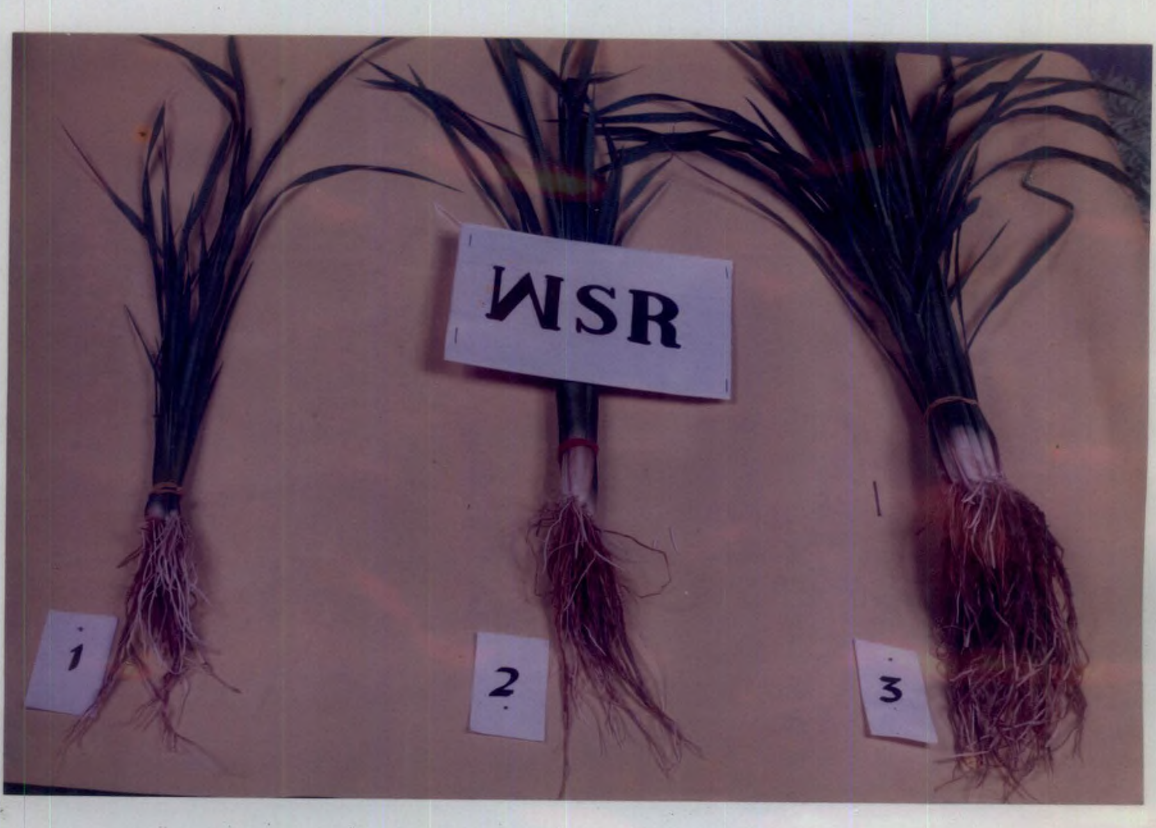

WSR
1
2
3

Plate 3 Progressional root damage in transplanted rice

1. Seedling stage
2. Maximum tillering stage
3. Panicle initiation stage
4. Boot leaf stage

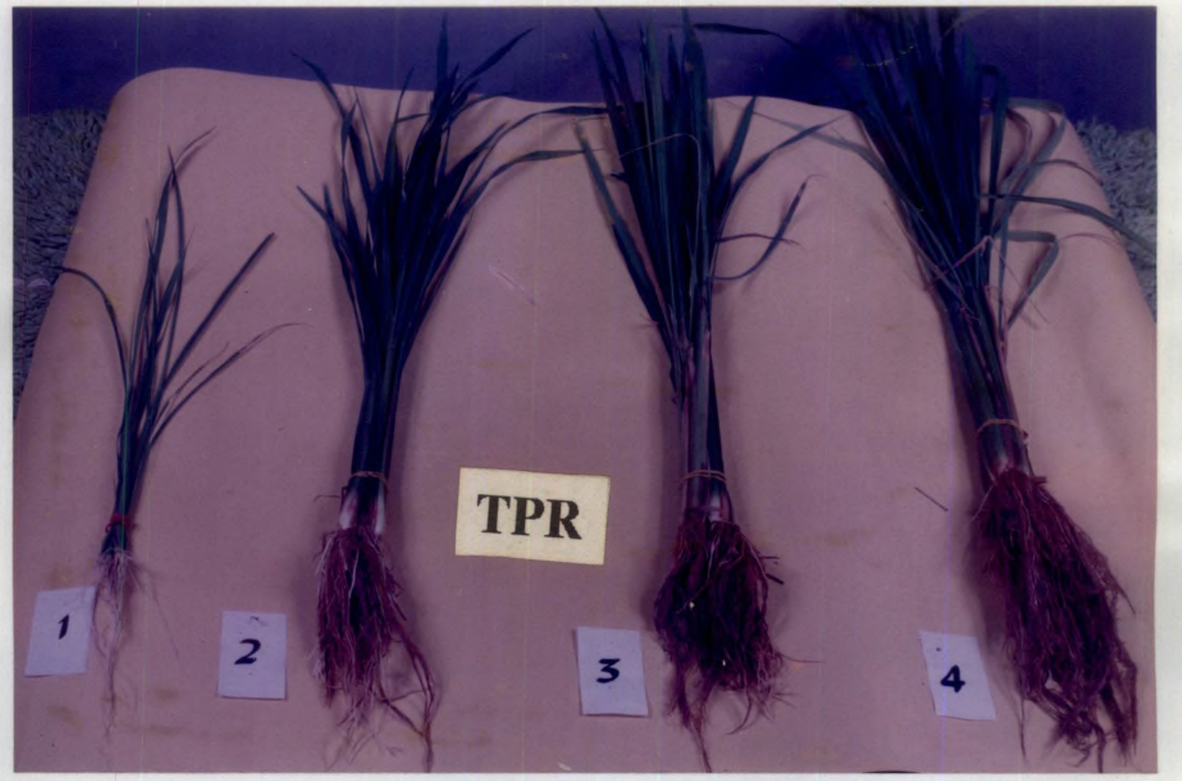

TPR
1
2
3
4

Plate 4 Comparative efficacy of method of crop establishment on root charactors at maximum tillering (MT) stage

DSR - Dry Seeded Rice
WSR - Wet Seeded Rice
TPR - Transplanted Rice

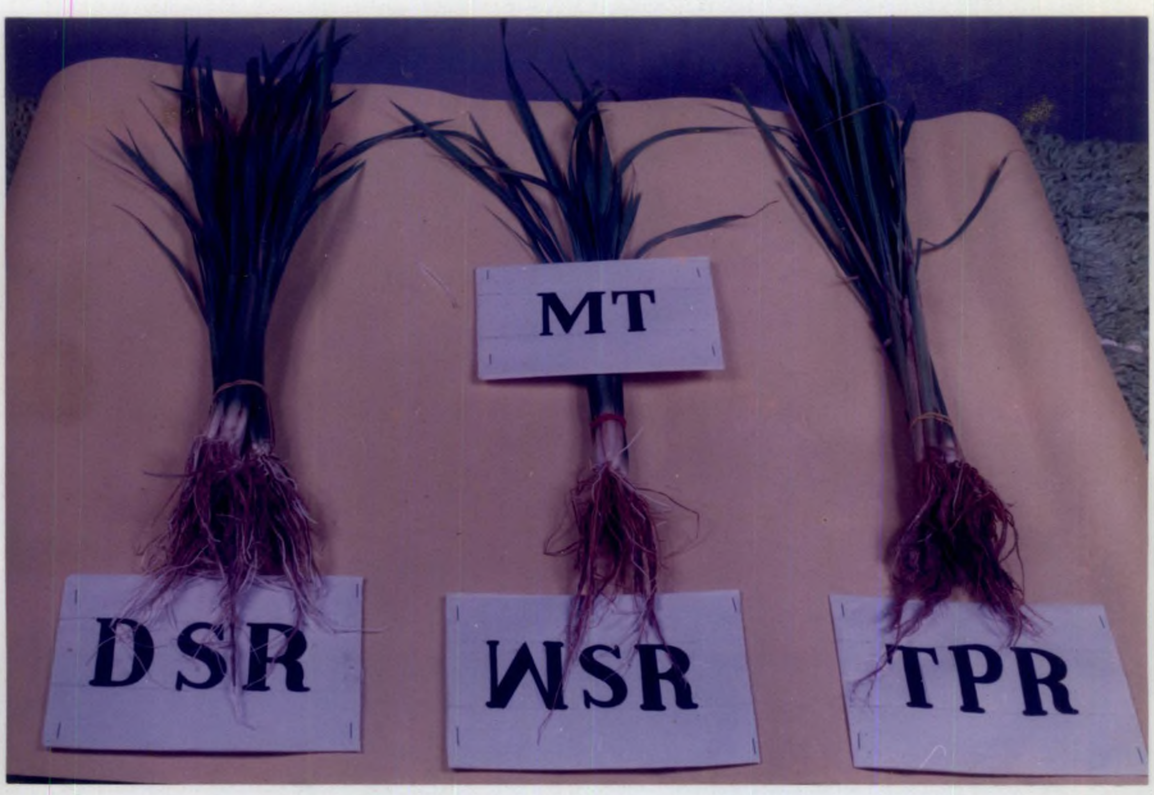
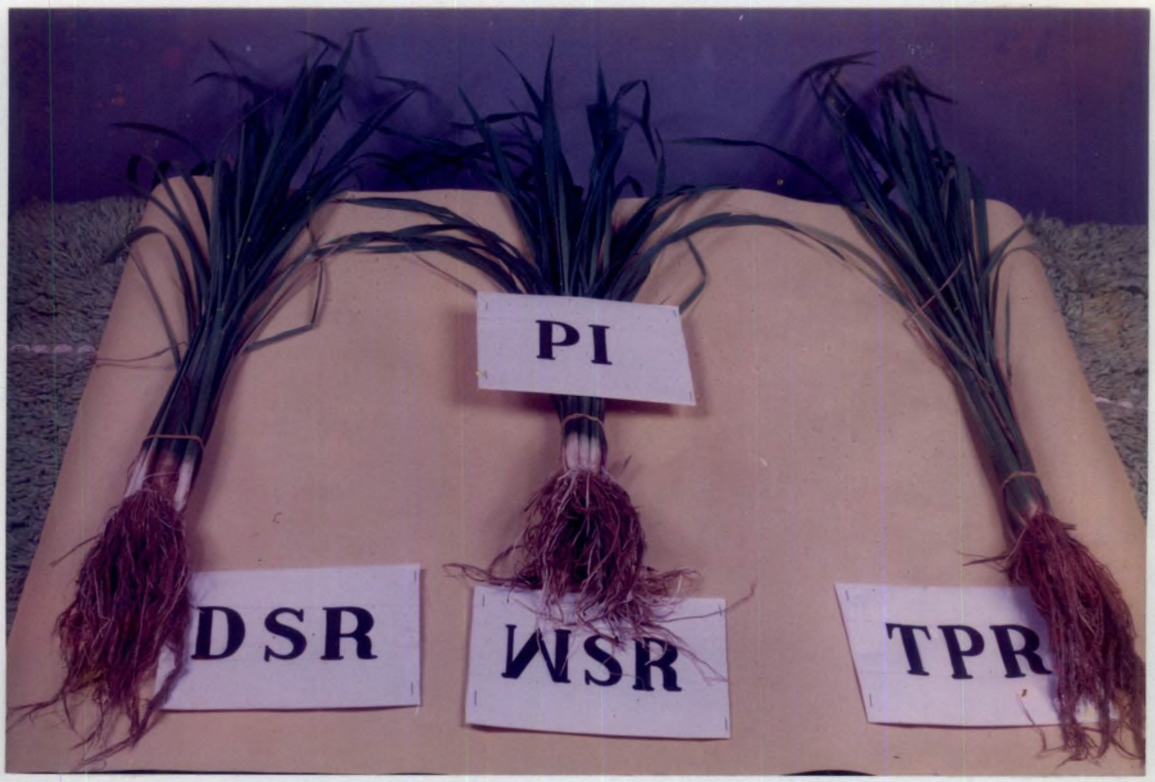

MT
DSR
WSR
TPR

Plate 5 Comparative efficacy of method of crop establishment on root charactors at panicle initiation (PI) stage

DSR - Dry Seeded Rice
WSR - Wet Seeded Rice
TPR - Transplanted Rice


PI
DSR
WSR
TPR

4.3.9.3 Interrelation of nutrient ratios of leaf and boot leaf

Data presented in Table 4.3.11. showed that the ratio N/Fe of leaf at PI was positively related with N/Mn and N/Zn of leaf at PI and N/Zn of boot leaf and negatively related with N/Fe and N/Mn of boot leaf.

The N/Mn ratio of leaf at PI was negatively related with N/Fe and N/Mn ratios of boot leaf and positively related with N/Zn ratio of both stages and the relationship between N/Mn of leaf and N/Fe ratio of boot leaf was statistically significant.

In the boot leaf, the ratio N/Fe recorded a significant positive relationship with N/Mn ratio of boot leaf and the latter showed significant positive relation with N/Zn ratio of boot leaf.

4.4 EXPERIMENT IV

4.4.1 Main effects

4.4.1.1 Method of crop establishment

4.4.1.1.1 Growth attributes

Data on the effect of cultural management and FYM on the performance of rice is presented in Table 4.4.1a.

Observations on the variability in crop performance between wet seeding and transplanting showed that the latter recorded significantly higher number of tillers at all the stages of growth and greater height at flowering and harvest. The increases in height at flowering and harvest worked out to 15.5 and 14.0 per cent over wet seeding. The increases in tiller counts at the four stages of growth in transplanted crop were 107.4, 173.9, 161.5 and 184.6 per cent.

4.4.1.1.2 Physiological attributes

Chlorophyll content was found to be significantly higher in wet seeded crop at MT but this superiority was extended to boot leaf only in respect of chlorophyll `a'.

Table 4.4.1a Effect of cultural management on morphophysiological characters of rice - Second crop (Oct - Feb)

	Growth attributes												
	Plant height (cm)				Tillers/hill				Root characters/plant				Av. root length at MT (cm)
	MT	PI	Flg.	Harvest	MT	PI	Flg	Harvest	No. of roots		Max. root length (cm)		
									MT	Flg	MT	Flg	
System													
WSR	46.3	51.0	59.2	60.5	2.7	2.3	2.6	2.6	42.0	45.2	11.86	9.8	2.4
TPR	47.3	52.4	68.4	69.0	5.6	6.3	6.8	7.4	123.1	113.0	10.81	12.5	4.7
CD(0.05)	NS	NS	2.52	2.26	0.466	0.432	0.768	0.680	14.8	10.35	NS	1.48	0.651
Digging													
D_{15}	47.2	51.9	63.9	64.3	4.1	4.2	4.8	5.0	73.6	73.5	11.25	10.70	3.6
D_{30}	46.3	51.5	63.8	65.4	4.2	4.5	4.6	5.0	91.5	84.8	11.42	11.70	3.6
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	14.8	10.35	NS	NS	NS
FYM													
M_0	44.2	49.2	60.1	62.3	4.0	4.0	4.6	4.6	88.7	70.5	10.33	10.3	3.4
M_5	46.6	51.8	64.1	64.5	4.5	4.4	4.8	5.1	79.8	85.4	11.95	11.6	3.5
M_{10}	49.5	54.2	66.9	67.7	4.0	4.7	4.7	5.3	79.1	81.4	11.72	11.6	3.9
CD(0.05)	3.00	3.75	3.08	2.77	NS	0.529	NS	NS	NS	NS	NS	NS	NS
CV(%)	7.59	8.57	5.70	5.05	16.23	14.42	23.67	19.62	26.01	33.18	21.84	19.16	26.3

WSR - Wet seeded rice TPR - Transplanted rice NS - Non significant

Table 4.4.1a contd.....

	Growth attributes								Physiologic attributes							
	Plant dry weight (g/plant)								Chlorophyll (mg/g fresh sample weight)							
	Maximum tillering				Flowering				MT			Boot leaf			Leaf sap pH	
	Shoot	Root	Total	S/R	Shoot	Root	Total	S/R	Chl.a	Chl.b	Total	Chl.a	Chl.b	Total	MT	Boot leaf
System																
WSR	2.20	0.4	2.5	6.0	14.5	1.59	15.54	9.5	2.01	1.25	3.18	1.40	1.30	2.69	6.74	6.47
TPR	6.41	1.4	7.8	4.7	19.3	1.98	21.88	10.5	1.75	1.01	2.64	1.47	1.25	2.71	6.55	6.33
CD(0.05)	0.597	0.150	0.659	NS	1.99	0.27	2.07	NS	0.11	0.22	0.18	0.069	NS	NS	0.049	0.044
Digging																
D_{15}	4.13	0.8	4.9	5.2	17.4	1.71	19.37	10.6	1.91	1.23	3.06	1.45	1.40	2.83	6.63	6.42
D_{30}	4.43	1.0	5.4	5.5	16.4	1.86	18.65	9.1	1.85	1.03	2.77	1.43	1.15	2.56	6.66	6.39
CD(0.05)	NS	0.15	NS	NS	NS	NS	NS	NS	NS	NS	0.180	NS	0.171	0.179	NS	NS
FYM																
M_0	3.7	0.7	4.4	5.5	15.8	1.60	17.28	10.2	1.85	1.14	2.92	1.42	1.27	2.68	6.63	6.40
M_5	4.2	0.9	5.2	5.4	18.0	1.95	19.59	9.6	1.93	1.09	2.93	1.44	1.25	2.69	6.65	6.40
M_{10}	4.9	1.1	6.0	5.2	17.0	1.81	19.26	9.8	1.86	1.16	2.89	1.46	1.30	2.79	6.66	6.40
CD(0.05)	0.731	0.186	0.808	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	20.18	24.18	18.45	45.5	17.07	21.85	15.99	21.43	8.35	28.27	8.97	7.10	19.36	9.62	1.04	0.98

WSR - Wet seeded rice TPR - Transplanted rice NS - Non significant

The increase in chlorophyll `a', chlorophyll `b' and total contents in wet seeding over transplanting were 14.9, 23.6 and 20.3 per cent respectively at MT stage.

Leaf sap pH also recorded significantly higher value in wet seeding at MT, the value being 6.74 in wet seeding and 6.55 in transplanting.

Transplanting registered a mean number of 123 and 113 roots per hill as against 42 and 45 in wet seeding at maximum tillering and flowering stages respectively and the differences were statistically significant. Transplanted crop also recorded a mean higher root length of 12.5 cm as against 9.8 cm in wet seeded crop at flowering.

4.4.1.1.3 Yield attributes and yield

Observations on yield attributes (Table 4.4.1b) showed that wet seeding was significantly superior to transplanting in respect of panicle weight, 1000 grain weight as well as percentage of filled grains and the percentage increases were 26.3, 3.4 and 15.8 per cent. But transplanting was better as far as the number of panicle per hill panicle length, number of branches per panicle, filled and unfilled grains were considered and the increases worked out to 191.3, 7.6, 9.4, 30.3 and 165.2 per cent respectively.

The data further revealed that while transplanting gave a higher yield of 5168 kg ha^{-1} which was 485 kg more than that of wet seeding, wet seeding gave 433 kg ha^{-1} of straw more than transplanting. The total biomass yield under both the treatments were statistically on par though transplanting recorded a significantly wider grain-straw ratio (Fig.4.4.1.).

4.4.1.2 Cultural management (Digging)

4.4.1.2.1 Growth attributes

Differential influence of depth of digging (15 and 30 cm) were not apparent on plant height or tiller counts at any phase of growth (Table 4.4.1a).

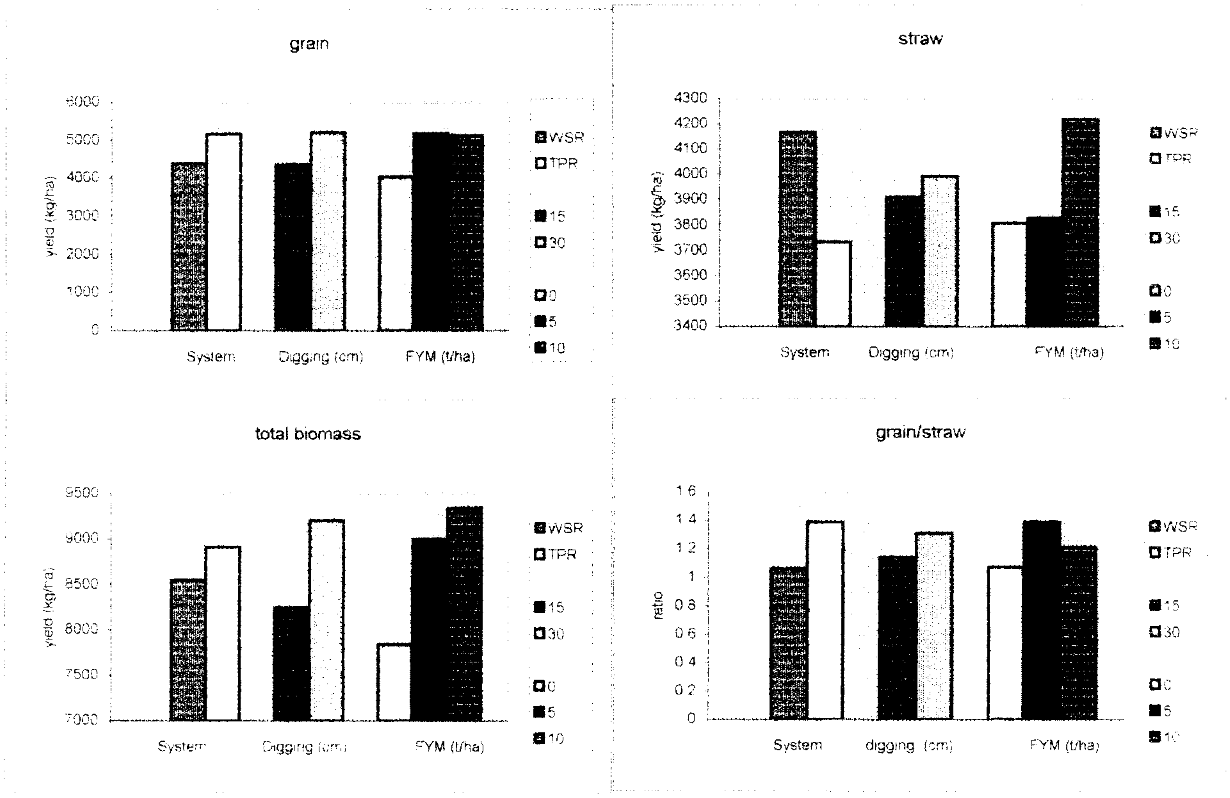


Fig. 4.4.1 Effect of cultural management on grain, straw and total biomass yield and grain / straw - second crop (October - February)

Table 4.4.1b Effect of cultural management on yield attributes and yield of rice - Second crop (Oct - Feb)

	No. of panicles/ hill	Panicle wgt/10 panicle (g)	Panicle length (cm)	Branches/ panicle (Nos.)	Filled grains/ panicle (Nos.)	Unfilled grains/ panicle (Nos.)	1000 grain weight (g)	Percentage of filling	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total biomass (kg ha^{-1})	Grain/ straw
System												
WSR	2.3	22.6	17.1	6.4	49.8	9.2	27.6	84.3	4383	4167	8549	1.06
TPR	6.7	17.9	18.4	7.0	64.9	24.4	26.7	72.8	5168	3734	8908	1.39
CD(0.05)	0.68	1.02	0.516	0.379	3.85	3.51	0.69	3.46	426.05	224.7	NS	0.098
Digging												
D_{15}	4.6	20.2	17.8	6.7	57.6	17.7	26.5	77.7	4339	3909	8250	1.14
D_{30}	4.4	20.3	17.8	6.6	57.0	16.0	27.7	79.4	5211	3992	9206	1.31
CD(0.05)	NS	NS	NS	NS	NS	NS	0.69	NS	426.05	NS	579.5	0.098
FYM												
M_0	4.2	19.1	17.5	6.6	52.2	19.7	27.3	75.4	4031	3808	7842	1.07
M_5	4.5	21.1	17.9	6.8	61.3	14.6	27.1	81.8	5176	3826	9001	1.39
M_{10}	4.8	20.5	17.9	6.6	58.5	16.2	27.0	78.5	5119	4218	9341	1.21
CD(0.05)	NS	1.217	NS	NS	4.71	4.30	NS	4.23	521.8	275.23	709.79	0.120
CV(%)	21.87	7.27	4.21	8.21	9.71	30.14	3.60	6.37	12.91	8.23	9.60	11.46

WSR - Wet seeded rice TPR - Transplanted rice NS - Non significant

4.4.1.2.2 Physiological attributes

Among the physiological traits total chlorophyll content at MT and boot leaf and chlorophyll `b' content at boot leaf were significantly higher when digging was confined to 15 cm only. The increases in total chlorophyll at MT and at boot leaf were 10.6 and 10.3 per cent. A perusal of the data also showed that between MT and boot leaf, chlorophyll contents tended to decline. Leaf sap pH was not significantly affected.

However, contrary to morphological development in the above ground parts, digging to a depth of 30 cm increased the number of roots by 24.3 and 15.4 per cent respectively at MT and flowering stage.

4.4.1.2.3 Yield attributes and yield

Differences due to the effect of digging to 15 and 30 cms were not apparent in yield attributes studied except 1000 grain weight (Table 4.4.1b). Digging to a depth of 30 cm increased the grain weight significantly by 4.5 per cent over that of 15 cm digging (Fig.4.4.1.).

Digging significantly increased the total biomass, grain yield and grain straw ratio but the straw yield remained unaffected. Digging to a depth of 30 cm recorded 5211 kg grain ha^{-1} as against 4339 kg under 15 cm depth. It also recorded a significantly higher grain straw ratio.

4.4.1.3 Farm yard manure/Organic manure

4.4.1.3.1 Growth attributes

Increasing levels of FYM (Table 4.4.1a) significantly increased the height of the rice plants at all stages and tiller counts at PI stage. Application of FYM at 10 t ha^{-1} was superior and the increases over control were 12.0, 10.2, 11.3 and 8.7 per cent at MT, PI, flowering and harvest stages while the increase in tiller count at PI was 17.4 per cent. Differences in tiller counts on the subsequent stages were not significant.

4.4.1.3.2 Physiological attributes

Chlorophyll content and leaf sap pH at all the stages remained unaffected (Table 4.4.1a).

Application of FYM significantly influenced the plant dry weight only at MT. Application of FYM at 10 t ha^{-1} increased the shoot, root and total dry weight and the increases over control were 32.4, 42.9 and 36.4 per cent respectively.

4.4.1.3.3 Yield attributes and yield

Application of FYM significantly affected the yield and yield attributes (Table 4.4.1b). FYM applied @ 5 t ha^{-1} recorded higher panicle weight, filled grains per panicle and lower number of unfilled grains per panicle and the increases over control were 10.5 and 17.4 per cent. Increasing the level beyond 5 t ha^{-1} did not have any beneficial effect.

Application of 5 t ha^{-1} of FYM recorded yield of 5176 kg ha^{-1} which was 1145 kg higher than that of control. Further increases in the level of FYM failed to increase the grain yield but increased straw yield significantly(Fig. 4.4.1.).

4.4.2 Interaction effects of cultural management on growth, yield attributes and yield

4.4.2.1 Combined effect of depth of digging and method of establishment on growth attributes, physiological characters, yield attributes and yield

a) Growth attributes

Data presented in Table 4.4.2a showed that only rooting characteristics were significantly influenced by the interacting influences of land preparation and crop establishment. Deep digging registered a higher number of roots both at MT and PI stages by 40.6 and 34.3 per cent over shallow digging in transplanted crop. It also

Table 4.4.2a Combined effect of crop establishment and digging on growth attributes, physiologic characters and yield attributes and yield of rice - Second crop (Oct-Feb)

System	No. of roots/plant at MT		No. of roots/plant at PI		Root dry weight (g/plant)			
					Maximum tillering		Panicle initiation	
	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
Digging								
D15	44.87	102.3	50.48	96.5	0.406	1.204	1.68	1.70
D30	39.15	143.8	39.96	129.6	0.366	1.650	1.50	2.23
CD(0.05)	20.99		25.66		0.214		0.381	

System	Chlorophill (mg/g fresh sample weight)						Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Total biomass (kg ha^{-1})	
	Chl.`a' at MT		Chl.`b' boot leaf		Total Chl. at boot leaf							
	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
Digging												
D15	1.985	1.831	1.318	1.477	2.693	2.966	4072	4606	4297	3521	8370	8131
D30	2.037	1.663	1.277	1.021	2.677	2.451	4693	5730	4037	3947	8729	9684
CD(0.05)	0.154		0.241		0.310		602.5		317.8		819.6	

increased the dry weight of roots by 37.0 and 31.2 per cent at MT and PI stage respectively. On the other hand deep digging only tended to reduce the number of roots and weight of roots in wet seeded crop. While wet seeding under shallow digging gave higher number of roots than under deep digging, the reverse was true in transplanting. Thus, the combined effect of deep digging and transplanting recorded 220.5 and 156.7 per cent more roots than the combined effect of wet seeding and shallow dogging at MT and PI stages. The corresponding increase in root weight were 306.4 and 32.7 per cent at MT and PI stages. Combined effect had no significant effect on shoot weight at both the stages.

b) Physiological attributes

Data on combined effect of digging and crop establishment on chlorophyll characteristics are presented in Table 4.4.2a.

The data showed that while deep digging significantly reduced the chlorophyll `a' content in transplanted crop at MT stage by 9.2 per cent, the same tended to increase it in wet seeding. The highest chlorophyll `a' content was recorded by the combined effect of wet seeding and digging to 30 cm depth which was 22.5 per cent more than that recorded in transplanted crop.

The data on the combined effect of digging and crop establishment presented in Table 4.4.2a. showed that chlorophyll `b' content of boot leaf varied significantly under the different combinations. Lowest chlorophyll `b' content was recorded in transplanted crop in deep dug soil environment and the decline worked out to 30.9 per cent as compared to that in shallow digging.

It was also seen that the significant inhibiting influence of deep digging was apparent on total chlorophyll content of the boot leaf also. The lowest content of total chlorophyll was recorded in transplanted crop combined with digging to 30 cm which was lower than that under 15 cm digging by 17.4 per cent.

c) Yield attributes and yield

It can be seen from the Table 4.4.2a that combined effect of treatment components modified the crop performance significantly and that the yield expression was a function of the combined effects. Thus the grain yield in wet seeding and transplanting crop under 30 cm deep digging significantly increased by 15.3 and 24.4 per cent when they were combined with 15 cm shallow digging.

In accordance with the increase in grain yield, straw yield also increased significantly by 12.1 per cent in transplanted crop when depth of digging was increased but it had no effect on wet seeded crop.

It was noted that the treatment effects were reflected in the total biomass production also. By increasing the depth of digging to 30 cm, the total biomass in transplanted crop increased by 19.1 per cent over that of 15 cm depth of digging. The effect was however not significant in wet seeded crop.

4.4.2.2 Combined effect of FYM and crop establishment on yield attributes and yield of rice

a) Yield attributes and yield

Data presented in Table 4.4.2b. showed that effectiveness of FYM in increasing the grain yield increased in transplanted crop over wet seeded crop and the same reached significant level at 10 t ha^{-1} level of FYM application. At this level the yield increase worked out to 22.7 per cent over wet seeded crop. The highest yield in the treatment combinations was also recorded at M_{10}TPR which was 54.0 per cent more than M_0WSR.

Table 4.4.2b Combined effect of crop establishment and FYM on yield attributes and yield or rice - Second crop (Oct-Feb.)

	No. of unfilled grains/panicle (Nos.)		Percentage of filling (%)		Grain yield (kg ha^{-1})		Total biomass (kg ha^{-1})	
	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
Mo	9.0	30.4	84.3	66.6	3662	4399	7730	7955
M5	8.3	21.0	86.8	76.8	4887	5464	8930	9022
M10	10.5	21.9	81.8	75.1	4598	5641	8938	9745
CD(0.05)	6.07		5.99		737.9		1003.8	

Table 4.4.2c Combined effect of FYM and digging on yield of rice - second crop (Oct-Feb)

	Grain yield (kg ha^{-1})			Total biomass (kg ha^{-1})		
	Mo	M5	M10	Mo	M5	M10
D15	3552	4660	4806	7291	8527	8933
D30	4509	5692	5433	8394	9476	9751
CD (0.05)	737.9			1003.8		

WSR - Wet seeded rice
TPR - Transplanted rice

D - Depth of digging
M - Organic manure/FYM

Total biomass production also was highest in transplanted crop receiving 10 t ha^{-1} FYM which was significantly superior to wet seeded or transplanted crop receiving no FYM.

Combined effect of organic manure levels and method of crop establishment significantly influenced the number as well as percentage of unfilled grains. Application of FYM @ 5 t ha^{-1} in transplanted crop significantly reduced the number of unfilled grains as well as increased the filling percentage. But FYM had no effect on any of the above two attributes when the crop was a wet seeded one. Thus FYM applied @ 5 t ha^{-1} reduced the number of unfilled grains by 30.9 per cent and increased the percentage filling by 15.3 respectively in transplanted crop. Wet seeded crop did not manifest any relationship.

4.4.2.3 Combined effect of digging and FYM

It can be seen from the Table 4.4.2c. that yield of *mundakan* rice crop was significantly affected by the effect of FYM and depth of digging. Highest grain yield of 5692 kg ha^{-1} was observed in $D_{30}M_5$ combination which was 60.2 per cent more than $D_{15}M_0$ combination which recorded the lowest yield.

Maximum biomass production was recorded in $D_{30}M_{10}$ combination which was 33.7 per cent more than $D_{15}M_0$.

4.4.3 Second order interaction effects

Combined effect of organic manure, method of land preparation and crop establishment on total as well as root and shoot dry weight at MT is presented in Table 4.4.2d.

It can be seen that method of land preparation and crop establishment influenced the rate and extent of response of rice crop to FYM levels. Total as well as root and

Table 4.4.2d Combined effect of crop establishment, FYM and digging on root characters of rice - Second crop (Oct-Feb)

Treatment	Root dry weight (g/plant) at MT			Shoot dry weight (g/plant) at MT			Total dry weight (g/plant) at MT		
	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR D_{15}	0.42	0.31	0.49	2.2	1.6	2.4	2.50	1.93	2.95
WSR D_{30}	0.34	0.40	0.35	2.0	2.4	2.2	2.42	2.78	2.57
TPR D_{15}	0.78	1.47	1.36	4.3	7.3	7.0	5.05	8.70	8.35
TPR D_{30}	1.19	1.52	2.24	6.4	5.7	7.8	7.55	7.25	10.00
CD (0.05)		0.371			1.46			1.615	

WSR - Wet seeded rice	D - Depth of digging
TPR - Transplanted rice	M - Organic manure/FYM

shoot dry weight were significantly lower in wet seeded crop irrespective of depth of digging and FYM levels. On the contrary, in the case of transplanted crop, depth of digging influenced the response to OM levels. When the land was dug only to a depth of 15 cm, response of rice was limited to 5 t ha^{-1} in respect of total as well as shoot and root dry weight at MT stage; whereas deep digging to 30 cm increased the response upto 10 t ha^{-1} of FYM. The increase in total as well as root and shoot dry weight at MT in transplanted crop was 72.3, 88.5 and 69.8 per cent over control and the corresponding increases under 30 cm digging and 10 t ha^{-1} FYM in transplanted crop were 32.4, 88.2 and 21.9 per cent respectively.

None of the second order interactions had any significant influence on yield of grain or straw or biomass production of rice.

4.4.4 Effect of cultural management on elemental composition of rice - second crop

4.4.4.1 Main effects

4.4.4.1.1 Elemental composition of root at MT and PI stages

a) Method of crop establishment

Data on the effect of various treatments on the elemental composition of root at MT and PI stages are presented in Table 4.4.3a. Transplanting significantly increased the K, S, Fe, Zn and Cu contents of the root at MT stage over wet seeding and the increases were 29.3, 31.6, 41.8, 26.4 and 23.5 per cent respectively. Nitrogen, P, Ca, Mg and Mn contents were unaffected.

At PI stage P continued to remain unaffected and S, Zn and Cu contents continued to be higher in the root in the transplanted crop by 25.5, 14.2 and 13.9 per cent. Nitrogen content of the root significantly increased and the K content

Table 4.4.3a Effect of cultural management on elemental composition of root in rice - Second crop (Oct-Feb)

Treatment	Root at Maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
WSR	0.950	0.212	1.703	0.024	0.075	1937	31621	1371	79.2	42.6
TPR	0.882	0.237	0.202	0.033	0.077	2550	44829	1370	100.1	52.6
CD(0.05)	NS	NS	0.227	NS	NS	110.2	1731	NS	9.75	7.27
Digging										
D_{15}	0.926	0.226	1.904	0.024	0.076	2337	41753	1334	92.4	50.0
D_{30}	0.906	0.223	2.001	0.033	0.076	2149	34698	1407	86.8	45.2
CD(0.05)	NS	NS	NS	NS	NS	110.2	1731	NS	NS	NS
FYM										
M_0	0.906	0.217	2.001	0.036	0.077	2359	31706	1141	88.0	55.5
M_5	0.921	0.222	1.915	0.024	0.075	2136	36031	1461	88.4	45.7
M_{10}	0.921	0.234	1.942	0.026	0.077	2235	46939	1510	92.5	41.6
CD(0.05)	NS	NS	NS	NS	NS	134.9	6705	302.7	NS	8.90
CV (%)	19.03	17.46	16.86	97.32	13.27	7.12	20.76	26.15	15.76	22.12

WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.4.3a contd...

Treatment	Root at panicle initiation									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
WSR	0.813	0.183	1.167	0.025	0.075	2085	31593	1168	74.1	45.3
TPR	1.007	0.188	1.122	0.020	0.063	2618	48933	1343	84.7	51.6
CD(0.05)	0.138	NS	NS	0.005	0.007	178.0	3615.2	166.4	NS	4.73
Digging										
D_{15}	0.856	0.180	1.075	0.021	0.069	2374	37846	1246	76.5	52.7
D_{30}	0.963	0.191	1.214	0.024	0.068	2329	42681	1264	82.3	44.2
CD(0.05)	NS	0.010	0.076	0.005	NS	NS	3615.2	NS	NS	4.73
FYM										
M_0	0.934	0.167	1.083	0.022	0.067	2327	35138	1157	77.3	56.3
M_5	0.811	0.189	1.192	0.023	0.066	2363	44220	1140	72.9	45.5
M_{10}	0.984	0.201	1.158	0.022	0.072	2364	41431	1468	87.9	43.5
CD(0.05)	NS	0.013	NS	NS	NS	NS	4427.7	203.8	NS	5.80
CV (%)	22.09	8.08	9.75	16.17	13.94	10.97	13.01	19.21	22.03	14.16

WSR - Wet seeded rice
NS - Non significant
TPR - Transplanted rice
M - Farm yard manure (0, 5 and 10 t ha^{-1})
D - Depth of digging

decreased and the change worked out to 23.9 and 3.9 per cent respectively. Calcium and Mg registered significantly lower contents (20 and 14.9 per cent) in the root at PI stage.

b) Method of land preparation (Digging)

Data (Table 4.4.3a) on the effect of depth of digging showed that the effect on root elemental composition was confined to S and Fe content at MT stage. Deep digging (D_{30}) significantly reduced the S and Fe contents of the root by 8.0 and 16.9 per cent over shallow digging (D_{15}).

Significant variation in the effect of digging on elemental composition of root was observed at PI stage in respect of more number of elements. Deeper digging significantly increased the P, K, Ca and Fe contents and the increases were 6.1, 12.9, 14.3 and 12.8 per cent over shallow digging (D_{15}). Deep digging reduced the copper content alone and it worked out to 16.1 per cent.

c) Application of FYM/OM

Increasing levels of FYM did not have any effect on the root contents of N, P, K, Ca, Mg and Zn at MT stage. Application of FYM @ 10 t ha^{-1} reduced the S and Cu contents and increased the Fe and Mn contents. The decrease in S and Cu contents and the increase in Fe and Mn contents at 10 t ha^{-1} FYM level worked out to 5.2 and 25.0 and 48.0 and 24.4 per cent respectively.

Data on the elemental composition at PI stage showed that P, Fe and Mn contents increased significantly due to FYM application. P and Mn contents registered continuous increase while Fe content rose only upto 5 t ha^{-1} level FYM application. Phosphorus and Mn increased their contents by 20.4 and 26.9 per cent at 10 t ha^{-1} FYM level while Fe increased by 25.8 per cent. Copper content decreased steadily with increasing levels of FYM.

4.4.4.1.2 Elemental composition of shoot at MT and culm at PI

Results showed (Table 4.4.3b) that transplanting recorded a significantly lower content of P, Mg and Zn over wet seeding by 8.4, 16.2 and 11.6 per cent. Iron content significantly increased in the shoot at MT stage by 18.0 per cent as compared to wet seeding.

At PI stage, the two methods of crop establishment differed significantly only in the N content of culm. Wet seeding showed a significantly higher content in the culm which was 18.9 per cent more than that of transplanted crop.

b) Method of land preparation

Effect of digging to a depth of 30 cm did not affect the elemental composition of shoot or culm except in the case of S at MT stage. Deep digging significantly reduced the S content in the crop by 16.1 per cent over shallow digging (D_{15}).

c) Application of FYM/OM

A perusal of the data (Table 4.4.3b) showed that application of OM @ 5 t ha^{-1} increased the P, K and Fe contents in the shoot at MT by 8.7, 11.4 and 14.9 per cent which were statistically significant. Other elements were not affected. Increase in level of application of FYM beyond 5 t ha^{-1} was ineffective in influencing the elemental composition.

Increasing levels of OM decreased the N, P, K and S content of culm significantly at PI stage. Application of FYM @ 10 t ha^{-1} decreased these elements by 23.8, 10.7, 18.0 and 18.9 per cent over control. Other elements remained unaffected.

4.4.4.1.3 Elemental composition of leaf at PI and boot leaf

Data on the elemental composition of leaf at PI and boot leaf as affected by different treatments are presented in Table 4.4.3c.

Table 4.4.3b Effect of cultural management on elemental composition of shoot at MT and Culm at PI - Second crop (Oct - Feb)

Treatment	Shoot at Maximum tillering									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
WSR	2.795	0.345	3.483	0.088	0.117	2884	895	2203	32.9	14.7
TPR	2.848	0.316	3.658	0.076	0.098	2774	1056	2329	29.1	14.6
CD(0.05)	NS	0.015	NS	NS	0.009	NS	124.8	NS	3.10	NS
Digging										
D_{15}	2.846	0.328	3.536	0.085	0.103	3076	1007	2270	31.9	15.2
D_{30}	2.797	0.333	3.606	0.079	0.111	2582	943	2262	30.1	14.1
CD(0.05)	NS	NS	NS	NS	NS	187.8	NS	NS	NS	NS
FYM										
M_0	2.964	0.323	3.417	0.087	0.111	2870	878	2186	33.3	14.9
M_5	2.769	0.351	3.808	0.074	0.105	2847	1009	2257	30.5	14.1
M_{10}	2.731	0.318	3.487	0.085	0.105	2769	1039	2356	29.2	14.8
CD(0.05)	NS	0.018	0.293	NS	NS	NS	152.8	NS	NS	NS
CV (%)	16.00	6.30	9.72	25.80	13.17	9.62	18.54	18.28	14.5	15.89

WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.4.3b contd...

Treatment	Culm at Panicle initiation									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
WSR	1.071	0.266	2.078	0.069	0.107	1808	560	1907	60.9	6.9
TPR	0.901	0.252	2.247	0.061	0.111	1699	656	1931	67.6	8.8
CD(0.05)	0.156	NS	NS	NS	NS	NS	NS	NS	NS	NS
Digging										
D_{15}	1.012	0.261	2.247	0.072	0.112	1730	613	1952	58.2	8.4
D_{30}	0.959	0.256	2.078	0.058	0.106	1777	603	1886	70.2	7.2
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FYM										
M_0	1.072	0.272	2.383	0.061	0.108	1883	582	1846	61.8	8.9
M_5	1.068	0.261	2.150	0.077	0.117	1851	628	2027	67.6	8.0
M_{10}	0.817	0.243	1.954	0.058	0.102	1527	614	1883	63.3	6.6
CD(0.05)	0.196	0.018	0.241	NS	NS	307.9	NS	NS	NS	NS
CV (%)	22.97	8.41	13.15	36.72	18.01	20.78	29.27	31.24	29.05	38.86

WSR - Wet seeded rice TPR - Transplanted rice D - Depth of digging

NS - Non significant M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.4.3c Effect of cultural management on elemental composition of leaf at PI and boot leaf - Second crop (Oct-Feb)

Treatment	Leaf at Panicle initiation									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
WSR	1.727	0.199	1.436	0.307	0.123	2025	706	3652	27.2	6.0
TPR	1.714	0.166	1.522	0.329	0.110	1688	667	3629	26.3	6.6
CD(0.05)	NS	0.022	NS	0.013	0.010	117.7	NS	NS	NS	NS
Digging										
D_{15}	1.863	0.185	1.469	0.318	0.118	1807	706	3638	26.8	6.1
D_{30}	1.578	0.180	1.489	0.317	0.115	1907	668	3643	26.7	6.6
CD(0.05)	0.224	NS	NS	NS	NS	NS	NS	NS	NS	NS
FYM										
M_0	1.636	0.180	1.429	0.306	0.123	1932	809	3523	26.9	6.6
M_5	1.812	0.179	1.471	0.333	0.113	1724	590	3802	25.6	6.4
M_{10}	1.714	0.189	1.537	0.315	0.114	1914	661	3597	27.7	6.0
CD(0.05)	NS	NS	NS	0.017	NS	144.1	79.7	213.7	NS	NS
CV (%)	18.91	15.55	13.50	6.34	13.34	9.18	16.81	6.94	8.57	24.08

WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.4.3c contd...

Treatment	Boot leaf									
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
System										
WSR	2.232	0.201	1.417	0.218	0.099	2196	2629	2614	22.6	8.8
TPR	2.598	0.213	1.414	0.298	0.107	1944	2774	2908	27.4	9.4
CD(0.05)	0.165	0.012	NS	0.031	NS	133.7	123.6	219.7	2.33	NS
Digging										
D15	2.313	0.208	1.439	0.235	0.095	2042	2685	2520	26.0	9.4
D30	2.517	0.207	1.392	0.281	0.111	2097	2718	3002	23.9	8.9
CD(0.05)	0.165	NS	NS	0.031	0.011	NS	NS	219.7	NS	NS
FYM										
M0	2.667	0.213	1.442	0.268	0.110	2031	2743	2833	25.5	9.6
M5	2.459	0.198	1.358	0.257	0.098	1940	2644	2819	25.5	9.0
M10	2.119	0.210	1.446	0.249	0.101	2239	2717	2631	23.8	8.8
CD(0.05)	0.202	NS	NS	NS	NS	163.7	NS	NS	NS	NS
CV (%)	9.85	8.30	9.94	18.51	15.35	9.36	6.63	11.53	13.50	19.49

WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

a) Method of crop establishment

It can be seen from the Table 4.4.3c that transplanting increased the Ca content but decreased P, Mg and S contents over wet seeding in the leaf at PI stage and the variations were significant. The variations for P, Mg, S and Ca were 16.6, 10.6, 16.6 and 7.2 per cent respectively. The boot leaf however registered significantly higher content of N, P, Ca, Fe, Mn and Zn in transplanted crop and the increases were 16.4, 6.0, 36.7, 5.5, 11.2 and 21.2 per cent respectively. Sulphur content alone decreased while K, Mg and Cu were not affected.

b) Method of land preparation (digging)

Data presented in Table 4.4.3c showed that deep digging to a depth of 30 cm decreased the N content of the leaf at PI stage by 15.3 per cent and the decrease was significant. No other element was affected at this stage by method of land preparation.

Digging to a depth of 30 cm significantly increased the N, Ca, Mg and Mn contents of boot leaf over shallow digging and the increases were 8.8, 19.6, 16.8 and 19.1 per cent respectively.

c) Application of FYM/OM

Application of FYM @ 5 t ha^{-1} increased the Ca content of the leaf by 8.8 per cent and Mn content by 7.9 per cent and decreased the content of S and Fe by 10.8 and 27.1 per cent over control. Nitrogen, P, K, Mg, Zn and Cu were not affected by levels at PI stage.

Farm yard manure levels affected only the N and S content of the boot leaf. Increasing levels significantly decreased N and increased S content and the percentage changes were 20.5 and 10.2 per cent respectively.

4.4.4.1.4 Elemental composition of grain and straw

1) Grain

a) Method of crop establishment

Data on the elemental composition of grain are presented in Table 4.4.3d.

The results showed that method of crop establishment significantly differed between themselves in affecting the elemental composition of the grain. Wet seeding registered higher content of Ca, S and Mn in the grain over transplanting and the increases were 12.5, 5.9 and 21.1 per cent. On the other hand transplanting recorded 7.2 and 4.8 per cent more Mg and Fe in the grain. All these were statistically significant. Nitrogen, P, K, Zn, Cu and SiO_2 were not affected.

b) Method of land preparation/digging

Shallow digging, ie, digging to a depth of only 15 cm gave significantly higher content of K, Mg, S and Cu in the grain over deep digging and the increases worked out to 14.9, 4.8, 13.4 and 10 per cent respectively. On the other hand, deep digging (D_{30}) increased the N and Mn contents of the grain and the increases were 21.3 and 8.7 per cent respectively.

c) Application of FYM/OM

FYM application significantly increased P and Mg contents of the grain and the highest content of these elements were recorded in the grain at 10 t ha^{-1}. FYM application reduced the K content of grain. It was significant at 5 t ha^{-1} level and the reduction worked out to 16.6 per cent.

2. Straw

a) Method of crop establishment

Data on the elemental composition of straw are presented in Table 4.4.3d. Wet seeding gave significantly higher contents of P, Mg and S in the straw and the corresponding increases were 11.4, 18.5 and 7.2 per cent respectively. Transplanting

Table 4.4.3d Effect of cultural management on elemental composition of grain and straw - Second crop (Oct-Feb)

Treatment	Grain										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_i0_2 (%)
System											
WSR	1.110	0.263	0.364	0.018	0.083	1390	2389	281.8	22.7	6.2	18.3
TPR	1.118	0.258	0.358	0.016	0.089	1312	2503	232.7	24.3	6.3	19.5
CD(0.05)	NS	NS	NS	0.001	0.003	53.6	67.3	12.5	NS	NS	NS
Digging											
D_{15}	1.007	0.255	0.386	0.016	0.088	1436	2448	246.5	24.2	6.6	18.9
D_{30}	1.221	0.265	0.336	0.017	0.084	1266	2444	268.0	22.8	6.0	18.8
CD(0.05)	0.143	NS	0.043	NS	0.003	53.6	NS	12.5	NS	0.38	NS
FYM											
M_0	1.127	0.253	0.404	0.017	0.086	1332	2429	266.3	22.6	6.1	18.2
M_5	1.111	0.247	0.337	0.016	0.083	1333	2433	228.5	24.3	6.0	18.8
M_{10}	1.103	0.281	0.342	0.017	0.089	1387	2475	277.0	23.6	6.8	20.2
CD(0.05)	NS	0.016	0.053	0.002	0.004	NS	NS	15.3	NS	0.48	NS
CV (%)	18.69	7.13	17.45	9.71	4.41	5.75	3.99	7.05	11.98	8.95	20.95

WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

Table 4.4.3d contd....

Treatment	Straw										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_iO_2 (%)
System											
WSR	0.830	0.244	2.142	0.301	0.141	1543	2627	3489	55.4	5.8	24.3
TPR	0.939	0.219	2.239	0.292	0.119	1440	2703	3416	46.5	6.1	24.7
CD(0.05)	0.107	0.012	NS	NS	0.010	73.7	60.5	NS	NS	NS	NS
Digging											
D15	0.833	0.238	2.133	0.322	0.130	1550	2647	3551	43.5	6.1	26.4
D30	0.944	0.225	2.247	0.271	0.130	1433	2683	3354	58.4	5.8	22.6
CD(0.05)	0.107	0.012	NS	0.044	NS	73.7	NS	NS	9.96	NS	3.43
FYM											
M0	0.942	0.234	2.146	0.302	0.134	1563	2658	3679	52.0	6.3	25.0
M5	0.824	0.223	2.092	0.338	0.126	1382	2644	3361	49.0	5.7	24.5
M10	0.898	0.238	2.333	0.260	0.129	1530	2693	3318	51.9	5.8	23.9
CD(0.05)	NS	NS	0.167	0.053	NS	90.32	NS	NS	NS	NS	NS
CV (%)	17.32	7.85	9.02	20.09	11.35	7.17	3.29	10.70	28.33	15.64	20.37

WSR - Wet seeded rice
TPR - Transplanted rice
D - Depth of digging
NS - Non significant
M - Farm yard manure (0, 5 and 10 t ha^{-1})

on the other hand gave higher contents of N and Fe in the straw and the increases were significant.

b) Method of land preparation

Shallow digging (D_{15}) was seen to have increased the P, Ca, S and SiO_2 contents of straw over deep digging and the significant increases worked out to 5.8, 18.8, 8.2 and 16.8 per cent respectively. Deep digging recorded higher N and Zn contents in the straw over shallow digging.

c) Application of FYM/OM

Different levels of FYM did not significantly affect N, P, Mg, Fe, Mn, Zn, Cu or SiO_2 contents of the straw. Application of FYM @ 5 t ha^{-1} reduced the K and increased the Ca content of straw significantly. Increasing FYM level beyond 5 t ha^{-1} did not have any significant effect.

4.4.5 Interaction effects

4.4.5.1 Interaction effects on elemental composition of root at MT

1. Method of crop establishment x FYM

Combined effect of crop establishment and FYM on elemental composition of roots in rice are presented in Table 4.4.4a.

From the data it can be seen that transplanting significantly reduced the S content when it was combined with FYM @ 5 t ha^{-1} and the reduction worked out to 22.7 per cent. A similar trend was not apparent in wet seeding.

The data showed that transplanting by itself significantly increased the root content of Fe over wet seeding by 141.5 per cent. Under both the methods of crop establishment, Fe content increased steadily with increasing FYM level, but was significant only in wet seeded crop. In wet seeded crop the increase was 117 per cent as against 15.2 per cent in transplanted crop with 10 t ha^{-1} of FYM.

Table 4.4.4a Interaction effects on elemental composition of root at MT and PI stage Second crop (Oct Feb)

I. Method of establishment x FYM

System	Root at MT stage						Root at PI stage					
	S (ppm)		Fe (ppm)		Zn (ppm)		P (%)		K (%)		Cu (ppm)	
	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
FYM M_0	1850	2869	20475	42938	62.5	113.5	0.155	0.178	0.067	1.200	58.0	54.7
M_5	1936	2337	29968	42096	85.3	91.5	0.187	0.191	1.367	1.017	44.7	46.3
M_{10}	2026	2444	44424	49454	89.7	95.3	0.207	0.194	1.167	1.150	33.3	53.7
CD(0.05)	191.2		9487.3		16.9		0.018		0.131		8.21	

II. Method of establishment x Depth of digging

System	Root at PI stage													
	P (%)		K (%)		Ca (%)		Mg (%)		S (ppm)		Mn (ppm)		Cu (ppm)	
	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
Digging D_{15}	0.168	0.192	0.950	1.200	0.022	0.021	0.069	0.069	2011	2738	1070	1423	45.0	60.4
D_{30}	0.198	0.184	1.383	1.044	0.028	0.020	0.079	0.056	2157	2498	1266	1262	45.7	42.6
CD(0.05)	0.014		0.107		0.0031		0.0036		252.2		235.7		6.71	

III Depth of digging x FYM

Digging	Root at MT stage								Root at PI stage							
	N (%)		Mg (%)		S (ppm)		Mn (ppm)		P (%)		K (%)		S (ppm)		Cu (ppm)	
	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}
FYM M_0	0.993	0.818	0.077	0.076	2454	2264	888	1394	0.173	0.160	1.125	1.042	2316	2337	61.0	51.7
M_5	0.965	0.877	0.083	0.067	2405	1866	1600	1323	0.179	0.199	0.950	1.433	2225	2502	43.3	42.7
M_0	0.820	1.022	0.068	0.087	2151	2318	1515	1505	0.188	0.213	1.150	1.167	2581	2147	53.8	33.2
CD(0.05)	0.207		0.011		191.2		429.1		0.018		0.131		308.9		8.21	

Zinc content at MT stage was also significantly influenced by method of crop establishment when combined with FYM. The lowest content of Zn was recorded in WSR M_0 and the highest content registered in TPR M_0 and the increase worked out to 81.1 per cent over wet seeding. Increasing the FYM level while reducing the Zn content in transplanted crop, increased it when combined with wet seeding and the increase worked out to 43.5 per cent with 10 t ha^{-1} FYM as against 24.1 per cent reduction in transplanted crop with 5 t ha^{-1} FYM.

2. Method of land preparation (digging) x FYM

Interaction effect between method of land preparation and FYM level on elemental composition of root at MT are presented in Table 4.4.4a.

The data showed that deep digging (30 cm) without FYM (M_0) led to the lowest N content while deep digging combined with 10 t ha^{-1} FYM gave the highest N content. The difference worked out to 21.4 per cent and was statistically significant.

It can be seen from Table 4.4.4a. that combined effect of digging and FYM significantly affected the Mg, S and Mn contents of root at MT stage. Lowest contents of Mg and S were recorded when deep digging was combined with 5 t ha^{-1} of FYM. Highest Mg content was observed when deep digging and higher dose of FYM were combined. Under shallow digging higher level of FYM significantly reduced the Mg content.

Increasing FYM while reducing the S content of root, increased it when combined with deep digging. The increase in S content worked out to 24.2 per cent when FYM was increased from 5 t ha^{-1} to 10 t ha^{-1} under deep digging.

Shallow digging without FYM recorded the lowest content of Mn in the root and the highest content when 5 t ha^{-1} of FYM and shallow digging were combined and the difference worked out to 80.2 per cent. Iron, Zn and Cu were not significantly affected by this interaction.

3. Method of establishment x digging

Combined effect of method of crop establishment and digging did not have any significant influence on elemental composition of root at MT stage.

4.4.4.2 Interaction effect on elemental composition of root at PI

1. Method of crop establishment x FYM

Data presented in Table 4.4.4a showed that P, K and Cu alone were significantly affected. Increasing levels of FYM in transplanting were ineffective in influencing the content of P and K in root. But in wet seeding increasing of FYM level upto 5 t ha^{-1} increased K and upto 10 t ha^{-1} increased P content. At 5 t ha^{-1} of FYM the increase in K was 41.4 per cent and at 10 t ha^{-1} the increase in P was 33.5 per cent.

Copper content of root at PI steadily declined by increasing the level of FYM to 10 t ha^{-1} and the decrease worked out to 42.6 per cent.

2. Method of land preparation (digging) x FYM

Data on combined effect of depth of digging and organic manure levels on the elemental composition of root at PI stage are presented in Table 4.4.4a.

Deep digging combined with 10 t ha^{-1} FYM recorded the highest P content in the root which was 33.1 per cent more than deep digging alone, while maximum K content of the root, 1.44 per cent, which was more than 37.5 per cent over deep digging alone, was recorded at 5 t ha^{-1} FYM. Shallow digging combined with FYM was less effective. But the highest P content was recorded at 10 t ha^{-1} FYM though it was significantly less than $D_{30} M_{10}$.

The lowest root contents of S and Cu were recorded in deep dug plots receiving 10 t ha^{-1} FYM and Cu content was significantly lower compared to all other plots. Shallow digging combined with FYM @ 10 t ha^{-1} registered a higher content of S and the increase worked out to 20.2 per cent over D_{30} M_{10}.

Shallow digging alone gave the highest Cu content which was significantly superior to all other treatments and the increase worked out to 119.4 per cent over D_{30} M_{10}.

3. Method of crop establishment x digging

It can be seen from the Table 4.4.4a. that P, K, Ca, Mg, S, Mn and Cu were significantly affected. The results showed that highest percentage contents of P, K, Ca and Mg in the roots at PI stage were recorded in plots wet sown after deep digging and the same was significantly superior to all other treatments in respect of K, Ca and Mg. However, in the case of P, WSR D_{30} treatment combination was significantly superior only to WSR D_{15} combination.

Highest root contents of S, Mn and Cu were registered in shallow dug transplanted crop and all of them were significantly superior to shallow dug wet seeded crop. Sulphur and Cu content in deep dug wet sown plots also were lower compared to shallow dug transplanted crop.

4.4.4.3 Interaction effects of shoot at MT stage

1. Method of land preparation x FYM

Combined effect of digging and FYM on elemental composition of shoot at MT stage are presented in Table 4.4.4b.

Calcium, Mg and S contents of the rice plant at MT stage were significantly affected by depth of digging and levels of FYM.

Table 4.4.4b Interaction effects on elemental composition of shoot at MT and culm at PI stage - Second crop (Oct - Feb)

I Method of establishment x FYM

	Shoot at MT stage							
	N(%)		P(%)		Mg (%)		Zn (ppm)	
	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
M_0	3.238	2.690	0.344	0.301	0.122	0.101	38.0	28.5
M_5	2.725	2.813	0.370	0.333	0.106	0.105	32.0	29.2
M_{10}	2.422	3.040	0.322	0.313	0.122	0.088	28.8	29.5
CD(0.05)	0.540		0.026		0.016		5.38	

II Method of establishment x depth of digging

	Shoot at MT stage				Culm at PI stage			
	P(%)		Fe (ppm)		K(%)		Ca (%)	
	WSR	TPR	WAR	TPR	WSR	TPR	WSR	TPR
D_{15}	0.326	0.330	1014	1001	1.961	2.533	0.087	0.056
D_{30}	0.364	0.302	777	1111	2.194	1.961	0.052	0.065
CD(0.05)	0.021		176.8		0.278		0.031	

III Depth of digging x FYM

	Shoot at MT stage					
	Ca (%)		Mg (%)		S (ppm)	
	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}
M_0	0.097	0.0763	0.103	0.120	3195	2546
M_5	0.064	0.085	0.116	0.095	2909	2785
M_{10}	0.094	0.076	0.096	0.118	3122	2416
CD(0.05)	0.026		0.016		325.8	

Shallow digging without FYM gave the highest shoot content of Ca and shallow digging combined with 5 t ha^{-1} of FYM gave the lowest Ca content and the difference worked out to 51.6 per cent. Increasing levels of FYM did not have any effect on Ca in deep dug plots.

Deep digging combined with FYM @ 5 t ha^{-1} significantly reduced the Mg content of the shoot at MT stage over all other treatments. The reduction was 20.8 per cent over deep digging alone.

Highest content of S in the shoot was recorded at $D_{15} M_0$ and lowest at $D_{30} M_{10}$. The difference was statistically significant and was of the order of 32.2 per cent. Deep digging combined with FYM irrespective of levels failed to match S content of the shoot under shallow digging.

2. Method of crop establishment x FYM

Data are presented in Table 4.4.4b. It can be noted that wet seeded crop without FYM gave the highest contents of N and P in shoot which was significantly superior to wet seeded crop combined with 10 t ha^{-1} FYM by 33.7 and 6.8 per cent respectively. In the case of both the elements, transplanted crop failed to match the N and P contents at any level of organic matter.

Highest contents of Mg and Zn in shoot were recorded by wet seeded rice without any FYM and the lowest registered by TPR M_0. The difference worked out to 20.8 and 33.3 per cent respectively over TPR M_0. Increasing the level of FYM to 10 t ha^{-1} increased the Mg content and reduced the Zn content in wet seeded rice. Zinc content in transplanted rice, on the contrary, increased with higher levels of FYM.

3. Method of crop establishment x digging

Data presented in Table 4.4.4b. showed that depth of digging and method of crop establishment significantly affected P and Fe contents of shoot at MT stage. Wet seeding after shallow digging gave the highest content of P which was significantly superior to all other combinations. The very same treatment also gave the lowest quantity of Fe in the shoot which was significantly inferior to other treatment combinations.

4.4.4.4 Interaction effect on elemental composition of culm at PI stage

1. Method of crop establishment x digging

Data presented in Table 4.4.4b. showed that deep digging combined with transplanting gave the highest content of K in the culm and it was significantly superior to all other treatment combinations. Deep digging and wet seeding followed by shallow digging and transplanting recorded the lowest Ca content and former was significantly superior to shallow digging combined with wet seeding.

4.4.4.5 Interaction effects on elemental composition of leaf at PI stage

1. Method of crop establishment x digging

Combined effect of depth of digging and method of crop establishment significantly influenced only the leaf Fe content (Table 4.4.4c). Highest leaf Fe content at PI stage was recorded in shallow dug wet seeded treatment and the lowest in shallow dug transplanted crop and the difference was statistically significant. Deep dug wet seeded plots also recorded significantly low iron content and was on par with shallow dug transplanted crop.

2. Method of crop establishment x FYM

Significant influence of the combined effect noticed in respect of K, Ca, S and Mn is presented in Table 4.4.4c.

Maximum leaf content of 1.683 per cent K was observed in transplanted crop receiving 10 t ha^{-1} of FYM followed by the one receiving no FYM and the difference

Table 4.4.4c. Interaction effects on elemental composition of leaf at PI and boot leaf - Second crop (Oct - Feb)

I Method of establishment x FYM

	Leaf at PI stage								Boot leaf							
	K (%)		Ca (%)		S (ppm)		Mn (ppm)		Ca (%)		S (ppm)		Zn (ppm)		Cu (ppm)	
System	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
FYM M_0	1.575	1.283	0.264	0.347	2027	1836	3205	3841	0.264	0.272	1979	2088	25.7	25.5	7.7	11.5
M_5	1.342	1.600	0.354	0.311	2022	1426	4080	3525	0.204	0.309	2004	1877	20.3	30.7	9.0	9.0
M_{10}	1.392	1.683	0.303	0.327	2025	1804	3672	3522	0.186	0.313	2616	1867	21.7	26.0	10.0	7.7
CD (0.05)	0.239		0.024		204.18		302.8		0.054		232.0		4.04		2.13	

II Method establishment x depth of digging

	Leaf at PI stage		Boot leaf	
System	Fe (ppm)		S (ppm)	
	WSR	TPR	WSR	TPR
Digging D_{15}	784	629	2020	2064
D_{30}	627	708	2372	1823
CD (0.05)	112.9		189.4	

III Depth of digging x FYM

	Leaf at PI stage										Boot leaf			
Digging	Ca (%)		Mg (%)		Mn (ppm)		Zn (ppm)		Cu (ppm)		Mg (%)		S (ppm)	
	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}
FYM M_0	0.293	0.318	0.112	0.134	3389	3657	26.2	27.6	5.3	7.8	0.091	0.129	1910	2152
M_5	0.356	0.310	0.121	0.105	3943	3663	24.8	26.5	6.7	6.2	0.101	0.094	2026	1854
M_{10}	0.306	0.324	0.122	0.106	3585	3609	29.3	26.0	6.3	5.7	0.093	0.110	2191	2287
CD (0.05)	0.024		0.018		302.8		2.74		1.83		0.019		232.0	

was significant. Increasing levels of FYM did not have any effect on K content of wet sown crop.

Lowest Ca content was observed in wet seeded plots with no FYM and the highest in transplanted crop with no FYM and the difference was 31.4 per cent.

Leaf S content was maximum in wet seeded crop under no FYM and minimum in transplanted crop with FYM @ 5 t ha^{-1} and the difference was 42.1 per cent.

Lowest Mn content of 3205 ppm and maximum content of 4080 ppm Mn were recorded in wet seeded plots with `0' and 5 t ha^{-1} FYM respectively. Transplanted crop irrespective of FYM registered significantly lower contents.

3. Depth of digging x FYM

The interaction significantly affected Ca, Mg, Mn, Zn and Cu contents of the leaf at PI stage (Table 4.4.4c).

Highest Ca content of 0.356 per cent in the leaf was recorded under D_{15} M_5 combination which was 21.5 per cent higher than the lowest content recorded by D_{15} M_0.

Magnesium content showed steady decline with increasing level of FYM in deep dug plots and the content in D_{30} M_0 was 27.6 per cent more than D_{30} M_{10}.

Highest Mn content was recorded at D_{15} M_5 combination which was significantly superior to all other treatments and was 16.3 per cent higher than the lowest recorded by D_{15} M_0.

Shallow dug plots with 5 t ha^{-1} of FYM recorded the lowest Zn content and the maximum was in D_{15} M_{10} where the level of FYM was raised to 10 t ha^{-1} and difference worked out to 18.1 per cent. Deep digging did not show any significant influence on leaf Zn content at different levels of FYM.

Lowest Cu content of 5.3 ppm was recorded by $D_{15} M_0$ followed by $D_{30} M_{10}$ level and the difference was statistically significant.

4.4.4.6 Interaction effects on elemental composition of boot leaf

1. Method of crop establishment x digging

Data presented in Table 4.4.4c showed that deep digging combined with wet seeding registered the highest sulphur content of 2372 ppm which was 30.1 per cent higher than deep digging combined with transplanting. All the other treatment combinations of depth of digging and crop establishment were significantly inferior to D_{30} WSR.

2. Method of crop establishment x FYM

Combined effect of crop establishment and FYM significantly influenced Ca, S, Zn and Cu content of boot leaf (Table 4.4.4c.).

The data showed that increasing levels of FYM tended to reduce the calcium in wet seeded crop while increasing it in the transplanted crop. The influence in wet seeded crop was statistically significant and the decrease was of the order of 41.9 per cent. The increase in Ca in transplanted crop failed to reach the significant level.

Influence of the combined effect in the case of S was just the reverse of that in Ca. Increasing levels of FYM significantly increased S content is wet seeded crop while significantly reducing it in transplanted crop and the respective increase and decrease were 32.5 and 11.3 per cent.

The combined effect was similar but less effective in the case of Zn as the combined effect was limited upto 5 t ha^{-1} of FYM only. Thus wet seeding combined with 5 t ha^{-1} FYM significantly reduced the Zn content by 26.6 over no FYM while it increased in the transplanted crop by 20.4 per cent.

Copper behaved similarly to S due to the combined effect of method of crop establishment and FYM levels. Application of FYM @ 10 t ha^{-1} combined with wet seeding increased the Cu content significantly by 29.9 per cent over wet seeding alone and decreased the Cu content of the boot leaf by 49.4 per cent in transplanted crop.

3. Depth of digging x FYM

Data presented in Table 4.4.4c showed that deep digging with no FYM gave significantly higher Mg content than combination of shallow digging with any level of FYM. Lowest content of Mg was recorded by $D_{15}M_0$ treatment.

Deep digging combined with 10 t ha^{-1} of FYM gave the highest content of S in the boot leaf which was significantly higher by 19.7 per cent than shallow digging alone. The results also showed that application of FYM at 10 t ha^{-1} level could significantly increase the S content when the plot was dug only a depth of 15 cm. Farm yard manure was ineffective in doing this when the plot was dug to a depth of 30 cm.

4.4.4.7 Interaction effects on elemental composition of grain

1. Method of establishment x FYM

Data presented in Table 4.4.4d showed that grain content of Mn was significantly lower in transplanted crop when the combined effects of crop establishment and FYM levels were compared. The results showed that 5 t ha^{-1} of FYM could significantly reduce the Mn content of the wet seeded crop by 32.5 per cent.

Data presented in the Table showed that FYM combined with wet seeding increased the Cu content significantly by 17.2 per cent while FYM failed to bring about any increase when it was combined with transplanting.

Table 4.4.4d. Interaction effects on elemental composition of grain and straw - Second crop (Oct - Feb)

I Method of establishment x FYM

System		Grain			
		Mn (ppm)		Cu (ppm)	
		WSR	TPR	WSR	TPR
FYM	M_0	306	227	5.8	6.3
	M_5	231	227	6.0	6.0
	M_{10}	309	245	6.8	6.7
CD (0.05)		21.7		0.67	

II Method of establishment x Digging

System		Grain				Straw					
		Mg (%)		Mn (ppm)		K (%)		Mg (%)		Mn (ppm)	
		WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
Digging	D_{15}	0.083	0.093	256	237	1.94	2.33	0.135	0.124	3430	3673
	D_{30}	0.083	0.085	308	228	2.34	2.31	0.146	0.114	3549	3160
CD (0.05)		0.004		17.72		0.193		0.015		361.3	

III Digging x FYM

		Grain						Straw									
		Mg (%)		Mn (ppm)		Cu (ppm)		N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
		D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}
FYM	M_0	0.087	0.084	245	288	6.2	6.0	0.980	0.905	0.236	0.233	2.06	2.33	0.364	0.291	0.142	0.126
	M_5	0.083	0.082	221	236	6.0	6.0	0.700	0.948	0.217	0.229	1.83	2.36	0.364	0.290	0.115	0.137
	M_{10}	0.093	0.085	273	281	7.5	6.0	0.818	0.978	0.263	0.213	2.52	2.15	0.240	0.280	0.183	0.126
CD (0.05)		0.005		21.7		0.67		0.186		0.021		0.236		0.076		0.018	

2. Method of crop establishment x depth of digging

Data in Table 4.4.4d showed that shallow digging combined with transplanting recorded a content of 0.093 per cent Mg which was 12.0 per cent higher than the corresponding treatment under wet seeding.

It can be seen from the Table that increasing depth of digging significantly increased the Mn content in wet seeded crop but failed to have any impact on transplanted crop. Wet seeding after digging to a depth of 30 cm recorded 308 ppm of Mn in the grain which was 35.1 per cent more than that obtained when deep digging and transplanting were combined.

3. Depth of digging x FYM

Shallow digging combined with FYM steadily increased the Mg content of grain upto 10 t ha^{-1} while FYM was not effective in doing so under deep dug condition. Highest content of 0.93 per cent Mg was obtained in D_{15} M_{10} level and it was significantly superior to all other treatment combinations (Table 4.4.4d).

Increasing the level of FYM also significantly increased the Mn content in shallow dug plots while deep digging by itself give the highest Mn content of the grain.

Shallow digging (15 cm) combined with 10 t ha^{-1} of FYM gave the highest Cu content of the grain which was significantly superior to all other treatment combinations. FYM combined with deep digging was ineffective in affecting the copper content of the grain.

4.4.4.8 Interaction effects on elemental composition of straw

1. Method of crop establishment x depth of digging

From the data presented in Table 4.4.4d. it may be noted that deep digging combined with wet seeding significantly increased the K, Mg and Mn contents of straw over those receiving only shallow digging alone.

2. Depth of digging x FYM

Data on the interaction effect between depth of digging and levels of organic manure are presented in Table 4.4.4d

It can be seen from the Table 4.4.4d. that FYM, irrespective of levels, failed to influence the nitrogen, P, K, Ca or Mg content of the straw in treatments where the land was dug to a depth of 30 cm and the influence was limited to situations where the land was dug only to a depth of 15 cm.

Highest N content of the straw, ie., 0.980 per cent was recorded by D_{15} M_0 treatment and the lowest in D_{15} M_5 and the difference worked out to 40.0 per cent.

Highest P content was recorded in D_{15} M_{10} treatment which was significantly superior to all other combinations. The lowest P content of 0.213 per cent was recorded in D_{30} M_{10} followed by $D_{15}M_{10}$ and the increase was 23.5 per cent.

The lowest K content of 1.83 per cent was recorded in D_{15} M_5 and it was significantly inferior to D_{15} M_{10} as well as D_{30} M_5.

Calcium content of this treatment (D_{15} M_5) was the highest. Further increases in FYM level reduced the Ca content significantly by 51.7 per cent.

Digging to a depth of 15 cm alone without any FYM gave the highest Mg content of the straw which was significantly superior to the one receiving 5 t ha^{-1} of FYM.

4.4.5 Second order interaction effects on elemental composition of different parts of rice

4.4.5.1 Effects on elemental composition of roots

Significant combined effects were noticed in the case of Mg, S and Fe and are presented in Table 4.4.5.

Table 4.4.5 Second order interaction effects of crop establishment, digging and FYM on elemental composition of root at MT, culm and leaf at PI, boot leaf, grain and straw

1. Root at MT

		Mg (%)			S (ppm)			Fe (ppm)		
		M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR	D_{15}	0.070	0.096	0.062	1840	2372	1800	20850	31700	49368
WSR	D_{30}	0.087	0.056	0.082	1859	1499	2251	20100	28233	39480
TPR	D_{15}	0.084	0.071	0.074	3068	2438	2502	56800	41242	50558
TPR	D_{30}	0.065	0.077	0.092	2669	2234	2386	29075	42950	48350
CD (0.05)			0.016			269.8			4248.9	

2. Culm at PI

		Mg (%)			S (ppm)			Fe (ppm)			Zn (ppm)		
		M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR	D_{15}	0.115	0.113	0.104	2133	1590	1635	758	506	491	55.3	60.0	49.3
WSR	D_{30}	0.107	0.121	0.085	1560	2597	1333	452	660	495	68.7	49.3	83.0
TPR	D_{15}	0.098	0.143	0.099	1923	1744	1355	552	790	583	53.7	62.7	68.3
TPR	D_{30}	0.114	0.090	0.119	1917	1471	1784	568	556	887	69.7	98.3	52.7
CD (0.05)			0.032			617.1			301.4			31.60	

3. Leaf at PI

		Mg (%)			S (ppm)			Fe (ppm)		
		M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR	D_{15}	0.121	0.125	0.132	1887	1868	2044	1064	639	650
WSR	D_{30}	0.125	0.127	0.111	2168	2176	2006	712	582	593
TPR	D_{15}	0.103	0.117	0.112	1856	1495	1690	498	616	767
TPR	D_{30}	0.143	0.083	0.101	1816	1357	1917	964	525	635
CD (0.05)			0.025			288.8			195.5	

4. Boot leaf

		N (%)			K (%)			Ca (%)			Mg (%)			Fe (ppm)			Mn (ppm)		
		M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR	D_{15}	2.45	2.10	1.62	1.63	1.27	1.45	0.282	0.170	0.165	0.099	0.083	0.092	2888	2521	2527	2658	2225	2146
WSR	D_{30}	2.29	2.60	2.33	1.40	1.40	1.35	0.245	0.239	0.208	0.115	0.106	0.099	2510	2530	2778	2808	3146	2704
TPR	D_{15}	2.60	2.66	2.45	1.25	1.43	1.60	0.192	0.352	0.249	0.084	0.120	0.094	2745	2523	2888	2289	3263	2543
TPR	D_{30}	3.33	2.48	2.07	1.48	1.33	1.38	0.352	0.266	0.376	0.143	0.083	0.120	2831	2982	2676	3577	2644	3131
CD(0.05)			0.404			0.028			0.076			0.028			303.4			339.23	

5. Grain

		K (%)			Mg (%)			S (ppm)			Mn (ppm)			Cu (ppm)		
		M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR	D_{15}	0.450	0.367	0.367	0.081	0.079	0.089	1535	1461	1459	260.6	225.3	281.0	6.2	6.0	7.5
WSR	D_{30}	0.333	0.333	0.333	0.082	0.079	0.088	1253	1255	1379	351.3	235.7	337.0	5.7	6.0	6.7
TPR	D_{15}	0.433	0.333	0.367	0.093	0.086	0.098	1336	1298	1525	229.3	217.3	265.7	6.3	6.0	8.0
TPR	D_{30}	0.400	0.317	0.300	0.087	0.086	0.081	1204	1319	1186	224.0	235.7	224.3	6.3	6.0	5.3
CD (0.05)			0.107			0.008			131.5			30.70			0.95	

6. Straw

		P (%)			Ca (%)			Mg (%)			S (ppm)			Zn (ppm)		
		M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR	D_{15}	0.233	0.231	0.300	0.339	0.349	0.257	0.144	0.128	0.134	1686	1565	1625	53.7	41.3	58.3
WSR	D_{30}	0.245	0.256	0.199	0.321	0.302	0.237	0.132	0.153	0.154	1612	1285	1482	50.3	53.7	75.3
TPR	D_{15}	0.239	0.202	0.225	0.389	0.378	0.223	0.141	0.101	0.131	1556	1258	1609	35.3	30.7	41.7
TPR	D_{30}	0.221	0.202	0.228	0.159	0.281	0.324	0.121	0.122	0.098	1396	1422	1402	68.7	70.3	32.3
CD (0.05)			0.030			0.107			0.026			180.9			24.45	

The treatment combination of WSR D_{15} M_5 gave the highest Mg content of 0.096 per cent in the grain, while a grain content of 0.092 per cent could be obtained in transplanted crop by the treatment combination of TPR D_{30} M_{10}.

Data on S content showed that TPR D_{15} M_0 gave the highest S content which was significantly superior to all other treatment combinations. The data also showed that deep digging and FYM were not effective in increasing the grain S content in the transplanted crop. Use of 10 t ha^{-1} of FYM was required in deep dug wet seeded plots to get grain S content equivalent to that of shallow dug M_5 wet seeded plots.

Data presented in Table 4.4.5 reveal that effectiveness of increasing levels of FYM varied depending upon methods of crop establishment and depth of digging. Increasing levels of FYM significantly reduced the root Fe content in shallow dug transplanted crop while significantly increasing it in deep dug transplanted crop. In wet seeded crop irrespective of depth of digging, Fe content increased with increasing levels of FYM. However the extent of increase was more in shallow dug plots.

4.4.5.2 Effect on elemental composition of culm

Significant interaction effects of the three factors on Mg, S, Fe and Zn are presented in Table 4.4.5.

Transplanting after digging shallow combined with FYM @ 5 t ha^{-1} gave the highest Mg content followed by deep digging combined with wet seeding and 5 t ha^{-1} of FYM.

Increasing levels of FYM beyond 5 t ha^{-1} significantly reduced the Mg in deep dug wet seeded and shallow dug transplanted crops and the decreases were 42.4 and 44.4 per cent respectively. FYM did not have any influence on Mg content of culm of shallow dug wet seeded and deep dug transplanted crops.

Application of FYM @5 t ha^{-1} combined with deep digging in wet seeded crops increased the S content in the culm over all other treatment combinations of transplanted and wet seeded crops except shallow dug wet seeded crop with no FYM. Here again FYM beyond 5 t ha^{-1} only tended to reduce the S content.

Highest Fe content of the culm was recorded by TPR D_{30} combination receiving 10 t ha^{-1} FYM followed by TPR D_{15} with 5 t ha^{-1} FYM. Increasing FYM level tended to reduce the Fe content in wet seeded rice irrespective of depth of digging. But in deep dug transplanted crop Fe content significantly increased by 56.2 per cent.

A higher level of FYM application of 10 t ha^{-1} combined with deep digging was required in wet seeded crop to significantly improve the Zn content in the culm whereas a lower level of 5 t ha^{-1} was sufficient in deep dug transplanted crop.

4.4.5.3 Interaction effect on Elemental composition of leaf at PI

Data presented in Table 4.4.5 showed that the second order interactions involving depth of digging, method of crop establishment and organic manure levels significantly affected Mg, S and Fe contents of leaf at PI.

It can be seen from the table that in the wet seeded crop combination of depth of digging and FYM failed to bring about any changes in Mg content. In transplanted crop digging combined with FYM both at 5 and 10 t ha^{-1} reduced the Mg content. Maximum Mg content of 0.143 per cent was recorded at D_{30} M_0 treatment combination which was 72.2 and 41.6 per cent more than FYM at 5 and 10 t ha^{-1} respectively.

It is apparent from the data that leaf S content remained unaffected in both transplanted and wet seeded crops by increasing doses of FYM. But between the wet seeded and transplanted crops ,wet seeded one was superior and at 5 and 10 t ha^{-1} FYM, the increased S content worked out to be 60.4 and 20.9 per cent.

It can be noted from the Table 4.4.5 that under shallow digging increasing levels of FYM decreased the Fe content in wet seeded crop and increased it in transplanted crop. However in deep dug situation, increasing levels of FYM significantly reduced the Fe content in transplanted crop. The reduction in leaf Fe content in shallow dug wet seeded and deep dug transplanted crop with 10 t ha^{-1} of FYM were 63.7 and 17.1 per cent respectively.

4.4.5.4 Interaction effects on elemental composition of boot leaf

Data on the interaction effects of depth of digging, method of crop establishment and FYM levels on elemental composition of the boot leaf in respect of N, K, Ca, Mg, Fe and Mn are presented in Table 4.4.5.

It is apparent from the table that increasing levels of FYM tended to reduce the boot leaf N content in all combinations and the same was significant in shallow dug wet seeded and deep dug transplanted crops. The decrease in N over no FYM worked out to 33.9 and 37.7 per cent respectively. The highest N content was in TPR D_{30} M_0 and the lowest in WSR D_5 M_{10} and the difference was 108.0 per cent.

The highest K content of 1.633 per cent was observed in WSR D_{15} M_0 followed by TPR D_{15} M_{10}. Both of them significantly differed between themselves and also were significantly superior to all other treatment combinations. It can also be seen from the table that in shallow dug transplanted crop alone K content of the boot leaf tended to increase with increasing levels of FYM whereas in other combinations increasing FYM tended to reduce the K content in boot leaf.

It is evident from the table that the highest Ca content was observed in the treatment combinations TPR D_{30} M_{10} followed by TPR D_{30} M_0 and TPR D_{15} M_5 which were significantly superior to all other treatment combinations. It is also evident from

Maximum and minimum content of K in the grain were recorded by WSR D_{15} M_0 and TPR D_{30} M_0 respectively and the significant difference worked out to 50.0 per cent. The general trend was a reduction in K content of grain with increasing level of FYM.

Magnesium content of the grain was not found to vary in treatment combination in wet seeded plots irrespective of the levels of FYM or depth of digging. In transplanted deep dug plots Mg content remained unaffected by FYM. Application of 5 t ha^{-1} of FYM significantly reduced the grain content of Mg in shallow dug transplanted crop.

Application of FYM 10 t ha^{-1} significantly increased the grain S content in shallow dug transplanted crop over lower levels. However shallow dug wet sown crop without any FYM also gave comparable grain S content. Deep digging significantly reduced the grain S content irrespective of depth of digging or FYM level. In both the methods of establishment deep digging irrespective of FYM level tended to reduce grain S content.

Highest grain Mn content was recorded in WSR D_{30} M_0 treatment combination which was significantly superior to all others and the lowest was in TPR D_{15} M_5 and the difference worked out to 61.7 per cent. It was found that under low and high levels of FYM tried in the experiment, Mn content of grain was high in both shallow and deep dug wet seeded plots. In the case of deep dug transplanted plots FYM had no effect though in shallow dug ones 10 t ha^{-1} FYM, significantly increased the Mn content.

It can be seen from Table 4.4.5. that 10 t ha^{-1} of FYM significantly increased the Cu content of the grain both in deep and shallow dug wet seeded plots whereas in the case of transplanted crop the effect was evident only in shallow dug plots.

4.4.5.6. Interaction effects on elemental composition of straw

Increasing levels of FYM increased the P content of straw in shallow dug wet seeded plots whereas it reduced it in deep dug plots. Thus the lowest content of P in straw was in WSR $D_{30} M_{10}$ and the highest in WSR $D_{15} M_{10}$ and the difference worked out to 50.8 per cent (Table 4.4.5)

Increasing levels of FYM reduced the Ca content of the straw in wet seeded plots as well as in shallow dug transplanted plots. Among these, the lowest Ca content was 0.22 per cent in TPR $D_{15} M_{10}$ which was 42.7 per cent less than the highest Ca content of 0.39 per cent observed in TPR $D_{15} M_{10}$.

Highest Mg content was observed in deep dug wet seeded plots receiving 5 t ha^{-1} of FYM and the lowest in TPR $D_{30} M_0$ and the difference was 56.1 per cent over TPR $D_{30} M_{10}$. Low and high levels of FYM significantly increased the Mg content of straw in transplanted crop with shallow digging whereas in deep dug plots, FYM had no effect.

Sulphur content of the straw differed in response to the treatment combinations both in transplanted and wet seeded crops. Increasing the depth of digging significantly reduced the S content both in wet seeded and transplanted crop at all levels of FYM except in transplanted crop with 5 t ha^{-1} of FYM. The lowest S content was recorded in TPR $D_{15} M_5$ and the difference worked out to 25.3 per cent over WSR $D_{15} M_0$.

Highest content of Zn in the straw was recorded in deep dug wet seeded plots receiving 5 t ha^{-1} of FYM and the difference was 145.3 per cent over TPR $D_{15} M_5$. In deep dug wet seeded plots 10 t ha^{-1} FYM significantly increased the Zn content while in transplanted crop Zn was significantly decreased.

4.4.6 Method of crop establishment, depth of digging and FYM on nutrient uptake by grain and straw

4.4.6.1. Main effects

1. Grain

a. Method of crop establishment

Data presented in Table 4.4.6a. showed that the transplanted crop accumulated significantly higher amounts of N, P, K, Mg, S, Fe, Cu and Silica than wet seeded crop and the increases were 16.1, 13.8, 17.4, 24.5, 11.8, 20.6, 18.5 and 24.9 per cent respectively over wet seeded crop. There was no significant difference in the Ca, Mn and Zn uptake between the two methods of crop establishment.

b. Method of land preparation (digging)

Digging to a depth of 30 cm facilitated a significantly higher uptake of N, P, Ca, Mg, Fe, Mn and Silica and the increases were 36.9, 21.7, 29.5, 14.1, 23.4, 30.6 and 31.6 per cent respectively over wet seeded crop. Depth of digging did not significantly differ in their influences on K, S, Zn and Cu uptake of the grain.

c. Farm yard manure/organic manure

Increasing levels of FYM also did not affect the K and Zn uptake of the grain. All the other elements were significantly influenced and the percentage increases were 36.6, 35.9, 26.4, 31.2, 32.7, 24.1, 26.6, 32.0 and 43.1 per cent for N, P, Ca, Mg, S, Fe, Mn, Cu and SiO_2 respectively over wet seeded rice.

2. Straw

a. Method of crop establishment

The total nutrient elements accumulated in the straw are presented in Table 4.4.6b. A perusal of the data showed that N, K, Cu and Silica uptake of straw were

Table 4.4.6a Nutrient uptake as influenced by cultural management - Second crop (October-February)

Treatments		Grain (kg ha^{-1})										
		N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO_2
System	WSR	47.85	11.53	15.61	0.78	3.64	6.04	10.46	1.202	0.143	0.027	777.88
	TPR	55.55	13.12	18.33	0.822	4.54	6.75	12.61	1.201	0.126	0.032	971.66
CD (0.05)		4.81	1.34	2.31	NS	0.363	0.54	1.34	NS	NS	0.0046	129.35
Digging	D_{15}	43.65	11.12	16.39	0.698	3.82	6.20	10.33	1.042	0.107	0.029	755.32
	D_{30}	59.76	13.53	17.56	0.904	4.36	6.58	12.75	1.361	0.161	0.031	994.22
CD (0.05)		4.81	1.34	NS	0.072	0.363	NS	1.34	0.09	NS	NS	129.35
FYM	M_0	41.64	10.26	16.40	0.709	3.46	5.29	9.82	1.069	0.156	0.025	724.69
	M_5	56.59	12.78	17.28	0.799	4.27	6.85	12.61	1.183	0.126	0.031	862.23
	M_{10}	56.88	13.94	17.24	0.896	4.54	7.02	12.19	1.353	0.120	0.033	1037.38
CD (0.05)		5.88	1.64	NS	0.088	0.445	0.664	1.646	0.110	NS	0.0056	158.43
CV (%)		13.44	15.74	19.69	13.19	12.84	12.27	16.86	10.94	94.84	14.39	21.39

WSR - Wet seeded rice
NS - Non significant
TPR - Transplanted rice
M - Farm yard manure (0, 5 and 10 t ha^{-1})
D - Depth of digging (15 and 30 cm)

Table 4.4.6b Nutrient uptake as influenced by cultural management - Second crop (Oct - Feb)

Treatments	Straw (kg ha^{-1})										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO$_2$
System WSR	34.34	10.14	88.51	12.51	5.83	6.46	10.97	14.74	0.233	0.024	966.87
TPR	34.98	8.20	83.76	10.82	4.45	5.37	10.11	12.64	0.180	0.023	880.25
CD (0.05)	NS	0.68	NS	1.47	0.457	0.393	0.623	0.797	0.043	NS	NS
Digging D$_{15}$	31.79	9.39	82.76	12.45	5.05	6.07	10.33	14.00	0.173	0.024	947.83
D$_{30}$	37.53	8.23	89.51	10.88	5.23	5.76	10.76	13.38	0.239	0.023	899.29
CD (0.05)	4.1	NS	NS	1.47	NS	NS	NS	NS	0.043	NS	NS
FYM M$_0$	35.49	8.93	80.38	11.41	5.05	6.01	10.12	13.97	0.201	0.024	952.02
M$_5$	31.30	8.44	80.26	12.44	4.90	5.30	10.11	13.13	0.198	0.024	886.48
M$_{10}$	37.19	10.11	97.76	11.15	5.48	6.45	11.41	13.97	0.219	0.023	932.18
CD (0.05)	NS	0.83	9.32	NS	NS	0.224	0.763	NS	NS	NS	NS
CV (%)	17.28	10.70	12.72	18.3	12.88	9.61	8.55	8.43	29.93	19.30	32.06

WSR - Wet seeded rice
NS - Non significant
TPR - Transplanted rice
M - Farm yard manure (0, 5 and 10 t ha^{-1})
D - Depth of digging (15 and 30 cm)

not affected by the method of crop establishment. Phosphorus, Ca, Mg, S, Fe, Mn and Zn were significantly higher in the wet seeded crop and the increases worked out to 23.7, 15.6, 31.0, 203.0, 8.5, 16.6 and 29.4 per cent respectively over transplanted crop.

b. Method of land preparation (digging)

Depth of digging significantly increased the N and Zn uptake in straw and reduced the Ca uptake by 19.0, 38.2 and 12.6 per cent.

c. Farm yard manure/organic manure

A perusal of the data showed that application of FYM at 10 t ha^{-1} significantly increased the P, K, S and Fe uptake in the straw and the increases were 13.2, 21.6, 7.3 and 12.7 per cent respectively. Other elements remained un affected.

4.4.7 Interaction effects of method of crop establishment, depth of digging and FYM on nutrient uptake in grain and straw

1. Grain

a. Method of crop establishment x FYM

It can be seen from the Table 4.4.7. that application of 5 t ha^{-1} of FYM significantly increased the N uptake in both the methods but the N uptake in grain under transplanted crop was significantly more than that under wet seeding and the increase was 26.1 per cent over wet seeding. This held good both at 5 and 10 t ha^{-1} of FYM, though in control the system did not vary.

b. Method of crop establishment x digging

Significant effect of the combined effect of the depth of digging and crop establishment showed that deep digging increased the Mn uptake in both cases though the extent of influence was less in transplanted crop as is evident from the percentage increases of 42.4 and 20.2 in wet seeded and transplanted crops respectively.

Table 4.4.7 Interaction effects of cultural management on nutrient uptake by grain and straw (kg ha^{-1}) - Second crop (Oct - Feb)

I Method of establishment x FYM

		Grain (kg ha^{-1})		Straw (kg ha^{-1})					
		N		Mn		Zn		SiO_2	
System		WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
FYM	M_0	42.79	40.48	15.69	12.25	0.214	0.188	1042.4	861.6
	M_5	50.06	63.12	14.22	12.04	0.194	0.201	1074.7	698.2
	M_{10}	50.70	63.05	14.31	13.64	0.289	0.149	783.5	1080.9
CD (0.05)		8.32		1.381		0.079		354.5	

II Method of crop establishment x depth of digging

		Grain (kg ha^{-1})		Straw (kg ha^{-1})									
		Mn		P		S		Fe		Zn		Cu	
System		WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR	WSR	TPR
Digging	D_{15}	0.99	1.09	11.0	7.78	6.97	5.18	11.12	9.55	0.221	0.126	0.026	0.021
	D_{30}	1.41	1.31	9.3	8.56	5.96	5.56	10.83	10.69	0.244	0.234	0.022	0.025
CD (0.05)		0.127		0.958		0.741		0.88		0.062		0.0004	

III Depth of digging x FYM

		Grain (kg ha^{-1})		Straw (kg ha^{-1})							
Digging		Ca		P		K		Ca		Mn	
		D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}	D_{15}	D_{30}
FYM	M_0	0.022	0.027	8.80	9.06	74.7	86.1	13.48	9.33	14.89	13.08
	M_5	0.028	0.034	8.34	8.53	70.7	89.9	13.96	10.92	13.76	12.50
	M_{10}	0.036	0.030	11.02	9.20	102.9	92.6	9.90	12.40	13.39	14.56
CD (0.05)		0.008		1.17		13.13		2.556		1.381	

c. Depth of digging x FYM

Data are presented in Table 4.4.7. It was found that effectiveness of FYM in increasing Cu uptake of the grain was confined to shallow digging only. In this combination application of 10 t ha^{-1} FYM significantly increased the Cu uptake by 63.6 per cent over control.

2. Straw

a. Method of crop establishment x FYM

The data are presented in Table 4.4.7. The data showed that application of 5 t ha^{-1} of FYM significantly reduced the Mn uptake in wet seeded crop over control by 9.4 per cent whereas in transplanted crop the influence was reverse and was apparent only at 10 t ha^{-1} FYM where the increase was 11.3 per cent. It is also evident from the data that wet seeded crop under control as well as 5 t ha^{-1} of FYM showed a significantly higher uptake of Mn in the straw over transplanted crop.

It is evident from the data that at 10 t ha^{-1} of FYM wet seeded crop registered a significantly higher uptake of Zn which was 94.0 per cent more than that of transplanted crop.

Significant variation in response of rice to this combined effect in silica uptake of straw was also observed. Wet seeded crop under 10 t ha^{-1} of FYM reduced the silica uptake of straw by 27.1 per cent over 5 t ha^{-1} level while transplanted crop increased it by 54.8 per cent.

b. Method of crop establishment x digging

Combined effect of depth of digging and methods of crop establishment on P, S, Fe, Zn and Cu contents are presented in Table 4.4.7.

It can be seen from the Table 4.2.5.b that deep digging significantly reduced the P and S uptake in wet seeded crop while it was not apparent in transplanted crop. The reduction worked out to 15.5 and 14.5 per cent for P and S respectively.

However in respect of Fe the data showed that deep digging increased the Fe uptake of straw by 11.9 per cent in transplanted crop and the increase was statistically significant.

In the case of Zn and Cu transplanted crop significantly increased the uptake by 85.7 and 19.0 per cent by deep digging while wet seeding failed to improve the Zn uptake by an increase in depth of digging though deep digging significantly reduced the Cu uptake by 15.4 per cent.

c. Depth of digging x FYM

The data presented in Table 4.4.7. showed that the accumulation pattern of P as well as K underwent a shift when the FYM level was increased from 5 t ha^{-1}. At 10 t ha^{-1} shallow digging accumulated more P and K than in deep dug plots and the increase which was statistically significant worked out to 19.8 and 11.1 per cent respectively. It was also seen that in control (M_0) as well as at 5 t ha^{-1} level deep digging accumulated more P and K. The increase at 5 t ha^{-1} level were 2.3 and 27.2 per cent.

However, this trend was reversed in the case of Ca. Deep digging was significantly inferior to shallow digging both at M_0 and M_5 levels of FYM but at 10 t ha^{-1} level, deep digging was significantly superior with 26.6 per cent advantage. At 5 t ha^{-1} level of FYM shallow digging which was better recorded an increase of 27.8 per cent Ca.

In the case of Mn, increasing levels of FYM significantly reduced the Mn uptake in shallow digging and increased it in deep digging and the increase and decrease worked out to 11.3 and 10.1 per cent respectively.

4.4.8 Second order interaction effect on nutrient uptake of grain and straw

1. Grain

A perusal of the results showed that combined effect of crop establishment, depth of digging and FYM level affected only N among the different elements in the grain and the data are presented in Table 4.4.8.

The results showed that a maximum quantity of 80.15 kg N accumulated in the grain in TPR D_{30} M_{10} as against 33.49 kg ha^{-1} in shallow dug wet seeded crop with no FYM and the difference was 71.8 per cent over WSR D_{15} M_0. Also evident is the steady significant increase in N content in deep dug transplanted crop receiving 10 t ha^{-1} of FYM as against a significant decline in grain uptake of N at 10 t ha^{-1} in shallow dug transplanted crop.

In the case of wet seeded crop, the data further showed that only 10 t ha^{-1} of FYM could significantly increase the N uptake in grain when the soil was dug to a depth of 15 cm. But in deep dug plots the significant effect was evident only upto 5 t ha^{-1} of FYM.

The results further showed that at no FYM level the nitrogen uptake did not significantly differ among treatment combinations.

2. Straw

Significant combined effect of depth of digging, method of crop establishment and FYM level on nutrient uptake of straw was observed only in the case of P and Ca and the data are presented in Table 4.4.8.

Table 4.4.8 Interaction effects of crop management, digging and FYM on nutrient uptake by grain and straw (kg ha^{-1})

		Grain			Straw					
		N (kg ha^{-1})			P (kg ha^{-1})			Ca (kg ha^{-1})		
		M_0	M_5	M_{10}	M_0	M_5	M_{10}	M_0	M_5	M_{10}
WSR	D_{15}	33.49	38.45	47.21	9.88	13.51	7.61	13.99	14.71	11.51
WSR	D_{30}	52.10	61.68	54.20	9.78	8.34	8.40	12.59	11.85	10.44
TPR	D_{15}	39.05	57.72	45.95	6.87	8.53	7.81	12.98	13.20	8.30
TPR	D_{30}	41.91	68.51	80.15	7.27	10.06	8.72	6.07	9.99	14.35
CD (0.05)			11.77			1.66			3.616	

It can be seen that maximum P uptake of straw of 13.51 kg ha^{-1} was observed in shallow dug wet seeded plots receiving 10 t ha^{-1} of FYM and this was significantly superior to all other combinations. The results showed that lowest P uptake in straw was noticed in shallow dug transplanted crop receiving 5 t ha^{-1} of FYM followed by deep dug transplanted crop receiving 5 t ha^{-1} FYM. Increasing levels of FYM beyond 5 t ha^{-1} significantly increased the P content while such an increase was not apparent in wet seeded crop.

Interaction effect on the calcium uptake of straw revealed a heavy accumulation of Ca in WSR $D_{15} M_5$ as well as TPR $D_{30} M_{10}$ which were significantly superior to $D_{30} M_{10}$ in wet seeded as well as $D_{30} M_0$ and $D_{30} M_5$ in transplanted crops and the differences worked out to 27.8, 136.4 and 43.6 per cent respectively. It can also be noted that transplanted crop differed significantly in its response to FYM levels as far as Ca uptake was concerned depending upon depth of digging. FYM 10 t ha^{-1} significantly reduced the Ca content by 56.4 per cent in shallow dug plots while it increased the Ca content by 136.4 per cent in deep dug plots.

4.5 EXPERIMENT V

The experiment entitled "Effect of K, Ca and S management on nutrient balance, iron absorption and productivity of rice" studied the direct and interactive influences of these elements on productivity of rice in lateritic alluvium.

4.5.1 Morphophysiological characters

a. Effect of K

Data on the main effects of K and S on morphophysiological attributes are presented in Table 4.5.1a. and 4.5.1b.

Table 4.5.1a Effect of K, Ca and S on growth attributes of rice

Treatments	Height (cm)				Tillers/hill (Nos.)			
	MT	PI	Flg	Harvest	MT	PI	Flg	Harvest
Potassium								
K_0	35.9	46.3	81.6	73.9	4.0	5.9	6.1	5.7
K_{60}	36.3	46.9	83.1	74.2	3.9	6.0	6.4	5.9
K_{120}	35.5	49.2	88.1	79.6	3.6	5.8	6.1	5.7
K_{180}	35.7	49.2	86.1	78.5	3.9	6.1	6.3	6.1
CD (0.05)	NS	2.3	3.5	2.9	NS	NS	NS	NS
Calcium L_0	36.3	47.7	83.9	75.6	3.9	6.0	6.3	5.7
L_{150}	35.5	48.2	85.6	77.4	3.8	5.9	6.1	5.9
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sulphur S_0	35.6	47.1	83.8	75.9	4.0	6.0	6.3	5.9
S_{100}	35.5	47.9	85.2	77.0	3.6	6.2	6.0	5.7
S_{200}	36.5	48.7	85.2	76.7	4.0	5.8	6.4	5.9
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	6.06	7.29	6.36	5.82	17.99	15.79	19.8	17.20

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})
L = Levels of Ca (0 and 150 kg lime ha^{-1})
S = Levels of S (0, 100 and 200 kg ha^{-1})
NS = Not significant

Table 4.5.1a contd.....

Treatments		Total dry weight at MT (g plant^{-1})	Plant dry weight (g plant^{-1})							
			PI				Flg			
			Shoot	Root	Total	Shoot/root	Shoot	Root	Total	Shoot/root
Potassium										
	K_0	10.74	18.30	4.57	22.9	4.46	32.96	4.23	37.22	7.90
	K_{60}	11.43	16.49	4.37	20.88	3.91	34.60	4.48	39.15	7.89
	K_{120}	11.39	17.88	3.48	22.63	5.55	42.73	4.84	47.51	8.90
	K_{180}	11.05	17.25	3.76	20.73	4.95	35.56	4.45	39.54	8.20
CD (0.05)		NS	NS	0.617	NS	0.594	2.685	NS	2.997	0.655
Calcium	L_0	11.22	17.43	4.20	22.24	4.60	36.93	4.45	41.41	8.41
	L_{150}	11.08	17.53	3.81	21.35	4.82	35.99	4.55	40.54	8.04
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS
Sulphur	S_0	11.30	17.11	4.05	22.08	4.51	37.16	4.56	41.65	8.27
	S_{100}	11.53	17.18	4.12	21.33	4.77	35.97	4.49	40.47	8.07
	S_{200}	10.63	18.17	3.98	21.97	4.86	36.26	4.45	40.80	8.34
CD (0.05)		0.689	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)		10.92	14.33	23.35	19.02	19.31	11.27	16.73	11.20	12.20

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

S = Levels of S (0, 100 and 200 kg ha^{-1})

NS = Not significant

Table 4.5.1b Effect of K, Ca and S on physiologic attributes of rice

Treatments	Leaf sap pH		Chlorophyll (mg/g fresh sample weight)					
			M.T.			Boot leaf		
	MT	Boot leaf	Chl. \`a'	Chl. \`b'	Total	Chl. \`a'	Chl. \`b'	Total
Potassium								
K_0	6.29	5.969	1.500	1.712	3.110	1.453	1.229	2.669
K_{60}	6.12	6.025	1.503	1.663	3.157	1.450	1.241	2.655
K_{120}	6.31	6.083	1.506	1.732	3.108	1.460	1.298	2.725
K_{180}	6.26	6.025	1.500	1.572	3.072	1.440	1.274	2.710
CD (0.05)	0.050	0.072	NS	0.115	NS	0.012	NS	NS
Calcium L_0	6.23	6.028	1.499	1.639	3.008	1.447	1.276	2.707
L_{150}	6.26	6.024	1.505	1.700	3.215	1.454	1.245	2.687
CD (0.05)	NS	NS	NS	NS	0.123	NS	NS	NS
Sulphur S_0	6.23	6.04	1.510	1.685	3.168	1.447	1.254	2.665
S_{100}	6.25	6.04	1.507	1.649	3.028	1.459	1.278	2.733
S_{200}	6.25	6.00	1.489	1.675	3.139	1.446	1.251	2.703
CD (0.05)	NS	NS	0.011	NS	NS	0.010	NS	NS
CV(%)	1.28	1.81	1.37	10.59	8.57	1.30	15.02	8.05

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

S = Levels of S (0, 100 and 200 kg ha^{-1})

NS = Not significant

Data showed that the increasing levels of K significantly increased the height of the plant at PI, flowering and harvesting stages and the increases were 1.2 and 6.2 per cent at PI and 1.8 and 8.0 per cent at flowering and 0.5 and 7.7 per cent at harvest over 60 and 120 kg K ha^{-1} respectively. Increasing the levels of K beyond 120 kg ha^{-1} did not have any effect.

The tiller counts were not affected by K application at any stage.

Data on plant dry weight showed that root dry weight and shoot root ratio alone were affected significantly at PI stage by application of K. Maximum root weight was recorded at control and K effect was to reduce the root weight significantly and at 120 kg k ha^{-1} the root weight was only 23.9 per cent of the control.

Similarly shoot-root ratio widened with increasing levels of K upto 120 kg K ha^{-1} and the ratio was significantly wider compared to other levels.

Data on dry matter accumulation at harvest showed that K application at 120 kg ha^{-1} significantly increased the dry weight of shoot, total dry weight and shoot-root ratio over control at harvest and the corresponding increases were 29.6, 27.6 and 12.7 per cent.

Potassium affected chlorophyll `b' content at PI and chlorophyll `a' of boot leaf. Highest contents were recorded at both stages at 120 kg ha^{-1} of K and the same were significantly lower at 180 kg K ha^{-1}.

Lowest status of leaf sap pH was recorded at 60 kg K ha^{-1} level at PI and at zero level of K in the boot leaf and highest leaf sap pH at both stages were recorded at 120 kg level of K application and the differences were statistically significant.

Effect of Ca and S

Data presented in Table 4.5.1a. showed that Ca and S did not have any significant effect on plant dry weight at harvest. Variations due to main effects of Ca and S on morphophysiological attributes were not statistically significant.

Among the physiological attributes, Ca affected the total chlorophyll content at MT and lime @ 150 kg ha^{-1} increased the total chlorophyll content over control and the increase was 6.9 per cent.

Application of 200 kg S ha^{-1} significantly reduced the chlorophyll `a' content over that of 100 kg S ha^{-1} at PI as well as in the boot leaf and the decreases were 1.2 and 0.9 per cent.

Leaf sap pH was not affected by S application.

b. Yield attributes

Application of K increased all the yield attributes (Table 4.5.1c) significantly except panicles/hill as well as length of the panicle. Application of K @ 120 and 180 kg K ha^{-1} significantly increased the number of branches per panicle, panicle weight, filled grains per panicle and grain weight significantly over 60 kg K ha^{-1}. Variations due to 120 and 180 kg K ha^{-1} were not statistically significant. Lowest number of unfilled grains were recorded at 60 kg ha^{-1} and maximum at 180 kg ha^{-1} and the difference was statistically significant.

Significant effect of application of Ca was confined to branches/panicle. Lime @ 150 kg ha^{-1} increased the panicle branches by 1.7 per cent.

Application of S at 200 kg ha^{-1} increased the number of branches/panicle and panicle weight by 4.3 and 5.2 per cent over control.

Main effect of treatments did not have any significant effect on percentage of filling.

Moisture content of the grain steadily increased with increasing level of K application and 120 kg level was significantly superior to control and the increase was 8.2 per cent.

4.5.1c Effect of K, Ca and S on yield attributes and yield of rice

ments	Panicles /hill	Panicle length (cm)	Branches/ panicle (Nos.)	Panicle wgt/10 panicle (g)	Filled grains/ panicle (Nos.)	Unfilled grains/ Panicle (Nos.)	Percentage filling	1000 grain weight (g)	Volume wgt. ratio of grain	Moisture content of grain (%)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total biomass (kg ha^{-1})	Grain/ straw	Weed dry weight (g/m^2)
:sium															
K_0	5.61	24.17	8.82	27.46	85.01	23.47	78.76	30.5	8.64	11.45	5961	3069	9029	1.96	26.98
K_{60}	5.72	20.68	8.58	26.75	84.03	20.68	80.15	30.3	8.93	12.15	6025	2959	8832	2.07	13.96
K_{120}	5.62	21.01	8.98	28.22	89.49	23.17	79.88	31.1	8.75	12.39	6489	3463	9762	1.80	44.70
K_{180}	5.94	21.24	8.95	29.71	88.92	25.78	77.72	30.7	9.03	12.66	6492	3541	9998	1.84	29.14
).05)	NS	NS	0.131	1.275	4.48	3.02	NS	0.55	0.233	0.84	453.28	364.85	762.30	0.143	10.85
um															
L_0	5.69	20.83	8.76	27.91	82.85	23.40	78.12	30.6	8.72	12.22	6172	3196	9350	1.92	28.60
L_{150}	5.76	22.71	8.91	28.16	91.14	24.12	79.14	30.7	8.95	12.11	6212	3320	9460	1.92	28.80
).05)	NS	NS	0.092	NS	NS	NS	NS	NS	0.165	NS	NS	NS	NS	NS	NS
ıur															
S_0	5.79	23.03	8.63	27.42	88.83	22.50	79.81	30.5	8.83	11.98	5980	3199	9187	1.92	31.18
S_{100}	5.61	21.01	8.88	27.85	85.79	24.36	78.09	30.8	8.92	12.63	6314	3215	9503	1.97	21.09
S_{200}	5.78	21.29	9.00	28.84	86.33	24.41	77.98	30.6	8.77	11.89	6281	3359	9527	1.87	33.82
).05)	NS	NS	0.113	1.105	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	9.415
	18.79	32.35	2.28	6.96	7.89	19.46	4.05	2.78	4.03	10.63	11.21	17.14	12.41	11.44	57.99

vels of K (0, 60, 120 and 180 kg ha^{-1})

vels of S (0, 100 and 200 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

NS = Not significant

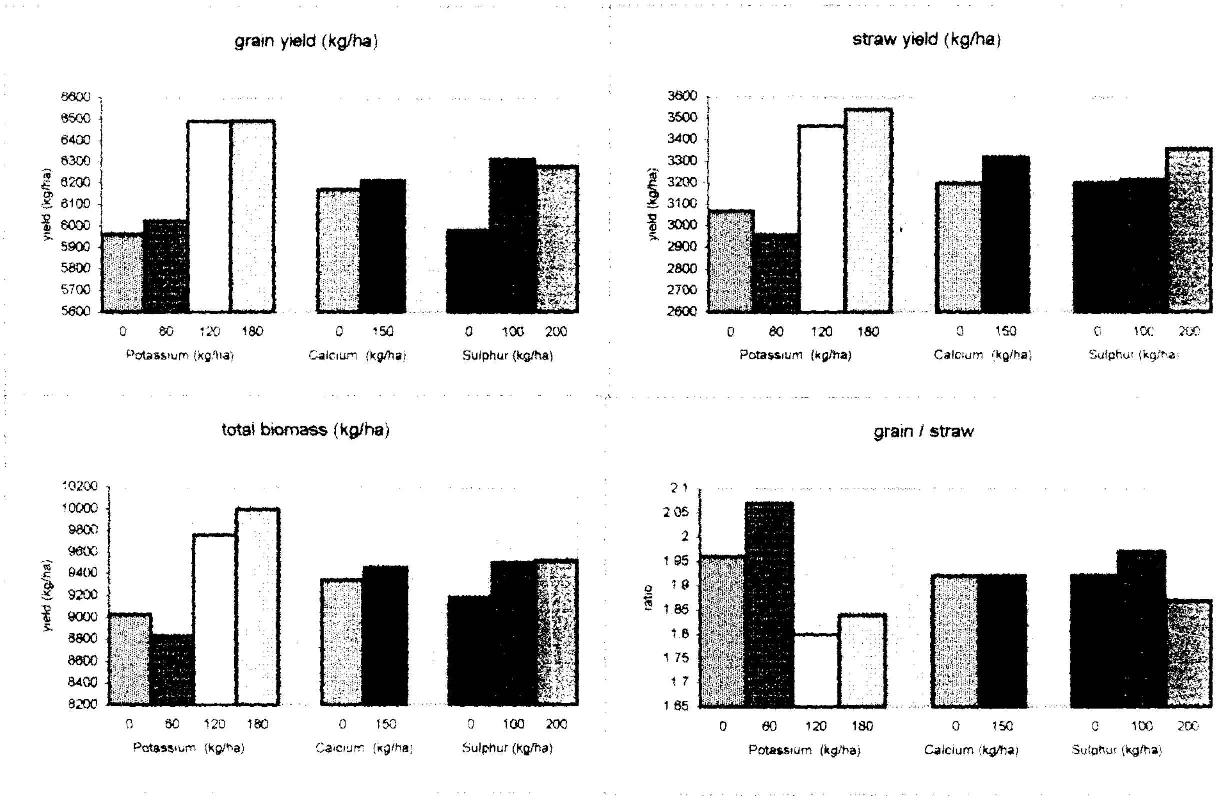


Fig. 4.5.1 Effect of K, Ca and S on grain, straw and total biomass yield and grain / straw

Calcium and S did not have any significant effect on moisture content of the grain.

Volume-weight ratio was significantly affected by the K and Ca. Application of 180 kg K ha^{-1} registered the highest ratio which was significantly superior to control and increased the ratio by 4.5 per cent.

Significant increase in volume weight ratio due to Ca worked out to 2.6 per cent over control.

Sulphur did not have any effect on volume-weight ratio.

Data presented in Table 4.5.1c showed that application of K @ 120 kg ha^{-1} significantly increased the yield which was on par with application of K @ 180 kg ha^{-1} and significantly superior to 0 and 60 kg K ha^{-1}. Application of Ca and S did not have any significant effect on yield though S @ 100 kg ha^{-1} had increased the yield by 334 kg ha^{-1} (Fig. 4.5.1).

4.5.2 Second order interaction effect (K x Ca x S)

a. Morphophysiological characters

Combined effect of K, Ca and S were found to affect chlorophyll `a' and cell sap pH at MT and chlorophyll `a' and `b' of the boot leaf and among productivity characters panicle weight and filled grains per panicle.

It may be observed from Table 4.5.2. that positive interaction of K, S and Ca was observed only when the level of all the elements are high. The data further showed that chlorophyll is positively affected only by K. Sulphur and Ca suppress the K effect which counteract between themselves and get neutralised. Thus at `0' level of K, 200 kg S ha$^{-1}$ significantly reduced chlorophyll `a' which was then neutralised by 150 kg lime ha^{-1}. With increasing levels of K, increasing levels of S increases the magnitude of its effect. Exactly same pattern of influence was observed in respect of the chlorophyll `a' content of the boot leaf.

With regard to chlorophyll `b' content, the data showed that in the combined interaction, Ca and S compensate their negative influences on each other and it was significant at the lower level of 60 kg K ha$^{-1}$. Thus significant reduction of chlorophyll `b' in K_{60} S_{200} was offset by K_{60} S_{200} L_{150}.

In the case of cell sap pH of the leaf at MT stage the pattern of interaction was similar at lower levels. Application of S tended to increase the leaf sap pH which was neutralised by Ca. However at 120 kg level of K, the pH of 6.17 was raised to 6.32 in the presence of L_{150}.

The highest shoot-root ratio of 8.10 at PI stage was observed on exclusive application of K at 120 kg ha^{-1} which was significantly reduced by K_{120} $S_{100,}$ K_{120} S_{200} and K_{120} S_0 L_{150} and K_{120} S_{100} L_{150} and K_{120} S_{200} L_{150}.

b. Yield attributes

The data on filled grains showed that the maximum number of filled grains per panicle was realised in K_{120} S_0 L_{150} treatment and all other treatment combinations were significantly inferior. Addition of S at 100 kg ha^{-1} level reduced the yield by 44.0 per cent which was then increased by addition of lime at 150 kg ha^{-1}.

The data further showed that the panicle weight was significantly influenced by application of K, Ca and S. Maximum weight of panicle was recorded by K_{180} S_0 when combined with L_{150} kg ha^{-1} and the lowest weight by K_{60} S_{100} Ca_0. In the absence of Ca at 120 kg ha^{-1} level of K, it required 200 kg ha^{-1} S and at 180 kg K ha^{-1}, it required 100 kg S ha^{-1}.

It can be seen from Table 4.5.2. that maximum grain- straw ratio was obtained when lime @ 150 kg ha^{-1} alone was applied and the lowest ratio registered by the treatment receiving 150 kg ha^{-1} of lime combined with 120 kg ha^{-1} of K without any S.

Table 4.5.2 Combined effect of K, Ca and S on growth and yield attributes of rice

K x Ca x S

	Chlorophyll (mg/g fresh sample)						Leaf sap pH at MT		Shoot/root at PI	
	Chl.`a' at MT		Chl.`a' boot leaf		Chl.`b' boot leaf					
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0 S_0	1.51	1.48	1.45	1.44	1.30	1.14	6.32	6.13	4.13	3.75
K_0 S_{100}	1.52	1.49	1.45	1.47	1.08	1.33	6.42	6.27	3.19	6.04
K_0 S_{200}	1.47	1.52	1.46	1.45	1.35	1.17	6.27	6.37	4.11	5.51
K_{60} S_0	1.55	1.46	1.46	1.44	1.53	0.93	6.08	6.07	3.88	3.81
K_{60} S_{100}	1.52	1.51	1.48	1.43	1.27	1.51	6.10	6.22	3.06	4.59
K_{60} S_{200}	1.50	1.48	1.44	1.46	0.96	1.26	6.05	6.22	3.24	4.86
K_{120} S_0	1.52	1.52	1.44	1.45	1.34	1.35	6.33	6.40	8.10	3.62
K_{120} S_{100}	1.51	1.48	1.47	1.47	1.24	1.23	6.20	6.35	5.68	6.23
K_{120} S_{200}	1.47	1.54	1.44	1.49	1.40	1.25	6.33	6.27	4.20	5.42
K_{180} S_0	1.53	1.52	1.44	1.46	1.34	1.12	6.20	6.30	5.05	3.80
K_{180} S_{100}	1.50	1.53	1.46	1.45	1.36	1.21	6.17	6.30	4.00	5.35
K_{180} S_{200}	1.41	1.53	1.39	1.44	1.16	1.45	6.30	6.27	6.60	4.93
CD (0.05)	0.032		0.0 27		0.303		0.123		1.45	

Contd.....

Table 4.5.2 contd....

	Filled grains/panicle		Grain/straw ratio		Panicle weight/ 10 panicle	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0 S_0	84.1	92.8	1.78	2.21	26.59	26.52
K_0 S_{100}	83.0	85.0	1.86	2.04	28.65	27.08
K_0 S_{200}	78.2	89.9	1.97	1.88	27.48	28.43
K_{60} S_0	82.7	84.5	2.06	2.07	27.35	25.33
K_{60} S_{100}	81.5	85.3	2.16	2.08	24.71	25.95
K_{60} S_{200}	78.0	92.2	2.01	2.07	29.36	27.80
K_{120} S_0	83.6	114.2	2.12	1.49	26.40	28.75
K_{120} S_{100}	79.3	89.8	1.89	1.88	26.98	28.34
K_{120} S_{200}	83.8	86.2	1.56	1.87	31.26	27.60
K_{180} S_0	76.9	91.9	1.88	1.77	25.57	32.82
K_{180} S_{100}	91.2	91.9	1.98	1.88	31.36	29.74
K_{180} S_{200}	91.9	90.5	1.76	1.80	29.5	29.60
CD (0.05)	10.98		0.351		3.12	

4.5.3 Main effects of K, Ca and S on elemental composition of rice

4.5.3.1 Elemental composition of root at MT stage

a. Effect of K

Application of K at 120 kg ha^{-1} recorded the highest content of (Table 4.5.3a) N, K, Fe and Zn and the lowest contents of Ca and Mg and the respective increases and decreases over control (K_0) were 5.9, 44.9, 0.6 and 18.6 and 38.9 and 27.8 per cent respectively. Highest contents of Fe and Mn were recorded at K_{120} kg ha^{-1} and the increases worked out to 68.2 and 33.0 per cent. In the case of Cu control recorded the highest content and which decreased with increasing level of K. Highest Ca content (0.027%) was recorded at K_{60} and was 38.9 per cent more than the lowest value recorded at 180 kg ha^{-1}. All these variationswere statistically significant.

b. Effect of Ca

Application of Ca as lime at 150 kg ha^{-1} significantly affected the elemental composition of the root at MT stage. Phosphorus, K, S, Mn and Zn contents increased by 7.0, 7.4, 5.2, 6.5 and 2.3 per cent and Ca and Fe decreased by 12.0 and 19.9 per cent respectively.

c. Effect of S

Application of S at 100 kg ha^{-1} significantly increased the P, K, S and Mn contents of the root and the increases were 11.5, 14.5, 14.8, 11.7 and 23.0 per cent respectively. Calcium and Fe content decreased significantly by 12.0 and 23.4 per cent at S level of 200 kg ha^{-1}.

4.5.3.2 Elemental composition of root at PI stage

a. Effect of K

Data presented in Table 4.5.3b. showed that all the elements except N were significantly affected by K levels. Potassium at 180 kg ha^{-1} recorded the highest

Table 4.5.3a Effect of K, Ca and S on elemental composition of root at MT

Treatment		Root at Maximum tillering									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Potassium	K_0	1.118	0.202	0.940	0.025	0.097	2292	58358	174.3	42.4	20.4
	K_{60}	1.202	0.173	0.625	0.027	0.056	1777	65260	181.8	37.7	17.4
	K_{120}	1.212	0.193	1.167	0.024	0.070	1918	98154	231.9	47.1	17.6
	K_{180}	1.093	0.214	1.362	0.018	0.070	2306	69825	190.8	50.3	16.9
CD(0.05)		NS	0.010	0.096	0.0026	NS	30.40	NS	16.34	1.58	1.03
Calcium	L_0	1.35	0.188	0.987	0.025	0.083	2021	81066	188.0	43.6	18.2
	L_{150}	1.178	0.203	1.060	0.022	0.064	2126	64933	201.4	44.9	18.0
CD(0.05)		NS	0.007	0.068	0.0018	NS	21.49	NS	11.55	1.12	NS
Sulphur	S_0	1.120	0.182	0.935	0.025	0.059	1953	84498	177.9	40.9	19.1
	S_{100}	1.172	0.203	1.093	0.025	0.068	2181	69484	218.9	44.9	17.4
	S_{200}	1.177	0.201	1.062	0.022	0.093	2086	64715	187.3	47.3	17.8
CD(0.05)		NS	0.008	0.083	0.0022	NS	26.25	NS	14.15	1.37	0.88
CV (%)		19.52	5.64	11.25	14.82	8692	1.74	87.71	9.94	4.21	6.72

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})
L = Levels of Ca (0 and 150 kg lime ha^{-1})
S = Levels of S (0, 100 and 200 kg ha^{-1})
NS = Not significant

Table 4.5.3b Effect of K, L and S on elemental composition of root at PI

Treatment		Root at panicle initiation									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Potassium	K_0	0.797	0.167	0.542	0.009	0.038	1578	67944	143.7	49.4	19.6
	K_{60}	0.870	0.186	0.571	0.012	0.047	1729	63929	185.4	54.8	21.9
	K_{120}	0.853	0.189	0.496	0.012	0.043	1507	60581	202.5	47.2	21.9
	K_{180}	0.877	0.208	0.642	0.010	0.043	1522	58472	183.7	48.8	18.8
CD(0.05)		NS	0.014	0.071	0.002	0.0017	32.57	2182.1	8.47	2.83	0.54
Calcium	L_0	0.854	0.186	0.548	0.010	0.041	1599	61832	183.2	48.3	20.5
	L_{150}	0.844	0.189	0.577	0.011	0.044	1568	63631	174.3	51.7	20.6
CD(0.05)		NS	NS	NS	NS	0.0011	19.92	1543.0	5.99	2.01	
Sulphur	S_0	0.834	0.178	0.566	0.010	0.040	1359	61136	158.6	49.4	19.4
	S_{100}	0.799	0.188	0.556	0.011	0.044	1698	66093	196.9	48.0	21.0
	S_{200}	0.914	0.196	0.566	0.010	0.043	1694	60966	180.8	52.6	21.3
CD(0.05)		NS	0.012	NS	NS	0.0014	23.02	1889.8	7.34	2.45	0.47
CV (%)		15.86	8.46	14.97	26.10	7.01	2.43	4.12	5.61	6.71	3.12

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})

S = Levels of S (0, 100 and 200 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

NS = Not significant

contents of P, and K and the increases over control were 10.1 and 18.5 per cent. Highest content of Ca, Mg, Mn and Cu content were recorded at 120 kg K ha^{-1} level and the increases over the lowest level were 33.3, 13.2, 58.8 and 10.2 per cent respectively.

Highest Mg and S contents were recorded at 60 kg level of K and the lowest in K_{120}. Application of K significantly reduced the Fe content of root and decrease over control at 180 kg k ha^{-1} was 13.9 per cent.

b. Effect of Ca

Data showed that application of Ca as lime at 150 kg ha^{-1} significantly increased the Mg, Fe and Zn contents and the increases were 7.3, 3.0 and 7.0 per cent. Sulphur and Mn content were significantly reduced by 1.9 and 4.9 per cent respectively.

c. Effect of S

Application of 200 kg S recorded the highest content of P, Zn and Cu in the root at PI stages and the increases were statistically significant. Main effect of 100 kg S was more effective in affecting the elemental composition and gave the highest levels of Mg, S, Fe and Mn and the increases were 1.0, 24.9, 8.1 and 24.1 per cent respectively.

4.5.3.3 Elemental composition of shoot at MT stage

Main effects of different levels of K, lime and S on the elemental composition of the shoot are presented in Table 4.5.3c.

It can be observed that application of K at 180 kg ha^{-1} level gave the highest shoot contents of P, K, Fe and Zn which were significantly superior to control and the immediate lower level except for K and the increases were 38.3, 30.6, 33.3 and 28.0 per cent respectively. Highest content of Ca and Mg were recorded at K_{60} which was significantly superior to the lower and higher levels.

Table 4.5.3c Effect of K, Ca and S on elemental composition of Shoot at MT

Treatment		Shoot at maximum tillering									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Potassium	K_0	2.737	0.253	2.871	0.102	0.091	2554	1329	231.8	23.6	7.25
	K_{60}	2.702	0.262	2.592	0.178	0.149	2419	1489	301.2	26.4	7.58
	K_{120}	2.802	0.297	3.142	0.121	0.117	2391	1328	305.8	24.9	7.25
	K_{180}	2.880	0.350	3.375	0.139	0.109	2315	1771	286.6	30.2	8.0
CD(0.05)		NS	0.185	0.291	0.011	0.012	50.21	37.32	11.63	1.46	NS
Calcium	L_0	2.860	0.270	2.962	0.137	0.113	2452	1474	267.8	25.7	7.4
	L_{150}	2.700	0.311	3.027	0.133	0.120	2387	1485	294.9	26.9	7.7
CD(0.05)		NS	0.013	NS	NS	0.008	35.50	NS	8.22	1.03	NS
Sulphur	S_0	2.709	0.271	2.944	0.135	0.107	2428	1455	278.8	25.9	7.4
	S_{100}	2.857	0.301	3.000	0.141	0.117	2433	1627	291.8	27.1	7.6
	S_{200}	2.774	0.300	3.041	0.129	0.125	2397	1356	273.4	25.8	7.5
CD(0.05)		NS	0.016	NS	NS	0.010	43.48	101.48	9.99	NS	NS
CV (%)		17.60	7.60	11.63	9.67	12.26	2.46	9.55	4.89	6.57	14.67

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

S = Levels of S (0, 100 and 200 kg ha^{-1})

NS = Not significant

b. Effect of Ca

Application of Ca as lime at 150 kg ha^{-1} significantly affected only P, Mg, S, Mn and Zn contents. All the elements except S registered an increase in the order of 15.2, 6.2, 10.2 and 4.7 per cent respectively. Sulphur content on the other hand decreased by 2.7 per cent.

c. Effect of S

Application of S significantly affected P, Mg, S, Fe and Mn. Sulphur at 200 kg ha^{-1} significantly increased the P and Mg content by 10.7 and 16.8 per cent but decreased S, Fe, Mn and Zn content by 1.2, 16.7, 6.3 and 4.8 per cent respectively over the S_{100}.

4.5.3.4 Elemental composition of culm at PI

Data on the elemental composition of the culm at PI stage are presented in Table 4.5.3d.

Increasing levels of K increased the K, S and Zn contents of the culm upto 180 kg of K ha^{-1} and the increases over control were 41.1, 11.6 and 69.4 per cent and decreased Mg content by 6.7 per cent. Potassium @ 120 kg ha^{-1} recorded the lowest levels of Ca and Fe and highest content of Cu and the per cent variations were 1.0, 29.7 and 16.3 respectively.

Nitrogen content was maximum in control and increasing levels of K significantly reduced the N content by 14.6 per cent over control.

b. Effect of Ca

Application of Ca as lime significantly increased K, S, Fe and Zn and reduced Mg and Mn. The respective increases and decreases were 8.0, 4.9, 17.3 and 16.1 and 2.0 and 14.0 per cent respectively.

Table 4.5.3d Effect of K, Ca and S on elemental composition of Culm at PI

Treatment		Culm at panicle initiation									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Potassium	K_0	0.760	0.261	2.567	0.030	0.099	1641	2038	438.5	80.8	4.3
	K_{60}	0.612	0.257	2.117	0.046	0.109	1690	1557	524.5	91.8	4.3
	K_{120}	0.745	0.248	2.925	0.027	0.092	1750	1433	498.7	106.4	5.0
	K_{180}	0.649	0.272	3.621	0.027	0.093	1831	1971	424.2	136.9	4.3
CD(0.05)		0.0999	NS	0.162	0.008	0.0078	45.21	70.05	17.22	14.79	0.46
Calcium	L_0	0.676	0.258	2.700	0.033	0.099	1687	1610	507.0	96.3	4.3
	L_{150}	0.707	0.261	2.915	0.031	0.097	1769	1889	435.8	111.8	4.6
CD(0.05)		NS	NS	0.115	NS	0.0085	31.97	49.53	12.18	10.46	NS
Sulphur	S_0	0.740	0.255	2.766	0.031	0.094	1662	1545	430.1	95.5	4.3
	S_{100}	0.656	0.255	2.837	0.034	0.097	1694	1837	570.6	117.1	4.5
	S_{200}	0.679	0.269	2.819	0.031	0.103	1829	1867	473.8	99.4	4.7
CD(0.05)		NS	NS	NS	NS	0.0067	39.15	60.65	14.91	12.82	0.40
CV (%)		17.10	10.46	6.28	30.72	9.62	3.10	4.74	4.32	16.85	12.30

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

S = Levels of S (0, 100 and 200 kg ha^{-1})

NS = Not significant

c. Effect of S

Application of S did not affect N, P, K and Ca. It increased Mg, S, Fe, Mn, Zn and Cu by 9.6, 10.0, 20.8, 10.2, 4.0 and 9.3 per cent over control. In the case of Mn, though both the levels increased Mn content, application of 100 kg ha^{-1} recorded the highest increase of 18.7 per cent over control.

4.5.3.5 Elemental composition of leaf at PI

Main effects of elements on the elemental composition of leaf are presented in Table 4.5.3e.

Application of K at 180 kg ha^{-1} recorded the highest content of P, Fe and Zn which were significantly higher over K level of 120 kg ha^{-1}. Highest contents of K and Ca were recorded at 120 kg of K ha^{-1} and the highest contents of Mg and S at 60 kg of K ha^{-1} and these treatments were significantly superior.

b. Effect of Ca

Application of Ca as lime at 150 kg ha^{-1} increased Ca, S, Fe and Zn significantly over control and the increases were 18.5, 3.1, 6.9 and 18.0 per cent respectively.

c. Effect of S

Sulphur applied @ 200 kg ha^{-1} gave significantly higher contents of P, Mg and S and the increases over 100 kg S ha^{-1} were 16.7, 24.0 and 5.5 per cent and corresponding changes over control were 0.4, 4.0 and 12.0 per cent. Highest content of K and Ca were recorded at 100 kg S level which was higher by 3.8 and 4.6 per cent over control and 9.3 and 16.1 per cent over 200 kg ha^{-1}.

4.5.3.6 Elemental composition of boot leaf

Main effects of treatments on the elemental composition of boot leaf are presented in Table 4.5.3f.

Table 4.5.3e Effect of K, Ca and S on elemental composition of Leaf at PI

Treatment		Composition of leaf at panicle initiation									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Potassium	K_0	0.832	0.216	1.892	0.328	0.170	1559	755	644.7	29.4	4.3
	K_{60}	0.971	0.230	1.558	0.385	0.148	1629	790	547.3	29.8	4.1
	K_{120}	1.051	0.209	2.096	0.457	0.131	1531	880	568.9	25.1	4.8
	K_{180}	1.043	0.251	1.846	0.411	0.121	1537	916	446.9	31.9	4.7
CD(0.05)		NS	0.027	0.196	0.011	0.013	18.93	36.96	40.77	1.58	NS
Calcium	L_0	0.937	0.220	1.881	0.362	0.141	1540	807	544.1	26.7	4.3
	L_{150}	1.011	0.232	1.815	0.429	0.145	1587	863	559.7	31.5	4.5
CD(0.05)		NS	NS	NS	0.010	NS	13.39	26.84	NS	1.11	NS
Sulphur	S_0	1.002	0.237	1.891	0.395	0.149	1475	869	539.1	30.0	4.4
	S_{100}	0.947	0.204	1.963	0.413	0.125	1566	905	493.6	27.2	4.8
	S_{200}	0.973	0.238	1.691	0.378	0.155	1652	731	623.1	30.0	4.1
CD(0.05)		NS	0.023	0.170	0.0078	0.011	16.39	32.87	35.31	1.38	NS
CV (%)		23.37	9.93	12.52	3.47	11.56	1.43	5.38	8.75	6.48	18.19

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})
L = Levels of Ca (0 and 150 kg lime ha^{-1})
S = Levels of S (0, 100 and 200 kg ha^{-1})
NS = Not significant

Table 4.5.3f Effect of K, Ca and S on elemental composition of boot leaf

Treatment		Boot leaf									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Potassium	K_0	1.556	0.243	1.780	0.343	0.150	2278	682	490.2	31.3	6.0
	K_{60}	1.203	0.214	1.650	0.416	0.147	1730	570	468.4	29.3	5.0
	K_{120}	1.438	0.245	1.596	0.411	0.122	1694	486	414.2	27.5	5.5
	K_{180}	1.364	0.228	1.729	0.403	0.128	1786	610	377.8	31.3	5.2
CD(0.05)		0.234	0.015	0.093	0.010	0.0016	18.29	27.92	11.06	2.97	0.75
Calcium	L_0	1.335	0.232	1.658	0.351	0.131	1911	610	431.9	29.6	5.5
	L_{150}	1.445	0.233	1.704	0.435	0.142	1833	564	443.4	30.0	5.4
CD(0.05)		NS	NS	NS	0.001	0.0011	12.93	19.75	7.82	NS	NS
Sulphur	S_0	1.347	0.220	1.700	0.319	0.136	2049	622	433.1	29.6	5.6
	S_{100}	1.358	0.218	1.686	0.470	0.131	1875	561	432.8	30.8	5.3
	S_{200}	1.466	0.259	1.678	0.391	0.143	1693	578	446.8	28.9	5.6
CD(0.05)		NS	0.013	NS	0.008	0.0014	15.85	24.19	9.58	NS	NS
CV (%)		19.99	7.28	6.50	2.81	2.81	1.16	5.63	2.99	11.81	16.21

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})
S = Levels of S (0, 100 and 200 kg ha^{-1})
L = Levels of Ca (0 and 150 kg lime ha^{-1})
NS = Not significant

Levels of K significantly affected all the elements studied though the pattern of effect varied with elements. Lowest content of N,P and Cu were recorded at 60 kg level of K and Mg, S, Fe and Zn at 120 kg level of K and Mn at 180 kg k ha^{-1}.

b. Effect of Ca

Main effects of Ca on the contents of Ca, Mg, S, Fe and Mn, contents revealed that application of Ca significantly increased Ca, Mg and Mn contents by 23.9, 8.4 and 2.7 per cent while S and Fe content decreased by 4.1 and 7.5 per cent. The decreases in S and Fe were also significant.

c. Effect of S

Application of S at 200 kg ha^{-1} significantly increased P, Ca, Mg and Mn and reduced S content and the respective variations over control worked out to 17.7, 22.6 5.2 and 3.2 per cent. In variation, the effect of S at 200 kg ha^{-1}, S at 100 kg ha^{-1} recorded the highest Ca content and the lowest contents of Mg, Fe and Mn contents of which Ca and Fe differences were significant.

4.5.3.7 Elemental composition of grain

a. Effect of K

Main effect of K and Mg on the elemental composition of grain is presented in Table 4.5.3g.

Application of increasing levels of K significantly affected the K, Mg, S, Fe, Mn and Zn contents.

Potassium applied at 120 kg ha^{-1} significantly increased the contents of K and silica in the grain by 33.1 and 48.5 per cent and decreased Mg, Fe, Mn and Zn significantly by 13.9, 17.4, 20.3 and 6.0 per cent.

Table 4.5.3g Effect of K, Ca and S on elemental composition of grain

Treatment		Composition of grain										
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	SiO_2 (%)
Potassium	K_0	1.022	0.276	0.354	0.001	0.072	1173	172.6	48.7	23.5	3.67	9.29
	K_{60}	1.029	0.268	0.346	0.001	0.062	1172	125.2	48.8	22.1	3.42	10.2
	K_{120}	1.080	0.271	0.463	0.001	0.063	1157	126.9	40.3	21.5	3.17	11.8
	K_{180}	1.058	0.281	0.471	0.001	0.062	1223	142.5	38.8	22.1	3.25	13.8
CD(0.05)		NS	NS	0.038		0.0055	20.60	3.16	2.79	0.466	NS	1.68
Calcium	L_0	1.017	0.281	0.400	0.001	0.064	1181	151.0	43.8	22.0	3.42	11.6
	L_{150}	1.077	0.267	0.417	0.001	0.066	1182	132.5	44.5	22.5	3.33	10.9
CD(0.05)		NS	0.009	NS	NS	NS	NS	2.23	NS	0.329	NS	NS
Sulphur	S_0	1.062	0.269	0.397	0.001	0.062	1164	138.3	44.2	22.1	3.44	9.4
	S_{100}	1.007	0.277	0.403	0.001	0.064	1198	140.6	43.1	22.6	3.25	12.6
	S_{200}	1.072	0.276	0.425	0.001	0.069	1182	146.6	45.1	22.2	3.44	11.7
CD(0.05)		NS	NS	NS		0.0046	17.85	2.73	NS	0.403	NS	1.46
CV (%)		14.24	5.22	11.42	21.65	7.82	2.07	2.63	7.48	2.47	17.11	17.68

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

S = Levels of S (0, 100 and 200 kg ha^{-1})

NS = Not significant

b. Effect of Ca

Application of Ca increased in the Zn content and reduced the P and Fe contents significantly and the variations over control were 2.3 and 5.0 and 12.3 per cent respectively.

c. Effect of S

Application of S at 100 kg ha^{-1} increased the Mg, s, Fe, Zn and silica contents significantly and the increases were 3.2, 2.9, 1.7, 2.3 and 34.0 per cent respectively.

4.5.3.8 Elemental composition of straw

a) Effect of K

Application of K at 180 kg ha^{-1} recorded the lowest content of Ca, Mg, Mn and Cu and the decreases over control were 15.6, 22.4, 22.8 and 19.0 per cent. Lowest content of K, Fe, Zn and silica contents were recorded at 60 ka ha^{-1} of K (Table 4.5.3h).

b) Effect of Ca

Application of lime at 150 kg ha^{-1} reduced the P, Mg, S, Fe, Mn and Zn and increased the Ca content. The respective decreases were 6.1, 6.2, 6.8, 7.2, 10.6 and 6.9 per cent and the increase in Ca worked out to 9.5 per cent and the changes were statistically significant.

c) Effect of S

Application of S significantly increased the K, Mg, S, Fe, Cu and silica content at 200 kg S level ha^{-1} and the increases were 3.2, 11.2, 9.6, 5.6, 11.8 and 35.2 per cent respectively over control. Sulphur applied at 100 kg ha^{-1} recorded the lowest level of K and Fe contents which were significantly lower than S at `0' and 200 kg ha^{-1}.

Table 4.5.3h Effect of K, Ca and S on elemental composition of straw

Treatment		Composition of straw										
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	SiO_2 (%)
Potassium	K_0	0.716	0.192	2.696	0.186	0.107	1556	1802	885.2	82.8	4.0	19.4
	K_{60}	0.636	0.181	1.883	0.237	0.091	1238	1264	717.5	71.9	3.3	18.3
	K_{120}	0.678	0.187	2.725	0.212	0.096	1270	1371	793.1	101.2	3.7	20.6
	K_{180}	0.672	0.204	2.712	0.157	0.083	1374	1627	683.1	114.9	3.2	18.5
CD(0.05)		NS	0.014	0.211	0.006	0.007	529.74	37.72	94.1	8.165	0.527	0.82
Calcium	L_0	0.690	0.197	2.527	0.189	0.097	1407	1572	812.9	96.0	3.5	19.6
	L_{150}	0.661	0.185	2.481	0.207	0.091	1311	1459	726.7	89.4	3.5	19.3
CD(0.05)		NS	0.010	NS	0.004	0.0055	21.02	26.67	66.55	5.77	NS	NS
Sulphur	S_0	0.702	0.186	2.541	0.213	0.089	1308	1525	715.3	95.6	3.4	15.9
	S_{100}	0.656	0.190	2.350	0.231	0.094	1337	1413	810.1	94.6	3.4	21.0
	S_{200}	0.668	0.197	2.622	0.150	0.099	1433	1611	783.8	87.9	3.8	21.5
CD(0.05)		NS	NS	0.184	0.005	0.0067	25.75	32.67	NS	NS	NS	0.71
CV (%)		24.80	8.79	10.05	3.83	9.60	2.59	2.95	14.47	10.43	17.75	4.99

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})
S = Levels of S (0, 100 and 200 kg ha^{-1})
L = Levels of Ca (0 and 150 kg lime ha^{-1})
NS = Not significant

4.5.4 Second order interactions of K, Ca and S on elemental composition of rice of different growth stages

4.5.4.1 Elemental composition of root at MT stage

Significant second order interaction effects on the elemental composition of root at MT stage are presented in Table 4.5.4a.

It can be seen that application of Ca in the absence of K increased P content of root with increasing levels of S. But at 60 kg ha^{-1} K, Ca significantly increased P only upto 100 kg S ha^{-1} level and from 120 kg K level application of Ca was ineffective in significantly affecting P content.

The data revealed that in the absence of K, Ca significantly increased K content. At 60 and 120 kg K ha^{-1} level Ca could increase K only in the absence of S and beyond 120 kg K ha^{-1}, Ca was ineffective both in the presence or absence of sulphur.

Calcium content of the root was not significantly influenced by application of Ca in the absence of S but increasing the levels of S to 100 or 200 kg ha^{-1} significantly reduced the Ca content both in the presence and absence of K.

In the absence of K and S, Ca reduced the S content but with its application, S content increased in the root. At 60 and 120 kg level of K and application of S at 100 kg ha^{-1}, S content increased in the presence of Ca. But when K content was raised to 180 kg ha^{-1}, Ca increased S only in the absence of S where as in the presence of applied S, application of Ca decreased S content of the root.

In the case of Fe, in the absence of K and S, Ca application increased the Fe content of root. At 60 and 120 kg K ha^{-1} it behaved as in the case of S and at 180 kg K ha^{-1}, application of Ca significantly increased the Fe content both in the presence and absence of S.

Table 4.5.4a Second order interaction effect of K x Ca and S on nutrient content of rice root at MT

	P (%)		K (%)		Ca (%)		S (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)	
	L0	L150	L0	L150	L0	L150	L0	L150	L0	L150	L0	L150	L0	L150	L0	L150
K_0S_0	0.185	0.205	0.800	0.905	0.026	0.023	2230	2105	39425	62425	137.5	165.5	45.0	38.0	25.5	15.5
K_0S_{100}	0.185	0.230	0.875	1.060	0.023	0.038	2380	2476	76075	60712	133.0	280.5	38.0	49.0	21.5	21.5
K_0S_{200}	0.185	0.220	1.025	0.975	0.022	0.019	2239	2326	54150	57312	200.0	129.0	38.0	46.5	16.0	22.5
$K_{60}S_0$	0.140	0.155	0.500	0.600	0.030	0.033	1733	2059	88575	60613	179.5	180.0	37.5	39.0	18.0	18.5
$K_{60}S_{100}$	0.175	0.210	0.575	0.725	0.032	0.023	1827	2142	62313	67600	208.0	185.0	34.5	41.0	17.0	15.5
$K_{60}S_{200}$	0.195	0.160	0.675	0.675	0.025	0.022	1576	1324	76163	66300	209.5	129.0	43.0	31.0	20.0	15.0
$K_{120}S_0$	0.115	0.205	0.750	1.225	0.026	0.022	1154	1817	72363	48250	117.5	249.0	23.0	49.0	15.0	20.5
$K_{120}S_{100}$	0.215	0.220	1.375	1.325	0.027	0.018	2034	2478	66175	69900	284.0	267.0	50.0	61.0	16.0	19.0
$K_{120}S_{200}$	0.230	0.175	1.225	1.100	0.033	0.019	2315	1713	63250	68989	263.5	211.0	61.5	38.0	17.5	17.0
$K_{180}S_0$	0.225	0.225	1.475	1.225	0.020	0.017	2475	2408	63663	70625	192.0	201.5	52.0	43.5	18.0	21.5
$K_{180}S_{100}$	0.185	0.205	1.300	1.350	0.018	0.018	1879	2235	81113	71988	200.0	194.5	41.0	45.0	14.0	15.5
$K_{180}S_{200}$	0.220	0.225	1.275	1.550	0.019	0.016	2408	2787	59525	72038	131.0	225.0	62.0	58.5	19.0	14.5
CD (0.05)	0.023		0.236		0.067		74.48		1718.3		90.03		3.86		2.52	

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0 and 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1})

Data on the Mn content as affected by the interactions revealed that in the absence of K and S, Ca increased the Mn content of the root. Calcium also increased it in the presence 100 kg S ha^{-1} and in the absence of K. At 60 and 120 kg level, application of Ca significantly reduced the Mn content in the presence of S at 200 kg ha^{-1} but beyond 120 kg level of K, S application reduced the content significantly.

In the case of Zn also, in the absence of K and S, Ca reduced Zn content but at S levels of 100 and 200 kg ha^{-1} it was increased. At 60 kg K ha^{-1}, Ca applied as lime at 150 kg ha^{-1} could significantly increase Zn only upto 100 kg S level and at 200 kg S, Zn content decreased significantly.

In the case of Cu, in the absence of K, Ca reduced Cu content of the root upto 100 kg S ha^{-1} but significantly increased it at 200 kg S ha^{-1}. This increase in Cu content could be observed even at 60 kg K level but beyond 120 kg K ha^{-1}, Ca could increase the Cu content only in the absence of S.

4.5.4.2 Elemental composition of root at PI stage

Data on the combined effect of K, Ca and S on elemental composition of root at PI stage (Table 4.5.3b) revealed the significant influence of treatment combinations on S, Fe, Mn, Zn and Cu.

Application of Ca as lime in the absence of K, significantly increased the S content of root both in the presence and absence of S. At 60 kg K application Ca significantly increased the S content in the absence of S but at 100 and 200 kg S ha^{-1} reduced it significantly. At 120 and 180 kg K ha^{-1}, application of Ca significantly reduced the S content in the absence of S but on increasing application upto and beyond 100 kg S ha^{-1}, the S content reduced with Ca application.

Table 4.5.4b Second order interaction effect of K, Ca and S on elemental composition of root at PI

	S (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0S_0	1171	1669	64538	73862	82.5	129.0	41.0	60.0	18.0	19.0
K_0S_{100}	1732	2017	71263	71538	198.5	158.0	45.5	69.5	20.0	22.0
K_0S_{200}	1636	1242	71050	55413	151.0	143.0	40.0	40.5	19.0	19.5
$K_{60}S_0$	1599	1791	65563	63700	172.0	228.5	51.5	70.5	29.0	19.5
$K_{60}S_{100}$	2000	1410	65313	71263	154.0	168.5	42.5	48.0	20.5	18.0
$K_{60}S_{200}$	1973	1601	71388	46350	208.0	174.5	66.0	50.0	25.0	21.0
$K_{120}S_0$	1337	901	32363	73300	153.0	135.0	42.0	47.5	18.0	15.5
$K_{120}S_{100}$	1494	1769	70113	69875	254.0	209.5	42.0	43.5	20.5	27.0
$K_{120}S_{200}$	1813	1730	57438	60400	294.5	167.5	61.5	46.5	26.5	24.0
$K_{180}S_0$	1337	1074	59638	56120	157.5	204.0	40.0	43.0	18.0	19.0
$K_{180}S_{100}$	1305	1860	54050	55338	221.0	211.5	39.5	53.5	15.0	25.0
$K_{180}S_{200}$	1803	1756	59275	66413	145.5	162.5	67.5	49.0	18.0	17.5
CD (0.05)	79.77		5345.0		20.75		6.949		1.33	

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0 and 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1})

The lowest content of Fe was recorded in the treatment combination $K_{120}S_0L_0$ and was significantly inferior to all other treatment combinations. Application of S @ 200 kg ha^{-1} significantly reduced the Fe content at K_0 and K_{60} plots whereas in K_{120} and K_{180} plots it increased the Fe content. At 120 kg K level application of Ca significantly increased the Fe content in the absence of S.

At `0' and 180 kg K ha^{-1} application of Ca significantly increased the Mn content in the absence of S but at 100 kg S ha^{-1} it decreased it. At 120 kg K ha^{-1}, irrespective of level of S application, Ca application significantly reduced the Mn content.

The general trend observed in the case of Zn was that at all levels of K application of Ca increased the Zn content upto 100 kg S ha^{-1} and beyond 100 kg S ha^{-1} it reduced it and the reduction in Zn content was significant at 60, 120 and 180 kg K ha^{-1}.

In the absence of K, application of Ca significantly increased the Cu content irrespective of levels of S but the reverse was observed when K level increased to 60 kg ha^{-1}. At 120 and 180 kg K ha^{-1} level, the increase in Cu content was observed by application of Ca only at 100 kg S ha^{-1}.

4.5.4.3 Elemental composition of shoot

Data on the combined effect of K, Ca and S are presented in Table 4.5.4c. It can be seen that application of Ca could significantly increase P in the absence of K and in the presence of 200 kg S ha^{-1}. Any significant influence thereafter could be observed only at 180 kg K combined with Ca as lime at 150 kg ha^{-1} and S applied at 100 or 200 kg ha^{-1}.

Table 4.5.4c Second order interaction effect of K, Ca and S on elemental composition of shoots at MT

	P (%)		Ca (%)		Mg (%)		S (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0S_0	0.215	0.255	0.097	0.121	0.084	0.069	2472	2368	1514	1305	221.0	205.5	23.5	25.0
K_0S_{100}	0.225	0.255	0.120	0.104	0.069	0.110	2497	2780	1373	851	239.0	294.0	24.0	25.5
K_0S_{200}	0.245	0.295	0.105	0.067	0.109	0.104	2565	2644	1584	1350	266.0	165.0	23.0	20.5
$K_{60}S_0$	0.285	0.290	0.192	0.208	0.141	0.157	2350	2705	1357	1333	290.0	336.0	23.5	29.0
$K_{60}S_{100}$	0.240	0.255	0.207	0.159	0.179	0.122	2667	2087	1767	1143	376.0	222.0	29.5	24.0
$K_{60}S_{200}$	0.270	0.250	0.183	0.119	0.159	0.134	2624	2085	1944	1393	311.0	272.0	30.0	22.5
$K_{120}S_0$	0.285	0.295	0.093	0.099	0.101	0.109	2576	2164	1004	2134	239.5	376.0	24.0	23.0
$K_{120}S_{100}$	0.305	0.295	0.123	0.116	0.095	0.105	2447	2374	1654	1143	311.0	244.0	23.0	22.5
$K_{120}S_{200}$	0.310	0.290	0.144	0.153	0.115	0.179	2233	2552	798	1240	281.5	383.0	26.5	30.5
$K_{180}S_0$	0.280	0.280	0.158	0.115	0.104	0.095	2692	2106	1009	1988	200.0	363.0	29.0	30.5
$K_{180}S_{100}$	0.265	0.535	0.088	0.208	0.093	0.161	2159	2457	2224	2865	206.0	382.0	26.5	42.0
$K_{180}S_{200}$	0.305	0.435	0.134	0.128	0.103	0.097	2149	2325	1465	1077	212.0	297.0	25.5	27.5
CD (0.05)	0.045		0.027		0.029		123.08		292.25		28.49		3.56	

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})   L = Levels of Ca (0 and 150 kg lime ha^{-1})   S = Levels of S (0, 100 and 200 kg ha^{-1})

Data on Ca content revealed that Ca applied with S decreased Ca content significantly upto 60 kg K ha^{-1} level of application. Calcium content decreased in the absence of Ca. At 120 kg K level application of Ca or S did not affect Ca content. Significant positive influence could then be observed only when K, Ca and S were applied at 180, 150 and 100 kg ha^{-1} respectively.

It can be observed from the data on Mg content that while S applied at 100 kg ha^{-1} in conjunction with Ca significantly increased S content, presence of S in conjunction with Ca significantly reduced Mg content when K had been applied at 60 kg ha^{-1}. However at 180 kg K combined with S whether at 100 or 200 kg ha^{-1}, Mg content increased significantly.

Significant influence on increasing the S content of the culm could be observed in K x Ca x S interaction at 180 and 150 kg ha^{-1} of K and lime respectively combined with S at 100 and 200 kg levels ha^{-1}. Sulphur application significantly decreased S content of the culm at 60 kg K and 150 kg level of lime as well as at 120 kg K and 100 kg level of S.

Combined application of K at 120 kg and lime at 150 kg ha^{-1} significantly reduced Fe content of the culm at all levels of S. At 60 kg K level, S applied at 100 kg ha^{-1} in conjunction with Ca could reduce the Fe content. But the lowest content of Fe was observed at $K_{120}S_{200}L_0$ level and at 120 kg K, application of Ca had significantly increased Fe content.

It can be observed from the data that the influence of Ca on reducing the Mn content was offset by S applied at 100 kg ha^{-1} both in the absence of K as well as at 60 kg and 120 kg K ha^{-1}. However, application of K at 180 kg ha^{-1} along with S and Ca increased Mn content.

Combined application of K at 60 kg with increasing levels of S at 100 or 200 kg ha^{-1} decreased Zn content of the culm. But at 120 and 180 kg K ha^{-1}, S application at 100 or 200 kg ha^{-1} with lime at 150 kg ha^{-1} significantly increased Zn content.

4.5.4.4 Elemental composition of culm at PI stage

Data on the combined effect of K, Ca and S on elemental composition are presented in Table 4.5.4d.

It can be seen that the two significant observations due to the interaction effect were significant decline in K content of the culm due to the combining effect of Ca as lime applied @ 150 kg ha^{-1} with 60 kg K and sulphur irrespective of the levels of the latter and significant interaction effect at 180 kg ha^{-1} level of K. Thus culm content of K reduced by 27.8 per cent due to $K_{60}L_{150}S_{200}$. At 180 kg level of K the increment in K content was 20.5 per cent due to $S_{100}L_{150}$ and P content, 4.1 per cent due to $K_{180}S_{200}L_{150}$ over $K_{180}L_0S_0$. Similar was the effect on the Mg content but the significant variations were confined to $K_{60}L_{150}S_{100}$ and $K_{180}L_{150}S_{200}$ treatment where the variation 14.7 per cent less than $K_0L_0S_0$ and 68.6 per cent more than $K_{180}L_0S_0$ respectively.

The data on the S content revealed that significant interaction effect were obtained at $K_{120}S_{100}$ and 200 kg level. Thus at K_0S_{100} combining with Ca, S content increased by 10.0 per cent and $K_{120}S_{100}$ and $K_{120}S_{200}$ combined application with Ca increased S content by 14.3 and 12.6 per cent respectively.

In the case of Fe combined effect of $K_{180}S_{200}L_{150}$ and $K_{60}S_{200}L_{150}$ alone showed significance over their corresponding treatments without Ca application and the decreases were 15.9, 22.6 and 37.4 per cent. Application of Ca as lime @ 150 kg ha^{-1} at levels of S without K significantly increased the Fe content and

Table 4.5.4d Second order interaction effect of K, Ca and S on elemental composition of Culm at PI stage

	K (%)		Mg (%)		S (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0S_0	2.700	2.700	0.102	0.098	1523	1591	902	1690	320.0	379.0	88.0	108.5	3.5	4.0
K_0S_{100}	2.400	2.500	0.106	0.109	1643	1808	1566	3586	608.0	420.0	59.0	74.0	4.0	6.0
K_0S_{200}	2.500	2.600	0.086	0.091	1625	1656	1526	2960	416.0	488.5	83.0	72.5	4.0	4.5
$K_{60}S_0$	2.400	1.85	0.107	0.113	1598	1685	1288	1605	488.0	428.0	63.5	75.5	4.0	4.5
$K_{60}S_{100}$	2.300	1.95	0.140	0.089	1702	1647	1528	1532	638.0	532.5	119.0	126.0	4.5	4.0
$K_{60}S_{200}$	2.400	1.75	0.106	0.098	1826	1702	2087	1305	473.0	487.5	76.0	91.0	4.5	4.0
$K_{120}S_0$	2.675	2.550	0.094	0.087	1688	1621	1301	2260	538.0	352.5	110.0	73.0	3.5	5.5
$K_{120}S_{100}$	2.600	3.475	0.081	0.088	1767	2020	1481	1263	563.0	532.0	168.0	137.0	5.0	5.5
$K_{120}S_{200}$	2.450	3.800	0.099	0.100	1603	1805	1086	1209	520.0	486.5	68.5	82.0	4.5	6.0
$K_{180}S_0$	3.650	3.600	0.086	0.068	1912	1699	1487	1472	480.0	355.0	147.5	98.0	5.5	3.5
$K_{180}S_{100}$	3.075	4.400	0.078	0.080	1503	1465	2035	1711	507.5	284.0	87.0	167.0	3.5	3.5
$K_{180}S_{200}$	3.200	3.800	0.098	0.145	1879	2534	2684	2077	535.0	383.5	85.5	236.5	5.5	4.5
CD (0.05)	0.398		0.019		110.74		171.59		42.19		36.25		1.14	

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0 and 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1})

increases over their corresponding treatments without Ca worked out to 87.3, 129.0 and 94.0 per cent respectively.

In the case of Mn, the data revealed that combined application significantly reduced the Mn content at the combined levels of K at 60, 120 and 180 kg of K and 100 and 200 kg of S and 150 kg of lime ha^{-1}.

In the case of Zn, combining K and S with Ca increased the content of Zn at 60 kg K and 100 and 200 kg levels of S but at 120 kg K the effect was to significantly reduce the same.

4.5.4.5 Elemental composition of leaf at PI stage

Data on the elemental composition of the leaf at PI stage are presented in Table 4.5.4e.

At 60 kg K level Ca application increased P content significantly by 52.5 per cent. Addition of S at 200 kg ha^{-1} increased P content which was further decreased by addition of Ca.

In the same way the data showed that addition of S increased K content of which was reduced by application of Ca to original level of $K_0S_0L_0$. At 60 kg K, however, S addition in the presence of Ca significantly decreased K content from 1.80 per cent to 1.3 per cent. At 120 kg K addition of S @ 100 kg ha^{-1} increased K content significantly by 75 per cent in the presence of Ca and decreased it by 50.0 per cent on the absence of Ca.

The data showed that at 60 kg K, Ca application increased the Ca content of the plant with increasing levels of S but at 120 kg level, S applied at 100 kg ha^{-1} reduced Ca content which was further reduced by Ca application. Thus at K_{120} kg ha^{-1} S applied at 100 and 200 kg reduced Ca content by 7.3 and 32.1 per cent.

Table 4.5.4e Second order interaction effect of K, Ca and S on elemental composition of leaf at PI stage

	P (%)		K (%)		Ca (%)		Mg (%)		S (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0S_0	0.210	0.230	1.600	1.800	0.188	0.296	0.204	0.186	1565	1588	660	610	486.5	757.0	22.0	33.0
K_0S_{100}	0.240	0.210	2.700	1.650	0.424	0.510	0.133	0.184	1550	1736	945	746	556.0	530.0	23.5	38.0
K_0S_{200}	0.205	0.200	1.850	1.750	0.252	0.296	0.148	0.163	1684	1268	915	652	809.0	729.5	19.0	41.0
$K_{60}S_0$	0.200	0.305	1.550	1.550	0.390	0.436	0.134	0.182	1481	1885	652	372	533.0	589.0	26.0	30.5
$K_{60}S_{100}$	0.125	0.215	1.650	1.800	0.364	0.382	0.096	0.114	1531	1514	1123	1078	336.0	497.0	39.0	24.5
$K_{60}S_{200}$	0.275	0.265	1.500	1.300	0.236	0.503	0.162	0.202	1704	1662	604	694	622.0	707.0	31.5	27.5
$K_{120}S_0$	0.175	0.235	2.775	1.600	0.545	0.531	0.102	0.121	1266	1620	870	914	476.0	522.0	23.5	29.5
$K_{120}S_{100}$	0.235	0.220	1.850	2.800	0.505	0.431	0.128	0.124	1526	1370	1436	636	605.5	499.0	22.0	23.5
$K_{120}S_{200}$	0.210	0.180	2.000	1.550	0.370	0.363	0.193	0.117	1739	1669	642	1112	811.0	499.5	27.5	24.0
$K_{180}S_0$	0.310	0.230	2.150	2.100	0.418	0.359	0.123	0.138	1116	1311	541	758	406.0	543.0	34.5	41.0
$K_{180}S_{100}$	0.170	0.220	1.450	1.800	0.188	0.503	0.105	0.112	1726	1573	695	1803	440.0	486.0	21.0	25.5
$K_{180}S_{200}$	0.295	0.280	1.500	2.075	0.461	0.539	0.160	0.096	1597	1900	731	854	448.0	359.0	30.0	39.5
CD (0.05)	0.065		0.481		0.027		0.033		46.37		92.98		99.87		3.89	

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0 and 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1})

At 100 kg S ha^{-1} level, Ca further reduced it by 14.7 per cent. At 200 kg S ha^{-1} reduction in Ca due to Ca application was not significant. Opposite was the trend at 180 kg K where S applied at 100 and 200 kg ha^{-1} increased K content.

The data further revealed that at 120 and 180 kg level of K with 200 kg S ha^{-1}, Ca application reduced the Mg content significantly whereas at 100 kg S there was no effect. At 60 kg level of K application, S at 100 kg significantly reduced the Mg content and Ca application did not have any effect. It can also be noted that Mg content was highest in the control plot receiving none of the elements.

Data on the S content revealed that the lowest content of 1266 ppm was recorded at K_{120} level which was significantly increased by 28.0 per cent by Ca and 20.5 per cent by S at 100 kg ha^{-1} individually. But combined application reduced the S content to 1370 ppm. A similar trend was observed at 180 kg K level also.

It can be seen that at 60 kg K while S increased and Ca decreased the Fe content of the leaf by 72.2 and 42.9 per cent respectively combined application recorded a midway value and the increase was 65.3 per cent. At 200 kg S ha^{-1} level, there was no significant difference between $K_{60}L_0S_{200}$ and $K_{60}S_{200}L_{150}$. At 120 kg K ha^{-1} and 100 kg S level, Ca application significantly reduced the Fe content whereas at 200 kg S level, Ca increased it. At 180 kg level of K, Ca application significantly increased the Fe content.

The data showed that except at 180 kg level of K, S tended to increase Mn content. At 60 kg level, S application @ 100 kg ha^{-1} recorded the lowest Mn content which was increased by Ca and the increase worked out to 47.9 per cent. At 120 kg level of K, combined application reduced Mn content both at 100 and 200 kg levels of S. However it was noted that at 120 kg level of K, S at 100 kg ha^{-1} has recorded the highest Mn content of the leaf (811 ppm).

Data on the Zn content revealed that a significantly increasing trend with S at 100 and 200 kg ha^{-1} and 60 kg level of K was reduced by Ca which was most pronounced at 100 kg level. The increase of Zn content by 50 per cent by 100 kg S reduced to 37.2 per cent by combined dose of Ca. It can also be seen that combining Ca did not have any beneficial effect on Zn content at 120 kg level of K whereas at 180 kg it significantly increased the Zn content.

4.5.4.6 Elemental composition of boot leaf

Significant combined effects on the elemental composition of boot leaf are given in Table 4.5.4f.

It can be seen that at 60 kg K the combined effect of K_{60} and S_{200}, had a reducing effect on P content by Ca applied as lime at 150 kg ha^{-1} and the reduction was 30.0 per cent. This effect of Ca was manifested at other levels of K also which was not significant however.

Sixty kg level of K and 100 kg of S combining Ca application as 150 kg lime ha^{-1} significantly increased the K content by 29.7 per cent. The data also showed that application of lime at 150 kg ha^{-1} in the absence of K and S as well as at 120 kg level increased the K content whereas at 180 kg it decreased the K content.

It can be seen that both at 60 and 120 kg K and 100 kg S application of Ca significantly increased Ca content. Same was the trend at 200 kg S along with 0, 60 and 120 kg level of K ha^{-1}.

It can be seen from the table that at 120 kg K and 200 kg S, application of Ca significantly reduced the Mg content whereas at 120 kg K and 100 kg S it increased the content. At 60 kg K, Mg content increased by 48 per cent. Increase in the Mg content by Ca has been decreased by S at 200 kg ha^{-1} level of application. It can also be

Table 4.5.4f Second order interaction effect of K, Ca and S on elemental composition of boot leaf

	P (%)		K (%)		Ca (%)		Mg (%)		S (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0S_0	0.200	0.230	1.450	1.800	0.268	0.297	0.172	0.163	2818	3000	885	595	400.5	459.5	26.0	32.5
K_0S_{100}	0.240	0.245	1.700	1.700	0.470	0.339	0.109	0.161	2178	1946	721	630	349.0	491.0	28.0	47.5
K_0S_{200}	0.260	0.285	1.950	1.900	0.226	0.460	0.150	0.145	2029	1698	636	626	683.5	557.5	26.0	28.0
$K_{60}S_0$	0.195	0.230	1.500	1.300	0.322	0.291	0.126	0.185	1759	1699	543	697	524.5	487.0	28.0	28.5
$K_{60}S_{100}$	0.210	0.230	1.600	2.075	0.416	0.508	0.156	0.127	1766	2030	504	525	481.0	408.5	31.5	26.5
$K_{60}S_{200}$	0.250	0.175	1.600	1.825	0.316	0.644	0.114	0.174	1805	1328	545	608	398.0	510.0	30.5	30.5
$K_{120}S_0$	0.230	0.220	1.150	2.100	0.387	0.268	0.079	0.105	1360	1975	619	397	359.5	393.5	21.5	28.0
$K_{120}S_{100}$	0.240	0.210	1.700	1.500	0.387	0.602	0.124	0.134	1848	1785	355	513	549.5	378.5	30.5	27.0
$K_{120}S_{200}$	0.290	0.280	1.475	1.650	0.359	0.463	0.150	0.142	1753	1445	562	470	352.5	451.5	29.5	29.0
$K_{180}S_0$	0.215	0.240	2.550	1.750	0.208	0.515	0.124	0.133	1963	1818	563	680	316.0	521.5	43.0	29.5
$K_{180}S_{100}$	0.185	0.185	1.500	1.550	0.536	0.501	0.119	0.122	1707	1749	725	518	430.0	374.0	30.0	26.0
$K_{180}S_{200}$	0.265	0.275	1.725	1.300	0.323	0.334	0.155	0.116	1955	1530	668	509	338.5	282.5	31.0	27.0
CD (0.05)	0.036		0.227		0.024		0.004		44.80		68.43		27.08		7.28	

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0 and 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1})

observed that at 60 and 120 kg level of K application of either Ca (150 kg lime ha^{-1}) or S (200 kg ha^{-1}), or both together increased Mg content.

Sulphur content of boot leaf showed a decrease by application of S both in the absence or presence of K and the decline was 22.7 and 30.9 per cent respectively. At 60 kg level of K, application of 200 kg S recorded a S content comparable with K_0S_{200}. At 120 kg K ha^{-1}, lowest S content was recorded at S_0L_0 level which was increased by application of Ca by 45.2 per cent. However, it can also be noted that all the variations were within the level recorded at $K_0S_0L_0$ and $K_0S_0L_{150}$.

The data showed that highest content of Fe was recorded in $K_0S_0L_0$ treatment which was significantly reduced in all treatment combinations. The lowest level of 355 ppm was recorded at $K_{120}S_{100}L_0$ treatment followed by $K_{60}S_{100}L_0$ (504 ppm) and the latter was 65.8 per cent higher than the former and the difference was statistically significant. However, the effect comparable to $K_{120}S_{100}L_0$ could also be brought about by $K_{120}L_{150}S_0$.

Lowest Mn content due to the interaction was recorded by the treatment combination $K_{180}S_{200}L_{150}$ followed by $K_{180}S_0L_0$ which was on par and they were significantly superior to other treatments. Combined effect was more pronounced at higher levels of K. It is also noted that both elements are effective in reducing the contents. Another significant observation is that here again all the elements in boot leaf were high in control.

At K_0 level application of Ca significantly increased Zn content but S failed to do so. But in the presence of 60 kg K, S significantly increased it while Ca failed to bring about any increase. Highest level of Zn (47.5) was recorded at $K_0S_{100}L_{150}$ which was followed by $K_{180}S_0L_0$ and both of them were on par.

4.5.4.7 Elemental composition of grain

Significant combined effects are presented in Table 4.5.4g. It can be seen that P, S, Fe and Zn alone were significantly affected.

The lowest content of P in the grain was recorded at $K_{60}S_{100}$ and the highest at $K_{180}S_{100}$ and the difference of 0.085 per cent was statistically significant. It can also be noted that in the absence of K as well as at 60 kg K the P content of grain were significantly higher than that under K_{120}. Application of S further increased it significantly where as Ca reduced it.

Data showed that the lowest S content of 979 ppm in the grain was recorded in $K_{120}S_{100}L_0$ treatment which was significantly lower than all other treatment combinations. At 60 kg level of K application of S (S_{200}) increased the S content significantly by 19.9 per cent, which was reduced significantly by Ca. But at 120 kg level of K the role of Ca was reversed. While S reduced the content, Ca increased it.

A perusal of the data on Fe content will reveal that the highest contents were recorded in control plots. Lowest level of 95 ppm followed by 102 ppm were recorded at $K_{60}S_{100}L_{150}$ and $K_{60}S_{100}L_0$ which were on par. It can be seen that at 60 kg K the increasing effect of S was being counteracted by Ca which was evident only upto 120 kg K and 100 kg S ha^{-1} level.

The lowest content of Zn (19 ppm) in the grain was recorded at $K_{120}S_0L_0$ followed by $K_{120}S_{100}L_0$ (20 ppm) level and they were statistically significant. It may be further noted that the highest level of 25.5 ppm was recorded at $K_0S_0L_{150}$ followed by $K_{180}S_{100}L_0$.

The data showed that the lowest and highest values of SiO_2 content in the grain were at K_0L_{150} and S_0 and the highest at $K_{120}S_{100}L_0$. In the absence of K application of Ca alone or in the presence of 200 kg S reduced the S_iO_2 content

Table 4.5.4g Second order interaction effect of K, Ca and S on elemental composition of grain

	P (%)		S (ppm)		Fe (ppm)		Zn (ppm)		SiO_2 (%)	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0S_0	0.255	0.260	1214	1149	200	180	21.5	25.5	8.2	6.3
K_0S_{100}	0.280	0.285	1103	1255	208	141	23.5	24.5	10.8	11.5
K_0S_{200}	0.300	0.275	1178	1137	141	166	23.5	22.5	9.6	9.4
$K_{60}S_0$	0.305	0.240	1206	1123	141	102	21.5	22.0	12.8	5.5
$K_{60}S_{100}$	0.310	0.230	1266	1116	102	95	22.5	20.0	12.7	6.2
$K_{60}S_{200}$	0.265	0.260	1162	1162	169	143	24.5	22.0	10.1	13.9
$K_{120}S_0$	0.240	0.300	1061	1142	134	94	19.0	24.5	12.4	7.5
$K_{120}S_{100}$	0.270	0.265	979	1208	157	129	20.0	23.5	14.3	12.2
$K_{120}S_{200}$	0.280	0.270	1332	1221	119	130	21.5	20.5	14.2	10.2
$K_{180}S_0$	0.265	0.285	1162	1259	107	149	19.5	23.5	11.7	11.1
$K_{180}S_{100}$	0.315	0.260	1377	1277	162	132	25.0	21.5	14.0	19.6
$K_{180}S_{200}$	0.290	0.270	1129	1135	175	131	22.5	20.5	8.4	17.9
CD (0.05)	0.029		50.48		7.73		0.346		4.12	

by K application combined with Ca. At 60 and 120 kg level of K without S and at 60 kg K with 100 kg S application of Ca reduced the S_iO_2 content of the grain.

4.5.4.8 Elemental composition of straw

Combined effect significantly influenced the contents of all elements except N, K and Cu and the data are presented in Table 4.5.4h.

It may be seen from the Table that in the absence of K and 200 kg S ha^{-1} application of Ca significantly increased the content of P whereas at further levels of K the effect of Ca was to reduce the P content. The lowest P content was 0.135 in $K_{60}S_{200}L_{150}$ and highest contents were in $K_0S_{200}L_{150}$ and $K_{180}S_{200}L_0$ and the range was 70.4 per cent.

An observation on the Ca content in the straw in different combinations reveal that it ranged from 0.084 per cent in $K_{120}S_0L_0$ to 0.434 in $K_{60}S_0L_{150}$. Application of Ca in the absence of K and 60 kg K with S at 100 kg decreased the Ca content of the straw. However at 120 and 180 kg, Ca application was ineffective both in the absence and presence of S.

Highest Mg content were recorded in the absence of K and in the presence of S and the lowest contents in $K_{180}S_0L_{150}$ and the range worked out to 81.8 per cent. The data further showed that application of S at 100 kg manifested a significant effect on increasing the Mg content in the absence of K. With increasing contents of K this effect got neutralised and was reversed at 180 kg level.

Lowest content of S was recorded in $K_{120}S_0L_{150}$ which was significantly lower than all other treatment combinations. The highest content (1991 ppm) was recorded in the absence of K. It can be seen that at K_{120} level Ca applied as lime at 150 kg significantly increased the S content.

Table 4.5.4h Second order interaction effect of K, Ca and S on elemental composition of straw

	P (%)		Ca (%)		Mg (%)		S (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)		Sio$_2$(%)	
	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}	L_0	L_{150}
K_0S_0	0.165	0.180	0.233	0.176	0.077	0.101	1473	1342	1609	1567	741.5	683.5	56.0	52.0	13.0	17.9
K_0S_{100}	0.205	0.180	0.304	0.157	0.120	0.107	1648	1371	1604	1556	1183.0	838.5	84.0	120.0	26.0	15.7
K_0S_{200}	0.190	0.230	0.127	0.117	0.118	0.118	1618	1881	1810	2664	1081.0	783.5	100.0	85.0	21.8	22.2
$K_{60}S_0$	0.190	0.165	0.317	0.434	0.097	0.096	1312	1109	2363	993	780.5	905.5	71.0	68.0	15.2	22.2
$K_{60}S_{100}$	0.200	0.185	0.162	0.101	0.087	0.089	1166	1348	932	1176	621.5	567.5	73.0	53.0	19.0	20.1
$K_{60}S_{200}$	0.210	0.135	0.218	0.188	0.101	0.078	1414	1081	1049	1070	866.5	564.0	77.5	89.0	17.8	21.0
$K_{120}S_0$	0.180	0.175	0.084	0.153	0.089	0.074	1326	990	1393	801	594.5	710.5	98.5	144.0	11.3	15.3
$K_{120}S_{100}$	0.180	0.205	0.352	0.387	0.089	0.102	1268	1402	888	2272	1031.5	848.5	159.0	62.0	25.3	22.4
$K_{120}S_{200}$	0.205	0.175	0.105	0.193	0.109	0.114	1465	1168	1492	1382	793.0	781.5	66.5	77.0	27.7	21.9
$K_{180}S_0$	0.220	0.210	0.158	0.148	0.113	0.166	1481	1429	1862	1609	634.0	672.0	144.0	131.0	14.8	16.8
$K_{180}S_{100}$	0.185	0.180	0.127	0.254	0.087	0.073	1208	1285	1806	1065	711.0	681.5	125.0	81.0	21.3	18.1
$K_{180}S_{200}$	0.230	0.200	0.077	0.175	0.082	0.076	1511	1330	2067	1354	716.5	683.5	98.0	110.5	21.4	18.4
CD (0.05)	0.033		0.014		0.019		72.85		92.41		230.5		20.00		2.01	

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0 and 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1})

Iron content of the straw ranged from 801 to 2664 ppm. The lowest contents of 801 and 888 ppm which were not significantly different were recorded at $K_{120}S_0L_{150}$ and $K_{120}S_{180}L_0$ and the highest at $K_0S_{200}L_{150.}$

A perusal of the data also show that in the absence of K both elements had increased Fe content but at 60 kg level, K significantly increased Fe content which was reduced both by Ca and S by 58.0 and 60.6 per cent. At 120 kg level, K decreased Fe which was further reduced by both S and Ca. However beyond 120 kg, K had no effect and S increased it but the reducing effect of Ca continued.

Data on the Mn content revealed that highest Mn content of 1183 ppm was found at $K_0L_0S_{100}$ followed by 1081 and 1032 ppm at $K_0L_0S_{200}$ and $K_{120}S_{100}L_0$ and they were on par. The lowest level was recorded at $K_{120}S_0L_{0.}$

It can be observed from the table that application of K at 120 and 180 kg ha^{-1} led to very high content of Zn and the highest contents 159, 144 and 144 ppm were recorded at $K_{120}S_{100}L_0$, $K_{120}S_0L_{150}$ and $K_{180}S_0L_0$ respectively. There were significantly superior to all other treatments combinations.

Highest SiO_2 content of straw was recorded at $K_{120}S_{200}L_0$ which was significantly superior to all other treatment combinations except $K_0S_{100}L_0$. Combined effect of K, Ca and S on increasing the S_iO_2 content of straw was observed only at $K_{60}S_{200}L_{150}$. At 180 kg level of K, combined effect was significantly negative irrespective of S levels.

4.5.5 Main effects of K, L and S on the nutrient uptake by rice

4.5.5.1 Grain

a. Effect of K

Data is presented in Table 4.5.5a. It may be observed that K significantly affected the uptake of K, Ca, Fe, Mn and sio_2. At 180 kg level of K, Ca, and Si

Table 4.5.5a Nutrient uptake of grain as influenced by different levels of K, Ca and S

Treatment		Grain (kg ha^{-1})										
		N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO_2
Potassium	K_0	60.03	16.06	21.10	0.050	4.31	6.97	1.02	0.289	0.155	0.021	551.37
	K_{60}	65.68	16.67	21.77	0.062	3.91	7.38	0.797	0.306	0.139	0.022	645.81
	K_{120}	68.58	19.01	29.26	0.056	3.99	7.34	0.800	0.253	0.135	0.020	702.30
	K_{180}	69.27	18.47	30.93	0.079	4.05	8.08	0.933	0.255	0.144	0.021	903.05
CD(0.05)		NS	NS	3.84	0.012	NS	NS	0.106	0.027	NS	NS	125.69
Calcium	L_0	64.08	18.54	25.28	0.062	4.00	7.45	0.942	0.273	0.146	0.021	705.75
	L_{150}	67.70	16.56	26.25	0.062	4.12	7.43	0.834	0.279	0.141	0.021	691.52
CD(0.05)		NS	NS	NS	NS	NS	NS	0.075	NS	NS	NS	NS
Sulphur	S_0	63.987	16.24	23.96	0.061	3.70	7.03	0.828	0.264	0.133	0.021	550.45
	S_{100}	64.71	18.57	25.83	0.049	4.05	7.72	0.894	0.276	0.156	0.020	800.70
	S_{200}	68.97	17.85	27.51	0.076	4.43	7.57	0.943	0.287	0.142	0.022	750.74
CD(0.05)		NS	NS	NS	0.010	0.395	NS	NS	NS	NS	NS	108.9
CV (%)		20.40	19.48	17.67	25.02	13.29	12.67	14.41	13.32	25.27	20.99	21.26

K = Levels of K (0, 60, 120 and 180 kg ha^{-1})

S = Levels of S (0, 100 and 200 kg ha^{-1})

L = Levels of Ca (0 and 150 kg lime ha^{-1})

NS = Not significant

increased by 46.6, 58.0 and 63.8 per cent respectively and Fe, Mn and Zn decreased by 8.5, 11.8 and 7.1 per cent over control. Lowest uptake of K and Ca were at Ko, Fe at K_{60} and M and Zn at $K_{120.}$

b. Effect of Ca

Application of Ca significantly affected only the Fe uptake of the grain which was reduced by 11.5 per cent.

c. Effect of S

Sulphur affected Mg and S_iO_2 uptake only and at 100 and 200 kg levels Mg and S_iO_2 uptake increased by 9.5 and 45.4 per cent and 19.7 and 36.4 per cent respectively.

4.5.5.2 Straw

a. Effect of K

Lowest uptake of Ca (Table 4.5.5b) was recorded at 180 kg level of K which was significantly lower than K_{60} or K_{120} kg ha^{-1}. Potassium applied at 60 kg ha^{-1} recorded the lowest uptake of P, K, Mg, S and Fe and compared to control they were 2.1, 10.4, 13.7, 20.6 and 29.4 per cent lower respectively.

b. Effect of Ca

Application of Ca as lime at 150 kg ha^{-1} significantly reduced the S and Fe uptake 8.7 and 8.9 per cent. No other element was affected.

c. Effect of S

Sulphur application significantly influenced only the Ca and S_iO_2 uptake. At 200 kg level of S, Ca decreased by 25.5 per cent and silica increased by 41.2 per cent.

4.5.6 Second order interaction effect of K, L and S on nutrient uptake by grain and straw

4.5.6.1 Grain

Combined effect of K, Ca and S on uptake of elements in the grain are presented in Table 4.5.6.

Table 4.5.5b Nutrient uptake of straw as influenced by different levels of K, Ca and S

Treatment		Straw (kg ha^{-1})										
		N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO_2
Potassium	K_0	21.91	5.68	62.28	5.67	3.21	4.72	5.45	2.70	0.253	0.012	590.39
	K_{60}	19.47	5.56	55.80	7.04	2.77	3.75	3.85	2.23	0.220	0.010	558.71
	K_{120}	23.08	6.27	88.37	7.12	3.22	4.31	4.67	2.66	0.332	0.012	686.04
	K_{180}	24.07	7.21	95.73	5.49	2.93	4.84	5.77	2.41	0.407	0.011	653.25
CD(0.05)		NS	0.912	12.34	1.054	NS	0.507	0.547	NS	0.046	NS	NS
Calcium	L_0	22.79	6.38	81.33	6.01	3.18	4.60	5.16	2.64	0.315	0.011	637.23
	L_{150}	21.48	5.98	79.76	6.65	2.88	4.21	4.71	2.31	0.291	0.011	621.97
CD(0.05)		NS	NS	NS	NS	NS	0.359	0.387	NS	NS	NS	NS
Sulphur	S_0	22.91	5.86	81.62	6.55	2.80	4.14	4.85	2.29	0.314	0.011	499.37
	S_{100}	21.80	6.20	75.11	7.57	3.05	4.41	4.71	2.67	0.306	0.011	684.05
	S_{200}	21.69	6.46	84.91	4.88	3.24	4.66	5.25	2.51	0.289	0.012	705.37
CD(0.05)		NS	NS	NS	0.912	NS	NS	NS	NS	NS	NS	76.99
CV (%)		31.50	17.48	18.17	19.72	16.65	13.67	13.14	27.26	19.51	21.05	16.73

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0 and 150 kg lime ha^{-1})
S = Levels of S (0, 100 and 200 kg ha^{-1}) NS = Not significant

Table 4.5.6 Interaction effect of K, Ca and S on nutrient uptake by grain and straw (kg ha^{-1})

	Grain				Straw							
	Fe		Sio$_2$		Ca		Mg		Fe		Zn	
	L0	L150	L0	L150	L0	L150	L0	L150	L0	L150	L0	L150
K_0S_0	1.05	1.09	433.2	369.7	7.06	4.90	2.35	2.84	4.88	3.37	0.17	0.14
K_0S_{100}	1.24	0.87	626.2	716.8	9.62	5.03	3.80	3.39	5.05	4.95	0.26	0.39
K_0S_{200}	0.88	0.99	607.7	554.7	3.90	3.50	3.36	3.50	5.53	7.94	0.30	0.25
$K_{60}S_0$	0.91	0.56	836.9	307.7	10.04	11.6	3.18	2.34	7.46	2.67	0.22	[illegible]
$K_{60}S_{100}$	0.67	0.70	814.9	425.9	5.05	3.30	2.68	2.73	2.87	3.85	0.23	0.17
$K_{60}S_{200}$	1.07	0.87	654.0	835.6	7.41	4.86	3.76	2.01	3.53	2.78	0.27	0.22
$K_{120}S_0$	0.90	0.56	615.0	448.0	2.62	5.44	2.81	2.61	4.43	2.85	0.30	0.51
$K_{120}S_{100}$	0.82	0.87	724.2	818.9	9.79	14.74	2.49	3.82	2.47	8.60	0.44	0.24
$K_{120}S_{200}$	0.79	0.89	930.1	678.2	3.40	6.73	3.57	3.99	4.87	4.82	0.21	0.26
$K_{180}S_0$	0.69	0.87	754.1	639.2	5.88	4.83	4.21	2.16	6.94	5.22	0.53	0.42
$K_{180}S_{100}$	1.10	0.89	948.6	1330.7	4.48	8.51	3.06	2.43	6.35	3.56	0.44	0.27
$K_{180}S_{200}$	1.21	0.86	572.2	1330.7	2.86	6.40	3.00	2.77	7.60	4.92	0.36	0.40
CD (0.05)	0.261		307.88		2.291		1.04		1.34		0.113	

Lowest uptake of 0.555 kg ha^{-1} was recorded by $K_{120}S_0L_{150}$ and the highest quantity of Fe (1.243 kg ha^{-1}) was recorded at $K_0S_{100}L_0$ combination. It can also be observed that in the combination $K_0S_0L_0$, $K_0S_0L_{150}$, $K_{60}S_{200}L_0$, $K_{180}S_{100}L_0$ and $K_{180}S_{200}L_0$ also registered uptake above 1.0 kg ha^{-1} in the grain.

Highest uptake of SiO_2 was recorded at $K_{180}S_{100}L_{150}$ followed by $K_{180}S_{200}L_{150}$ and the former was significantly superior to all other treatment combinations. It can also be observed that the lowest uptake of 369.7 kg ha^{-1} was recorded at $K_0L_{150}S_0$ combinations.

4.5.6.2 Straw

The data showed that uptake in straw was significantly affected in the case of Ca, Mg, Fe and Zn.

Highest Ca uptake of 14.74 kg ha^{-1} was recorded in $K_{120}S_{100}L_{150}$ combination and the treatment receiving oniy $K_{120}S_{100}$ was significantly lower by 34.2 per cent. Lowest Ca uptake of 2.62 kg ha^{-1} was observed in $K_{180}S_{100}L_0$ which was on par with $K_{120}S_{200}L_0$ and $K_{60}S_{100}L_{150}$.

The lowest Mg uptake of 2.01 kg ha^{-1} was recorded at $K_{60}S_{200}L_{150}$ and the highest in $K_{180}S_0L_0$ (4.21 kg ha^{-1}). The lowest uptake of Mg in $K_{60}S_{200}L_{150}$ combination was on par with that recorded in $K_{120}S_{100}L_0$ and $K_{120}S_0L_0$.

The highest Fe uptake of 8.60 kg ha^{-1} was recorded at $K_{120}S_{100}L_{150}$ and the lowest uptake of 2.47 recorded in $K_{120}S_{100}L_0$ combinations. All the treatment combination with K gave higher contents of Fe.

Lowest uptake of Zn was recorded at $K_0S_0L_{150}$ which was 0.144 kg ha^{-1} and the highest content of 0.511 kg ha^{-1} was recorded in $K_{120}S_0L_{150}$. The treatment combination $K_{120}S_{100}L_0$ recorded 0.449 kg ha^{-1} and the addition of L_{150} to this reduced the Zn uptake to 0.241 kg ha^{-1}.

4.5.7 Nutrient ratios

4.5.7.1 Effect of K, Ca and S on nutrient ratios of shoot at MT

Data presented in Table 4.5.7a. showed that application of K beyond 60 kg ha^{-1} registered significantly wider ratios of N/S, P/S, Mn/Fe, Mn/Zn, $\frac{\underline{Ca+Mg}}{K}$ and $\frac{\underline{Ca+Mg+Fe.}}{P+K+S}$ The ratios N/Ca, N/Mg and N/Zn among N relationships, P/K, P/Ca, P/Mg and P/Mn among P relations and K/Ca, K/Mg and K/Mn among K relations and S/Fe and S/Cu among S relations were significantly increased by application of K at 120 kg ha^{-1} but not beyond control.

Application of K significantly narrowed down the N/P and S/Mn ratio and widened down N/Fe, N/Cu, P/Fe, P/Zn, P/Cu, K/S, K/Zn and K/Cu ratios beyond control.

Application of Ca as lime @ 150 kg ha^{-1} recorded wider ratios for all P based ratios and narrowed down N/P, N/Mg, N/Mn, K/Mn, S/Mn and S/Cu ratios.

Application of S at 100 kg ha^{-1} level significantly widened the ratios of P/Ca, P/S, P/Fe, P/Zn and Mn/Fe in the shoot at PI stage and narrowed down K/Mg ratio. The ratios K/Fe, K/Mn, S/Fe and S/Mn were narrowed by application of 100 kg S ha^{-1} but were widened at 200 kg S ha^{-1}.

4.5.7.2 Effect of K, Ca and S on nutrient ratios of leaf at PI stage

Data presented in Table 4.5.7b showed that almost all the ratios related with N, P and K registered significantly wider ratios by application of K but the ratios P/Ca, P/Cu and K/Ca narrowed down.

The ratios N/Ca, P/Ca, P/Zn, K/Ca. K/Zn, S/Cu and Mn/Zn significantly narrowed down due to Ca application and P/Fe, K/Fe, S/Fe, Mn/Fe and $\frac{\underline{Ca+Mg}}{K}$ ratios widened.

Table 4.5.7a Effect of K, Ca and S on nutrient ratios of shoot at MT stage

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca
Potassium																		
K_0	11.0	0.99	28.4	31.8	10.7	21.4	123.8	1174	3876	0.09	2.7	2.89	1.00	2.0	11.5	108	358	29.7
K_{60}	10.5	1.05	15.7	18.5	11.3	18.8	92.1	1040	3638	0.102	1.5	1.79	1.10	1.82	8.9	100	350	15.3
K_{120}	9.4	0.89	23.9	25.3	11.9	23.6	95.6	1143	3901	0.095	2.5	2.67	1.25	2.49	10.1	121	412	26.7
K_{180}	8.9	0.87	23.5	27.4	12.6	18.4	107.4	981	3766	0.103	2.6	3.22	1.52	2.23	12.5	116	437	26.2
CD (0.05)	1.6	NS	5.6	4.5	NS	2.7	15.3	144	NS	0.008	0.36	0.23	0.08	0.175	1.013	6.58	45.4	3.9
Calcium																		
L_0	10.8	0.98	23.1	27.4	11.8	21.1	110.0	1124	3983	0.092	2.2	2.56	1.12	2.02	10.5	106	374	24.0
L_{150}	9.1	0.92	22.6	24.1	11.4	20.0	99.0	1044	3607	0.103	2.5	2.73	1.32	2.25	11.0	116	406	24.9
CD (0.05)	1.2	NS	NS	3.2	NS	NS	10.8	NS	NS	0.006	0.25	0.16	0.06	0.124	NS	4.65	NS	NS
Sulphur																		
S_0	10.1	0.93	21.7	26.7	11.3	20.0	102.6	1060	3709	0.093	2.2	2.65	1.13	2.0	10.2	105	368	24.1
S_{100}	10.1	0.99	23.0	27.0	11.9	19.6	102.0	1090	3922	0.100	2.3	2.71	1.25	2.0	10.4	111	396	24.0
S_{200}	9.6	0.93	23.8	23.6	11.6	22.0	109.5	1103	3754	0.099	2.6	2.57	1.27	2.41	11.6	118	404	25.3
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.3	NS	0.07	0.152	0.88	5.69	NS	NS
CV (%)	20.1	22.0	29.2	20.6	18.3	15.5	17.3	15.7	21.6	11.7	17.9	10.1	8.4	9.7	11.2	7.0	13.8	18.9

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0, 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1}) NS - Not significant

Table 4.5.7a contd...

	K/Mg	K/S	K/Fe	K/Mn	K/Zn	K/Cu	S/Fe	S/Mn	S/Cu	Mn/Fe	Mn/Zn	$\frac{Ca+Mg}{K}$	$\frac{Ca+Mg+Fe}{P+K+S}$	$\frac{Ca+Mg+Fe+k}{P+S}$	$\frac{Ca+Mg+Fe+K}{N+P+S}$
Potassium															
K_0	32.9	11.3	22.6	127.3	1222	4056	2.04	11.4	109	0.187	9.8	0.069	0.098	6.3	1.01
K_{60}	17.8	10.9	18.0	88.7	1002	3489	1.67	8.1	92	0.205	11.4	0.128	0.155	6.1	0.97
K_{120}	28.2	13.2	26.5	106.8	1276	4355	2.01	8.1	97	0.248	12.3	0.076	0.101	6.6	1.06
K_{180}	31.8	14.7	21.9	122.4	1140	4335	1.54	8.6	79	0.177	95	0.073	0.107	6.7	1.12
CD (0.05)	3.14	1.18	2.99	11.2	121	629	0.125	0.48	4.3	0.012	0.51	0.008	0.008	NS	NS
Calcium															
L_0	28.5	12.2	22.1	115.2	1170	4114	1.81	9.4	96	0.194	10.5	0.087	0.117	6.5	1.01
L_{150}	26.9	12.9	22.3	107.4	1149	4003	1.81	8.7	92	0.214	11.0	0.086	0.114	6.3	1.07
CD (0.05)	NS	NS	NS	7.9	NS	NS	NS	0.34	3.1	0.008	0.36	NS	NS	NS	NS
Sulphur															
S_0	29.3	12.3	21.6	111.5	1149	4008	1.83	9.3	95	0.197	10.8	0.085	0.114	6.5	1.04
S_{100}	28.0	12.5	20.7	106.2	1136	4064	1.74	8.6	93	0.198	10.9	0.090	0.122	6.3	1.02
S_{200}	25.8	12.8	24.3	116.1	1194	4103	1.87	9.3	95	0.217	10.6	0.084	0.110	6.4	1.05
CD (0.05)	2.72	NS	2.59	9.7	NS	NS	0.108	0.41	NS	0.01	NS	NS	0.007	NS	NS
CV (%)	13.4	11.1	15.93	12.0	12.4	18.3	8.1	6.2	5.4	7.4	5.6	11.5	9.5	10.5	18.2

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0, 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1}) NS - Not significant

Table 4.5.7b Effect of K, Ca and S on nutrient ratios of leaf at PI stage

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca
Potassium																		
K_0	4.0	0.46	2.79	5.0	5.5	49.6	13.6	296.4	2046	0.117	0.725	1.31	1.40	12.8	3.5	80.3	529	6.3
K_{60}	4.5	0.63	2.66	6.9	6.1	79.3	18.6	336.1	2443	0.151	0.633	1.56	1.40	19.0	4.2	79.8	578	4.3
K_{120}	5.1	0.54	2.35	8.6	7.0	86.5	19.4	418.1	2294	0.110	0.468	1.68	1.38	17.0	3.8	84.2	455	4.7
K_{180}	4.3	0.58	2.91	8.8	7.0	75.1	23.9	348.9	2339	0.138	0.654	2.12	1.71	18.4	5.8	80.5	574	4.9
CD (0.05)	NS	0.11	NS	2.0	NS	14.2	3.8	71.5	NS	0.017	0.076	0.217	0.134	1.35	0.57	NS	92.8	0.59
Calcium																		
L_0	4.5	0.53	2.92	7.2	6.3	65.6	18.8	361.9	2227	0.124	0.681	1.63	1.47	15.1	4.3	85.6	529	5.6
L_{150}	4.4	0.58	2.44	7.5	6.5	79.7	18.9	338.1	2325	0.134	0.559	1.71	1.48	18.4	4.3	76.8	538	4.4
CD (0.05)	NS	NS	0.41	NS	NS	NS	NS	NS	NS	NS	0.053	NS	NS	0.95	NS	6.26	NS	0.41
Sulphur																		
S_0	4.4	0.55	2.67	7.5	7.0	79.6	19.4	345.7	2353	0.131	0.666	1.68	1.65	18.8	4.6	80.3	558	5.2
S_{100}	4.8	0.52	2.60	7.9	6.1	71.5	19.9	366.8	2045	0.109	0.529	1.69	1.32	15.1	4.1	80.5	446	5.1
S_{200}	4.2	0.60	2.74	6.6	6.0	66.8	17.3	337.2	2443	0.146	0.674	1.63	1.45	16.4	4.3	82.8	598	4.9
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.015	0.065	NS	0.116	1.17	NS	NS	80.4	NS
CV (%)	28.5	24.5	25.6	32.9	24.9	23.2	23.6	24.0	28.7	16.18	14.6	15.46	10.8	9.5	15.6	12.9	20.6	13.8

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0, 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1}) NS - Not significant

Table 4.5.7b contd...

	K/Mg	K/S	K/Fe	K/Mn	K/Zn	K/Cu	S/Fe	S/Mn	S/Cu	Mn/Fe	Mn/Zn	Ca+Mg / K	Ca+Mg+Fe / P+K+S	Ca+Mg+Fe+k / P+S	Ca+Mg+Fe+K / N+P+S
Potassium															
K_0	11.7	12.3	110.8	30.9	713	4755	9.3	2.5	58.6	3.9	24.0	0.27	0.232	6.5	2.06
K_{60}	11.5	9.7	132.8	30.8	535	3988	13.7	3.1	55.8	4.5	19.0	0.35	0.283	5.6	1.61
K_{120}	17.2	14.2	161.0	38.5	855	4529	12.5	2.8	61.6	4.6	22.9	0.31	0.259	7.6	2.00
K_{180}	15.8	12.6	135.6	42.4	594	4131	11.0	3.5	51.7	3.2	14.9	0.29	0.244	6.0	1.68
CD (0.05)	2.54	1.23	13.1	4.7	97.2	NS	0.57	0.33	4.10	0.32	2.3	0.04	0.027	0.63	0.34
Calcium															
L_0	14.5	12.6	131.3	37.0	745	4555	10.6	3.0	61.0	3.8	21.9	0.28	0.234	6.6	1.92
L_{150}	13.6	11.8	141.8	34.0	604	4147	12.6	3.0	52.8	4.3	18.5	0.33	0.275	6.2	1.75
CD (0.05)	NS	NS	9.2	NS	68.7	NS	0.40	NS	2.90	0.23	1.59	0.03	0.019	NS	NS
Sulphur															
S_0	14.1	13.5	1456	36.7	657	4414	11.5	2.8	51.4	4.1	18.5	0.30	0.250	6.6	1.82
S_{100}	16.4	12.8	145.5	40.4	772	4569	11.8	3.3	60.5	3.7	19.4	0.29	0.246	7.0	2.00
S_{200}	11.7	10.4	118.6	29.6	593	4269	11.6	2.9	58.8	4.4	22.7	0.33	0.268	5.6	1.69
CD (0.05)	2.2	1.06	11.3	4.1	84.2	NS	NS	0.284	3.55	0.28	1.95	0.033	NS	0.55	0.29
CV (%)	21.4	11.9	11.3	15.7	17.1	23.2	5.8	13.0	8.5	9.5	13.2	15.8	13.0	11.7	21.7

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0, 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1}) NS - Not significant

Application of S did not influence the ratios based on N. The ratios K/S and K/Fe were significantly narrowed while Mn/Zn widened due to S application. Application of S at 100 kg ha^{-1} recorded wider ratios of K/Mg, K/Mn, K/Zn and S/Fe and narrow ratios of P/K, P/Ca, P/S, P/Fe, P/Cu, Mn/Fe and $\frac{Ca+Mg}{K}$ but at 200 kg S ha^{-1} the reverse occurred.

4.5.7.3 Effect of K, Ca and S on nutrient ratios of boot leaf

Main effects of treatments on the ratios of different elements in boot leaf with N, P and K are presented in Table 4.5.7c.

Application of K @ 120 kg ha^{-1} significantly widened the ratios of N/S, N/Fe, P/S, P/Fe, K/S, K/Fe, S/Fe, Mn/Fe and $\frac{Ca+Mg}{K}$ and narrowed down N/Ca, K/Ca and Mn/Zn ratios. The ratios of N/Mg, N/Mn, P/K, P/Ca, P/Mg, P/Mn, P/Zn, K/Mg, K/Mn, K/Zn, S/Zn, S/Mn and S/Cu were widened by application of K beyond 60 kg ha^{-1}.

Application of Ca as lime at 150 kg ha^{-1} widened the ratios of N/S, N/Fe, P/S, P/Fe, K/S, K/Fe, S/Fe, Mn/Fe, $\frac{Ca+Mg}{K}$ and $\frac{Ca+Mg+Fe}{P+K+S}$ of boot leaf and narrowed down P/Ca, P/Mg, K/Ca, S/Mn and S/Cu ratios.

Application of S registered a significantly wider ratio of N/S and narrower ratio of N/Ca.

Ratios of elements with P showed that P/S, P/Fe, P/K, P/Ca, P/Mg, P/Mn and P/Zn ratios significantly widened due to S application while P/s and P/Fe narrowed down.

Table 4.5.7c Effect of K, Ca and S on nutrient ratios of boot leaf

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca
Potassium																		
K_0	6.5	0.90	5.0	10.5	7.1	8.9	32.8	529	2612	0.139	0.758	1.68	1.13	1.38	5.14	81.4	409	5.5
K_{60}	5.7	0.76	3.2	8.4	7.1	10.7	25.9	411	2409	0.133	0.572	1.54	1.24	1.89	4.68	73.6	430	4.2
K_{120}	5.9	0.92	3.7	12.0	8.6	11.6	35.6	524	2699	0.159	0.637	2.09	1.48	2.00	6.08	90.1	466	4.2
K_{180}	6.1	0.83	3.9	10.8	7.7	8.8	38.5	453	2740	0.140	0.645	1.79	1.29	1.46	6.45	75.9	457	5.2
CD (0.05)	NS	NS	0.94	1.58	1.17	1.61	5.2	NS	NS	0.015	0.060	0.143	0.08	0.11	0.57	7.29	NS	0.38
Calcium																		
L_0	5.8	0.83	4.2	10.4	7.0	9.2	32.4	461	2500	0.144	0.715	1.85	1.25	1.62	5.68	80.5	436	5.3
L_{150}	6.3	0.88	3.7	10.5	8.2	10.9	34.0	497	2730	0.141	0.591	1.70	1.32	1.74	5.84	80.0	445	4.3
CD (0.05)	NS	NS	NS	NS	0.83	1.14	NS	NS	NS	NS	0.042	0.10	0.06	0.08	NS	NS	NS	0.27
Sulphur																		
S_0	6.2	0.83	4.7	10.3	6.8	9.9	32.2	469	2500	0.138	0.734	1.75	1.15	1.61	5.25	77.3	414	5.9
S_{100}	6.3	0.83	3.0	10.5	7.3	10.3	32.2	456	2654	0.132	0.485	1.70	1.16	1.71	5.13	73.0	423	3.7
S_{200}	5.7	0.89	4.2	10.4	8.8	9.7	35.1	513	2692	0.159	0.740	1.87	1.55	1.72	6.37	90.5	485	4.7
CD (0.05)	NS	NS	0.81	NS	1.02	NS	NS	NS	NS	0.013	0.052	0.125	0.07	0.098	0.40	6.3	NS	0.33
CV (%)	19.7	23.1	28.3	18.0	18.3	19.1	18.7	24.6	25.7	12.0	11.1	9.7	7.8	8.03	12.1	10.8	19.3	9.5

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0, 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1}) NS - Not significant

Table 4.5.7c contd...

	K/Mg	K/S	K/Fe	K/Mn	K/Zn	K/Cu	S/Fe	S/Mn	S/Cu	Mn/Fe	Mn/Zn	Ca+Mg	Ca+Mg+Fe	Ca+Mg+Fe+k	Ca+Mg+Fe+K
												K	P+K+S	P+S	N+P+S
Potassium															
K_0	12.1	8.1	10.0	37.0	588	2926	1.34	4.97	76.8	0.28	16.5	0.28	0.30	5.18	1.24
K_{60}	11.8	9.7	14.2	35.9	568	3271	1.51	3.77	59.7	0.41	16.1	0.34	0.34	6.18	1.50
K_{120}	13.6	9.4	13.7	39.2	582	2966	1.42	4.19	62.0	0.35	15.1	0.35	0.35	5.49	1.25
K_{180}	13.6	9.6	10.8	48.2	556	3367	1.14	4.96	58.9	0.24	12.6	0.33	0.34	6.02	1.38
CD (0.05)	1.08	0.53	0.72	3.06	NS	323	0.017	0.23	5.07	0.008	1.04	0.027	0.017	0.33	0.181
Calcium															
L_0	13.1	8.8	11.4	40.8	563	3061	1.31	4.67	66.2	0.30	15.1	0.31	0.32	5.49	1.35
L_{150}	12.4	9.6	13.1	39.4	584	3204	1.39	4.28	62.5	0.33	15.1	0.35	0.35	5.95	1.34
CD (0.05)	NS	0.37	0.51	NS	NS	NS	0.012	0.17	3.6	0.006	NS	0.019	0.012	0.24	NS
Sulphur															
S_0	13.5	8.6	12.4	41.5	574	3100	1.47	4.87	70.7	0.31	15.2	0.29	0.30	5.49	1.34
S_{100}	13.0	8.9	13.1	39.3	564	3241	1.46	4.45	63.4	0.34	14.4	0.37	0.36	5.98	1.41
S_{200}	11.9	10.1	11.3	39.3	583	3056	1.13	4.09	58.9	0.30	15.6	0.32	0.33	5.69	1.29
CD (0.05)	0.93	0.46	0.63	NS	NS	NS	0.015	0.20	4.4	0.007	0.90	0.023	0.015	0.29	NS
CV (%)	10.0	6.8	7.0	9.0	9.4	12.2	1.5	6.2	9.3	3.4	8.2	8.1	6.3	6.9	16.0

K = Levels of K (0, 60, 120 and 180 kg ha^{-1}) L = Levels of Ca (0, 150 kg lime ha^{-1}) S = Levels of S (0, 100 and 200 kg ha^{-1}) NS - Not significant

4.5.8 Interrelation of growth differentials and physiological attributes, nutrient content and nutrient ratios with yield of rice

4.5.8.1 Growth differentials and physiological attributes

The data on interrelations of growth differentials with yield of rice are presented in Table 4.5.8.

The data showed varying degrees of positive and negative correlations between yield and growth differentials though the relationships were not statistically significant. Among the physiological attributes, chlorophyll `a' : chlorophyll `b" ratio of boot leaf showed a significant negative correlation with grain yield and total biomass.

4.5.8.2 Correlation of nutrient content with yield

Varying responses were observed between nutrient content of different parts of rice with yield. Grain yield was not influenced by P content in any part of the plant where as a significant positive correlation was obtained between P content of culm at PI and straw and total biomass yield (Table 4.5.9).

Sulphur content of root at MT and culm at PI, Fe content of shoot at MT and Mn content of root at MT and PI and of shoot at MT were positively correlated with its corresponding P content and the relations were statistically significant (Table 4.5.9).

As in the case of P, K content of different parts of rice significantly correlated with straw yield and total biomass yield. Potassium content of straw had a negative influence on grain yield and total biomass. Straw yield was positively related with K content of all parts except boot leaf and straw. Total biomass also showed a positive correlation with P content of culm and leaf at PI and grain (Table 4.5.10).

The interrelationships of Ca content of different parts of rice with grain and straw yield and total biomass production (Table 4.5.10) were negative except in leaf Ca content at PI though the relations were not significant.

Table 4.5.8 Inter-relations of growth attributes and physiologic attributes with yield of rice as influenced by K, Ca and S

Attributes	Grain yield	Straw yield	Total biomass
Chl.`a' at PI	0.013	-0.017	0.036
Chl.`a' of boot leaf	0.021	-0.167	-0.095
Chl.`a'/Chl.`b' at PI	-0.027	0.028	-0.030
Chl.`a'/Chl.`b' at boot leaf	-0.250**	-0.199	-0.236**
Leaf sap pH at PI	0.098	0.149	0.138
Leaf sap pH at boot leaf	-0.213	-0.096	-0.177
Total dry weight (MT - PI)	-0.098	-0.094	-0.083
Total dry weight (Flg - PI)	0.088	0.156	0.126

Table 4.5.9 Corelation coefficient of P content of different parts of rice with yield, S, Fe and Mn content

P Content	Grain yield	Straw yield	Total biomass	S	Fe	Mn
Root at MT	-0.059	0.298**	0.158	0.657**	0.189	0.469**
Shoot at MT	0.206	0.153	0.234	-0.147	0.398**	0.296**
Root at PI	0.078	0.169	0.094	0.269	-0.183	0.513**
Culm at PI	0.214	0.443**	0.322**	0.372**	0.147	0.084
Leaf at PI	-0.064	0.172	0.003	0.117	0.056	0.079
Boot leaf	-0.084	0.093	0.113	-0.047	-0.102	0.034
Grain	0.034	0.131	0.070			
Straw	0.232	0.396**	0.452**			

Table 4.5.10 Correlation coefficient of K and Ca content of different parts of rice with yield

K Content	K			Ca		
	Grain yield	Straw yield	Total biomass	Grain yield	Straw yield	Total biomass
Root at MT	0.050	0.416**	0.267	-0.150	-0.163	-0.121
Shoot at MT	0.017	0.377**	0.178	0.103	-0.005	-0.093
Root at PI	0.109	0.298**	0.204	-0.065	-0.110	-0.047
Culm at PI	0.191	0.439**	0.365**	-0.070	-0.204	-0.097
Leaf at PI	0.209	0.271**	0.313**	0.077	0.030	0.031
Boot leaf	0.024	0.177	0.072	0.182	-0.056	-0.035
Grain	0.152	0.546**	0.365**	-0.051	-0.073	-0.123
Straw	-0.022	0.019	-0.013	-0.290**	-0.173	-0.226

Table 4.5.11 Correlation coefficient of S content of different parts of rice with yield, leaf sap pH, P, Fe and Mn content

S content	Grain yield	Straw yield	Total biomass	Sap pH MT stage	Sap pH boot leaf	P	Fe	Mn
Root at MT	0.054	0.223	0.204	-	-	0.067	0.066	0.159
Shoot at MT	-0.227	-0.075	-0.079	-	-	0.147	-0.238	0.044
Root at PI	0.218	-0.043	0.118	-	-	0.269	0.217	0.208
Culm at PI	0.097	0.358*	0.233	-	-	0.372*	0.191	0.125
Leaf at PI	-0.026	-0.137	-0.104	-0.146	-0.154	0.117	0.081	0.155
Boot leaf	-0.256	-0.074	-0.114	-0.082	-0.257	0.047	0.350*	0.034
Grain	-0.267	0.032	0.143					
Straw	0.016	-0.027	0.005					

Sulphur content of different parts of rice did not have any significant relation with grain and total biomass yield. Sulphur content of culm at PI stage showed a positive significant correlation with straw yield (Table 4.5.11).

The leaf sap pH of leaf at PI and boot leaf were related with S content of leaf and boot leaf but the relations were not statistically significant.

Iron content of different parts of rice did not show any significant relation with yield of rice by itself though the relations with grain and straw yield and total biomass were not statistically significant (Table 4.5.12).

The data presented in (Table 4.5.12) showed significant negative correlation between Mn content of leaf, boot leaf and grain with grain yield, straw yield and total biomass.

4.5.8.3 Interrelation of nutrient ratios of leaf at PI with yield

The correlation of nutrient ratios of leaf at PI with yields of rice is presented in Table 4.5.13.

The nutrient ratios N/Fe and $\frac{Ca+Mg}{K}$ had a negative relationship with grain yield and the relation with $\frac{Ca+Mg}{K}$ was significant.

A significant positive correlation was observed between yields and the ratios N/Zn, K/Mg, K/Fe and K/Mn. The ratios K/Ca and K/Zn also showed positive trend with yields.

4.5.8.4 Interrelation of nutrient ratios of boot leaf with leaf sap pH

The ratios, N/Fe, S/Fe, Mn/Fe, P/Fe, K/Fe, K/Ca, K/Mn, K/Zn and Mn/Zn were negatively related with leaf sap pH of leaf at PI and the relationship was significant with Mn/Fe. A significant positive correlation was obtained with N/Mg ratio and leaf sap pH at PI (Table 4.5.14).

Table 4.5.12 Correlation coefficient of Fe and Mn content of different parts of rice with yield

Fe and Mn Content	Fe			Mn		
	Grain yield	Straw yield	Total biomass	Grain yield	Straw yield	Total biomass
Root at MT	0.150	0.022	0.071	-0.109	0.206	0.081
Shoot at MT	0.025	0.012	0.013	-0.071	0.009	-0.029
Root at PI	-0.215	-0.088	-0.182	-0.071	0.030	-0.029
Culm at PI	0.125	0.182	0.192	0.084	0.026	0.057
Leaf at PI	-0.172	0.012	0.013	-0.166	-0.346**	-0.306**
Boot leaf	0.025	0.105	0.089	-0.326**	-0.380**	-0.392**
Grain	0.153	-0.033	-0.159	-0.286**	-0.428**	-0.432**
Straw	-0.136	-0.118	-0.159	-0.166	0.013	-0.051

Table 4.5.13 Correlation of leaf nutrient ratios of rice with yield

Leaf at PI	Grain yield	Straw yield	Total biomass
N/Fe	-0,259	-0.125	-0.251
N/Zn	0.278**	0.332**	0.297**
K/Ca	0.015	0.128	0.119
K/Mg	0.379**	0.318**	0.445**
K/Fe	0.303**	0.276**	0.371**
K/Mn	0.252	0.374**	0.384**
K/Zn	0.158	0.143	0.199
Ca+Mg / K	-0.219	-0.293**	-0.383**

Table 4.5.14 Correlation coefficient of boot leaf nutrient ratios of rice with yield and leaf sap pH

Boot leaf	Grain yield	Straw Yield	Total biomass	Leaf sap pH at MT	Leaf sap pH of boot leaf
N/K	-0.116	-0.015	-0.068	0.080	0.089
N/Mg	0.117	0.292**	-0.068	0.291**	0.044
N/S	0.087	0.119	0.016	0.050	0.100
N/Fe	-0.259	-0.125	-0.251	-0.171	0.191
N/Mn	0.137	0.356**	0.257	0.252	-0.099
N/Zn	-0.008	0.005	0.032	0.216	-0.091
P/K	-0.019	-0.043	0.061	0.090	0.186
P/Mg	0.181	0.191	0.293**	0.247	0.139
P/S	0.120	0.070	0.133	0.062	0.183
P/Fe	-0.210	-0.136	-0.148	-0.221	0.276**
K/Ca	-0.060	0.191	0.098	-0.027	-0.281**
K/Mg	0.195	0.284**	0.268	0.124	-0.075
K/Fe	-0.120	-0.058	-0.137	-0.064	0.121
K/Mn	0.283**	0.430**	0.375**	-0.196	-0.233
K/Zn	0.192	0.116	0.179	0.141	-0.308**
Mn/Fe	0.319**	-0.367**	-0.402**	-0.354**	0.227
Mn/Zn	-0.142	-0.329**	-0.230	-0.066	-0.066
S/Fe	-0.283**	-0.188	-0.228	-0.172	0.116
Ca+Mg/K	0.126	-0.136	-0.065	0.018	0.248

A significant negative correlation was obtained between leaf sap pH of boot leaf and K/Ca and K/Zn ratios while its relationship with P/Fe ratio was positive.

4.5.8.4 Interrelation of nutrient ratios of boot leaf with yield

Data presented in Table 4.5.14 showed that the ratios N/Mg, N/S, N/Mn, P/Mg, P/S, K/Mg, K/Mn, K/Zn, Mn/Fe and $\frac{Ca+Mg}{K}$ were positively related with grain yield and the relationship was significant with Mn/Fe and K/Mn ratio.

Significant negative correlation was obtained between grain yield and S/Fe ratio.

Straw yield recorded a significant positive correlation with N/Mg, N/Mn, K/Mg and K/Mn and the relationship was significantly negative with Mn/Fe and Mn/Zn.

A significant positive relationship was obtained between total biomass and K/Mn ratio and the relation was negative with Mn/Fe of boot leaf.

4.6 EXPERIMENT VI

The experiment entitled "Modifying influences of silica and zinc on the nutrient balance, iron absorption and productivity of rice" studied the direct and indirect effect of silica and zinc on improving the productivity of rice in iron rich lateritic alluvium.

4.6.1 Main effects of silica and zinc on growth attributes, physiological characters and yield attributes and yield

4.6.1.1 Effects of silica

Data on the main effects of increasing levels of silica are presented in Table 4.6.1. Among the 39 plant parameters used to evaluate the treatment effects, only three were significantly affected by silica application.

Application of silica reduced the weed dry weight significantly. The lowest weed dry weight was recorded when silica was applied @ 500 kg ha^{-1} and the reduction in

Table 4.6.1 Effect of silica and zinc on growth attributes, physiologic attributes and yield attributes and yield of rice

Treatment	Growth attributes							
	Plant height (cm)				Total tillers/hill			
	MT	PI	Flg.	Harvest	MT	PI	Flg.	Harvest
Silica								
Si_{0}	36.8	46.9	76.1	71.5	5.3	5.8	7.5	6.6
Si_{250}	37.8	48.6	79.6	73.2	5.6	6.5	7.5	6.3
Si_{500}	36.6	47.2	78.8	73.0	5.4	5.9	7.3	6.3
Si_{750}	37.3	48.5	78.1	76.1	6.2	6.6	7.3	6.4
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Zinc								
Zn_{0}	37.4	47.1	77.3	73.6	5.7	6.3	7.6	6.5
Zn_{20}	37.9	48.6	79.3	73.3	5.8	6.7	7.5	6.3
Zn_{40}	36.6	46.6	78.1	73.9	5.1	5.8	7.0	6.2
Zn_{60}	37.3	48.5	77.9	73.5	6.0	6.0	7.4	6.6
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	6.39	4.89	5.50	6.08	21.52	18.55	24.51	22.86

NS - Not significant

Table 4.6.1 contd...

Treatment	Growth attributes									
	Plant dry weight (g) - Flowering stage					Plant dry weight (g) - Harvest				
	Total dry wt. (MT)	Shoot	Root	Total	S/R	Shoot	Root	Total	S/R	Weed dry wt. (g plot^{-1})
Silica										
Si$_0$	7.0	25.06	3.48	28.85	7.7	32.67	5.07	37.19	6.5	81.92
Si$_{250}$	6.9	24.04	3.85	29.23	6.0	31.31	5.33	36.56	6.1	42.09
Si$_{500}$	7.0	25.90	4.34	30.34	6.4	30.28	5.30	35.59	5.9	37.94
Si$_{750}$	6.7	25.63	5.01	30.68	5.6	33.65	5.79	39.43	6.0	40.61
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	18.72
Zinc										
Zn$_0$	6.4	25.95	4.45	30.85	6.3	33.95	5.59	39.16	6.2	38.71
Zn$_{20}$	6.9	24.14	4.23	28.31	6.2	32.64	5.55	38.36	6.0	46.41
Zn$_{40}$	7.1	24.13	4.40	28.52	6.1	32.14	5.21	37.49	6.4	62.75
Zn$_{60}$	7.2	26.41	4.60	31.41	7.1	29.18	5.14	33.76	5.8	54.69
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	18.723
CV (%)	18.16	15.14	33.46	15.37	34.65	17.87	22.61	17.11	20.61	44.35

NS - Not significant

Table 4.6.1 contd...

Treatment	Yield attributes and yield												
	Panicles/ hill	Panicle weight (g)	Panicle length (cm)	Branches/ panicle	Filled grains/ panicle	Unfilled grains/ panicle	1000 grain weight (g)	Percent-age of filling	Moisture content in grain (%)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total biomass (kg ha^{-1})	G / S
Silica													
Si_0	6.6	25.9	20.2	8.4	85.0	20.4	29.6	80.5	13.1	5376	4276	9652	1.3
Si_{250}	6.1	26.6	20.0	8.5	87.9	19.6	31.0	81.9	11.5	6095	4754	10849	1.3
Si_{500}	6.3	26.2	19.9	8.2	89.0	19.0	31.4	85.0	12.8	5828	4688	10520	1.2
Si_{750}	6.2	25.4	20.1	8.2	87.2	20.5	31.0	80.9	11.4	5863	4491	10355	1.3
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	1.47	566.2	NS	NS	NS
Zinc													
Zn_0	6.5	25.7	20.4	8.2	85.1	21.2	30.8	79.7	13.0	5941	4603	10544	1.3
Zn_{20}	6.0	25.4	19.9	8.2	88.0	19.9	31.9	82.0	11.7	5775	4721	10477	1.2
Zn_{40}	6.1	26.5	20.0	8.5	90.7	19.5	31.0	82.4	11.6	5677	4361	10038	1.3
Zn_{60}	6.6	26.5	19.8	8.3	85.5	18.9	32.0	82.1	12.7	5769	4524	10044	1.3
CD (0.05)	NS	NS	NS	NS	NS	NS	0.50	NS	NS	NS	NS	NS	NS
CV (%)	23.42	9.7	3.61	5.39	9.57	25.5	2.06	4.98	14.52	11.73	16.05	11.73	15.94

NS - Not significant

Table 4.6.1 contd...

Treatment	Physiologic attributes							
	Chlorophyll (mg/g) fresh weight of sample						Leaf sap pH	
	PI stage			Boot leaf			PI	Boot leaf
	Chl. ‘a’	Chl. ‘b’	Total	Chl. ‘a’	Chl. ‘b’	Total		
Silica								
Si$_0$	1.504	1.740	3.198	2.080	1.205	3.288	6.30	6.04
Si$_{250}$	1.496	1.515	3.046	2.004	1.232	3.257	6.22	6.07
Si$_{500}$	1.496	1.642	3.041	2.212	1.209	3.372	6.35	6.13
Si$_{750}$	1.478	1.451	2.993	2.115	1.347	3.463	6.20	6.08
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Zinc								
Zn$_0$	1.502	1.552	3.099	2.223	1.281	3.505	6.27	6.11
Zn$_{20}$	1.496	1.732	2.956	2.078	1.269	3.307	6.34	6.12
Zn$_{40}$	1.497	1.669	3.277	1.972	1.266	3.272	6.31	6.05
Zn$_{60}$	1.480	1.393	2.948	2.134	1.177	3.297	6.15	6.05
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	3.06	25.88	15.08	22.41	18.94	19.57	3.88	2.32

NS - Not significant

weed dry weight worked out to 53.7 per cent over control. Levels of silica did not significantly differ in their influences on weed biomass.

Application of silica also reduced the moisture content of the grain. The lowest moisture content of 11.4 per cent was recorded in the treatment receiving silica @ 750 kg ha^{-1} which was 7.38 per cent less than that of control. Levels of silica did not significantly influence the moisture content of the grain.

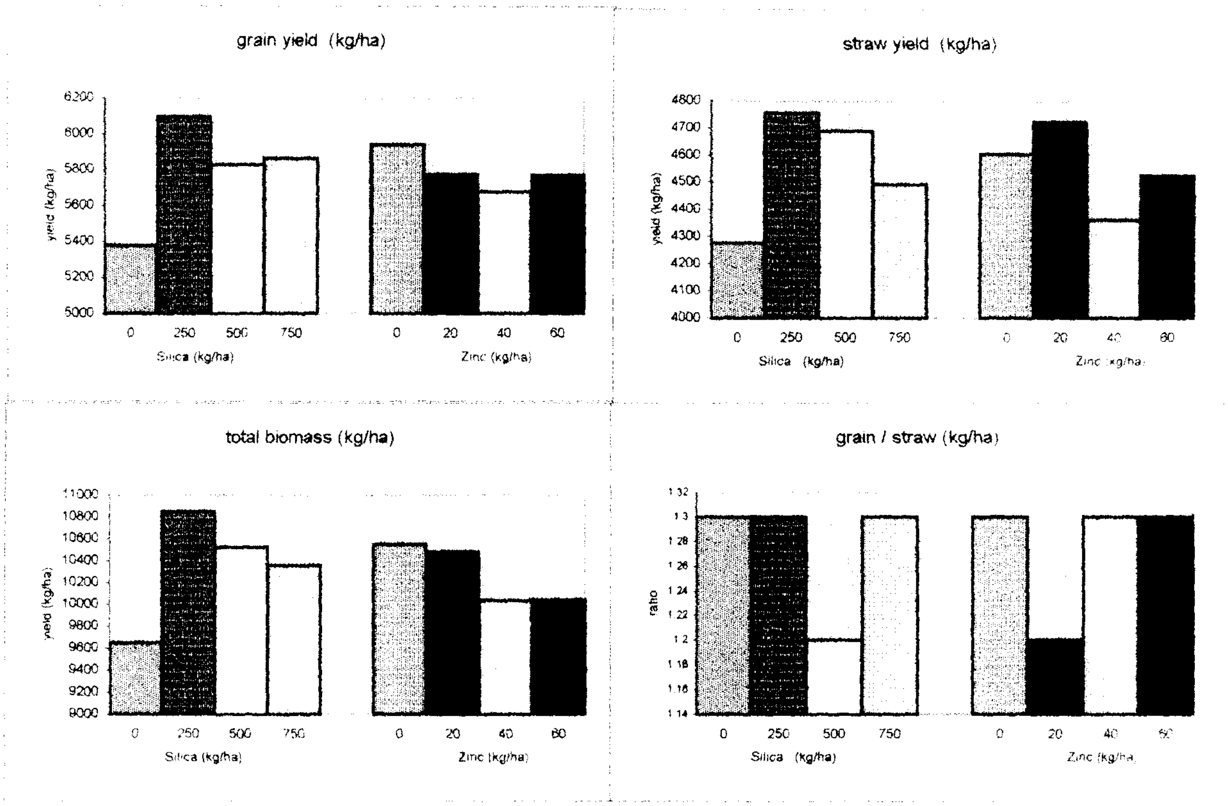
Highest grain yield of 6095 kg grain ha^{-1} was recorded when silica was applied at the rate of 250 kg ha^{-1} and the increment over control worked out to 13.4 per cent. Increasing levels of silica did not have any significant effect on yield of grain (Fig. 4.6.1).

4.6.1.2 Main effects of zinc

Data on the influence of main effect of Zn presented in Table 4.3.1 revealed that Zn affected weed dry weight and 1000 grain weight only. Application of @ 40 kg ha^{-1} registered the highest weed dry weight of 62.75 gm/plot which was 62.1 per cent higher than control. Application of Zn also increased the 1000 grain weight. Application of Zn @ 20 kg ha^{-1} increased the 1000 grain weight significantly over control (Fig. 4.6.1).

4.6.2 Interaction effects of silica and zinc on weed dry weight

Data on the combined effect of SiO_2 and Zn (Table 4.6.2) showed that highest weed dry weight was recorded when Zn was applied @ 20 kg ha^{-1} without Sio_2. Silicate application tended to reduce the weed dry weight. 250 kg ha^{-1} level of SiO_2 application combined with 20 kg Zn ha^{-1} recorded the lowest weed dry weight of 10.1 kg ha^{-1}.



grain yield (kg/ha)

straw yield (kg/ha)

total biomass (kg/ha)

grain / straw (kg/ha)

Fig. 4.6.1. Effect of Si and Zn on grain, straw and total biomass yield and grain / straw

Table 4.6.2 Interaction effect of silica and zinc on weed dry weight (g/m^2)

Treatment	Zinc levels			
	Zn_0	Zn_{20}	Zn_{40}	Zn_{60}
Silica levels				
Si_0	44..1	109.3	96.2	78.0
Si_{250}	32.1	10.1	47.9	78.2
Si_{500}	43.6	28.7	40.7	38.9
Si_{750}	34.9	37.6	66.3	23.6
CD (0.05)	37.44			

4.6.3 Main effects of silica and zinc on elemental composition of rice

4.6.3.1 Root composition at MT and PI stage

Data on the elemental composition of root at MT and PI stages of rice as affected by application of graded levels of SiO_2 and Zn are presented in Table 4.6.3a. It can be seen that the influence of treatment was confined mainly to MT stage.

Application of increasing levels of SiO_2 significantly affected P, Ca, Fe, Zn, Cu and SiO_2 content of root at MT stage.

Application of SiO_2 @ 250 kg ha^{-1} reduced the Ca content of the root significantly and the decrease worked out to 62.5 per cent. Higher levels of SiO_2 failed to be as effective as this treatment.

Application of SiO_2 @ 500 kg ha^{-1} gave the highest Zn content of 93 ppm in the root and it was statistically significant over other levels.

Silica applied @ 750 kg ha^{-1} significantly reduced the Cu content of the root over control and increased the P, Fe and SiO_2 content of the root and the percentage increases were 9.8, 13.9 and 108.6 over control.

However, at PI stage the influence of silicate levels were confined to only Zn. Application of 750 kg silica ha^{-1} increased the Zn content of root by 37.8 per cent and the increase was statistically significant.

Data on the effect of graded levels of Zn on the elemental composition of root presented in Table 4.6.3a. showed that application of Zn @ 40 kg ha^{-1} increased the Fe, Mn and Zn content of the roots significantly over control and the increases were 23.3, 40.3 and 52.4 per cent respectively.

Table 4.6.3a Effect of silica and zinc on nutrient content of rice root at MT and PI stage

Treatment	Root at maximum tillering										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_iO_2 (%)
Silica											
Si_0	0.962	0.194	1.031	0.013	0.044	2384	56046	226	71	14.3	7.0
Si_{250}	0.986	0.183	1.162	0.008	0.048	2579	60484	272	74	15.5	9.3
Si_{500}	0.931	0.195	1.075	0.013	0.042	2607	60506	210	93	13.0	9.7
Si_{750}	0.931	0.213	1.181	0.010	0.045	2639	63843	257	79	11.3	14.6
CD (0.05)	NS	0.018	NS	0.003	NS	NS	4036.9	NS	8.76	2.58	2.51
Zinc											
Zn_0	1.017	0.199	1.100	0.012	0.041	2446	52262	206	61	12.6	9.2
Zn_{20}	0.964	0.181	1.131	0.011	0.047	2478	60484	227	67	13.3	10.5
Zn_{40}	0.976	0.204	1.150	0.010	0.048	2663	64481	289	93	15.1	10.0
Zn_{60}	0.854	0.200	1.069	0.010	0.044	2623	63169	243	95	13.1	11.0
CD(0.05)	0.150	NS	NS	NS	NS	NS	4036.9	61.82	8.76	NS	NS
CV (%)	12.55	9.10	14.39	24.68	13.99	13.12	6.29	24.04	10.4	17.92	23.22

NS - Not significant

Table 4.6.3a contd....

Treatment	Root at panicle initiation stage										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_iO_2 (%)
Silica											
Si_0	0.580	0.150	0.313	0.017	0.048	2198	59575	185	162.6	23.8	16.0
Si_{250}	0.734	0.153	0.300	0.013	0.047	2311	61581	178	184.5	25.6	17.7
Si_{500}	0.636	0.144	0.288	0.013	0.060	2060	60088	178	147.3	23.4	22.9
Si_{750}	0.559	0.158	0.275	0.012	0.053	2170	65591	200	224.0	24.1	17.3
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	59.26	NS	NS
Zinc											
Zn_0	0.624	0.144	0.319	0.015	0.055	2081	63453	184	50.5	22.8	18.5
Zn_{20}	0.635	0.151	0.325	0.014	0.047	2006	59069	174	102.5	25.2	20.8
Zn_{40}	0.592	0.155	0.256	0.014	0.057	2417	63005	178	179.0	25.0	15.7
Zn_{60}	0.657	0.154	0.275	0.013	0.049	2235	61306	205	386.4	23.9	19.0
CD(0.05)	NS	NS	0.048	NS	NS	257.5	NS	NS	59.26	NS	NS
CV (%)	29.76	10.85	16.37	55.64	21.43	11.06	13.03	35.96	30.97	27.25	34.77

NS - Not significant

Zinc application also decreased the N content of the root. Application of Zn @ 60 kg ha^{-1} level decreased the N content by 19.1 per cent over control and the decrease was significant.

The nature of influences of Zn changed at PI stage. Apart from the Zn content, itself, zinc effect was manifested in decreasing the K content and increasing the S content of the root. Thus application of Zn at 60 kg ha^{-1} increased the Zn content of root by 665 per cent over control. At 40 kg level Zn increased the S content by 16.1 per cent and decreased the K content by 19.7 per cent.

4.6.3.2 Elemental composition of shoot at MT and culm at PI

Application of sodium silicate significantly influenced only the SiO_2 content of shoot at MT stage (Table 4.6.3b). Increasing levels of sodium silicate application increased the SiO_2 content of the shoot by 49.5 per cent.

At the PI stage silicate application affected Fe and Mn content. Application of silica @ 750 kg ha^{-1} increased the Fe and Mn content by 51.5 and 60.3 per cent respectively over control.

Application of graded levels of Zn could increase only the Zn content of the shoot by MT stage. Even this effect was apparent only at 40 kg ha^{-1} level of application. Thus application of Zn @ 40 kg ha^{-1} increased the Zn content by 25.1 per cent over control. Increase in the level of Zn beyond 40 kg ha^{-1} failed to bring about any improvement in the Zn content.

However, Zn application even upto 60 kg ha^{-1} level failed to significantly modify the content of any element in the culm at PI stage.

4.6.3.3 Composition of leaf at PI stage and boot leaf

Application of Sio_2 significantly affected only the Mn content of leaf at PI stage and the increase in the content with the application of 250 kg ha^{-1} SiO_2 worked out to 41.3 per cent (Table 4.6.3c). Beyond 250 kg level, effect of SiO_2 tended to decline.

Table 4.6.3b Effect of silica and zinc on nutrient content of shoot at MT and culm at PI stage

Treatment	Shoot at maximum tillering										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_iO_2 (%)
Silica											
Si_0	1.82	0.256	2.056	0.129	0.083	2056	2008	269	29.9	6.1	18.8
Si_{250}	1.794	0.267	2.056	0.124	0.095	2131	2020	273	28.9	6.3	28.1
Si_{500}	1.542	0.272	2.094	0.151	0.094	2099	1716	304	30.8	6.6	27.3
Si_{750}	1.794	0.273	2.069	0.107	0.087	1941	1732	257	30.8	6.0	23.0
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	7.40
Zinc											
Zn_0	1.641	0.267	2.006	0.127	0.085	1928	2082	262	26.3	6.1	21.4
Zn_{20}	1.749	0.265	2.118	0.131	0.103	2042	1726	257	28.0	5.9	24.3
Zn_{40}	1.684	0.266	2.100	0.132	0.092	2127	1998	312	32.9	6.9	24.0
Zn_{60}	1.881	0.270	2.050	0.118	0.084	2131	1672	272	33.1	6.1	27.0
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	3.97	NS	NS
CV (%)	17.98	7.26	11.00	29.08	27.62	12.33	35.64	24.95	12.44	20.2	28.57

NS - Not significant

Table 4.6.3b contd....

Treatment	Culm at PI										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_i0_2 (%)
Silica											
Si_0	0.719	0.165	2.506	0.057	0.090	1476	1184	418	118.8	5.3	21.7
Si_{250}	0.861	0.167	2.375	0.059	0.094	1568	1127	671	165.0	4.9	21.3
Si_{500}	0.709	0.155	2.356	0.052	0.103	1493	1425	620	99.9	5.5	20.8
Si_{750}	0.811	0.175	2.366	0.044	0.089	1450	1794	670	98.5	3.9	21.3
CD (0.05)	NS	NS	NS	NS	NS	NS	478.2	186.3	NS	NS	NS
Zinc											
Zn_0	0.841	0.179	2.300	0.046	0.098	1511	1566	534	127.5	5.1	21.4
Zn_{20}	0.690	0.162	2.547	0.056	0.088	1569	1362	513	122.0	5.0	19.3
Zn_{40}	0.777	0.155	2.525	0.055	0.091	1490	1312	690	103.0	4.6	21.7
Zn_{60}	0.791	0.162	2.231	0.055	0.098	1415	1288	642	129.6	4.8	22.6
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	23.95	17.00	18.77	33.63	18.98	11.66	32.44	29.42	52.17	27.01	41.03

NS - Not significant

Table 4.6.3c Effect of silica and zinc on nutrient content of leaf at PI and boot leaf

Treatment	Leaf at panicle initiation										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_iO_2 (%)
Silica											
Si_0	1.309	0.216	1.531	0.476	0.114	1572	792	724	27.8	4.9	29.8
Si_{250}	1.445	0.186	1.363	0.514	0.123	1543	858	1023	25.4	5.1	34.5
Si_{500}	1.456	0.198	1.138	0.489	0.119	1618	823	929	23.9	4.8	41.0
Si_{750}	1.249	0.185	1.131	0.535	0.104	1564	889	897	23.6	5.1	39.0
CD (0.05)	NS	NS	0.307	NS	NS	NS	NS	212.4	NS	NS	NS
Zinc											
Zn_0	1.353	0.200	1.294	0.513	0.116	1566	835	724	21.5	4.8	36.4
Zn_{20}	1.266	0.205	1.313	0.465	0.118	1500	939	990	23.5	5.0	32.0
Zn_{40}	1.432	0.197	1.313	0.522	0.119	1432	838	983	26.6	5.1	37.7
Zn_{60}	1.425	0.183	1.244	0.514	0.106	1601	748	877	29.0	5.0	38.2
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	212.4	NS	NS	NS
CV (%)	21.27	19.82	22.29	24.18	13.18	12.44	24.16	22.32	23.98	26.22	35.6

NS - Not significant

Table 4.6.3c contd...

Treatment	Boot leaf										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_i0_2 (%)
Silica											
Si_0	1.896	0.185	1.275	0.446	0.089	1859	421	597	23.9	6.6	20.1
Si_{250}	1.881	0.171	1.231	0.444	0.102	1878	311	873	22.3	5.6	21.0
Si_{500}	1.861	0.165	1.125	0.468	0.105	1853	306	721	20.9	5.8	24.0
Si_{750}	1.888	0.179	1.394	0.439	0.104	1826	364	647	23.8	4.8	21.6
CD (0.05)	NS	NS	0.178	NS	NS	NS	NS	190.56	NS	NS	NS
Zinc											
Zn_0	1.797	0.184	1.238	0.425	0.094	1856	376	571	18.3	6.1	21.4
Zn_{20}	1.845	0.185	1.213	0.479	0.108	1914	324	709	22.6	6.0	23.6
Zn_{40}	2.037	0.164	1.275	0.475	0.109	1908	399	793	24.8	5.9	19.9
Zn_{60}	1.849	0.168	1.300	0.420	0.089	1738	303	764	25.3	4.8	22.3
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	16.22	16.22	13.44	23.06	29.12	15.55	32.44	25.21	35.00	30.62	29.47

NS - Not significant

At boot leaf stage also, the influence of silicate application on the Mn content was confined to 250 kg ha^{-1}. Manganese content increased from 597 ppm to 873 ppm with 250 kg ha^{-1} and then declined to 647 ppm at 750 kg ha^{-1} level of application.

Application of graded levels of Zn had improved only the Mn content of the leaf and the effect was confined to only the PI stage. Application of Zn @ 20 kg ha^{-1} increased the Mn content by 36.7 per cent. Further increases in Zn levels were ineffective to modify even the Mn content of the leaf.

4.6.3.4 Composition of grain and straw

Data on the elemental composition of grain and straw are presented in Table 4.6.3d. It can be seen that effect of SiO_2 on modifying the S content of the grain alone was significant. Application of SiO_2 at 250 kg ha^{-1} reduced the sulphur content by 7.8 per cent over control. The data also showed that this effect vanished when the level of sodium silicate was raised from 500 to 750 kg ha^{-1}. Silicate application did not influence the elemental composition of straw.

Data presented in Table 4.6.3d showed that application of Zn significantly influenced only the SiO_2 content of grain. Grain content of SiO_2 tended to decline with increasing levels of Zn application and the decline was significant at 40 kg ha^{-1} level of application. Beyond 40 kg ha^{-1} level Zn was not effective in modifying the SiO_2 content of grain.

Zinc did not have any influence in modifying the elemental composition of straw.

4.6.4 Interaction effect of zinc and silica on elemental composition

4.6.4.1 Composition of root at MT and PI stage

Data on the combined effect of SiO_2 and Zn on the elemental composition of root is presented in Table 4.6.4. The data showed that the effect was different in different elements.

Table 4.6.3d Effect of silica and zinc on nutrient content of grain and straw

Treatment	Grain										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	S_iO_2 (%)
Silica											
Si_0	1.129	0.252	0.281	0.009	0.058	1380	131	50	24	4.1	15.9
Si_{250}	1.194	0.252	0.275	0.008	0.057	1272	136	51	24	4.5	13.4
Si_{500}	1.247	0.247	0.250	0.009	0.056	1268	141	49	23	3.9	14.6
Si_{750}	1.71	0.252	0.275	0.009	0.053	1366	133	47	25	3.9	12.9
CD (0.05)	NS	NS	NS	NS	NS	73.66	NS	NS	NS	NS	NS
Zinc											
Zn_0	1.182	0.255	0.269	0.008	0.056	1323	123	45	23	4.1	16.1
Zn_{20}	1.182	0.247	0.281	0.009	0.058	1299	132	52	24	3.8	13.0
Zn_{40}	1.062	0.250	0.256	0.008	0.057	1355	134	49	25	4.6	12.0
Zn_{60}	1.314	0.252	0.275	0.009	0.054	1307	151	52	23	3.9	15.7
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	3.35
CV (%)	23.33	6.58	23.74	15.56	9.15	5.23	27.78	27.71	9.53	30.23	22.15

NS - Not significant

Table 4.6.3d contd....

Treatment	Straw										
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	SiO_2 (%)
Silica											
Si_0	0.789	0.156	1.894	0.228	0.087	1581	1434	867	129	3.9	24.0
Si_{250}	0.842	0.148	1.750	0.292	0.092	1552	1082	1022	94	4.0	26.0
Si_{500}	0.756	0.150	1.644	0.257	0.090	1503	1316	943	175	4.1	26.3
Si_{750}	0.766	0.151	1.531	0.274	0.090	1457	1090	895	126	4.0	24.1
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc											
Zn_0	0.809	0.151	1.731	0.241	0.084	1502	1292	810	76	4.1	27.5
Zn_{20}	0.766	0.140	1.756	0.300	0.097	1548	1149	899	157	3.8	24.8
Zn_{40}	0.811	0.149	1.638	0.266	0.088	1511	1167	1078	149	3.9	25.5
Zn_{60}	0.767	0.161	1.694	0.243	0.089	1532	1312	940	142	4.3	22.7
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	20.16	21.74	24.7	31.2	20.82	12.34	36.6	26.38	60.82	21.29	19.97

NS - Not significant

Table 4.6.4 Interaction effect of silica and zinc on elemental composition of root

Zinc level	P (%) at MT				Fe (ppm) at MT				Mn (ppm) at MT			
	Zn_0	Zn_{20}	Zn_{40}	Zn_{60}	Zn_0	Zn_{20}	Zn_{40}	Zn_{60}	Zn_0	Zn_{20}	Zn_{40}	Zn_{60}
Silica levels												
SiO_2 0	0.230	0.190	0.165	0.190	39363	55625	60050	69150	167	237	200	300
SiO_2 250	0.180	0.160	0.205	0.185	58988	58375	61700	62875	247	127	448	268
SiO_2 500	0.170	0.185	0.210	0.215	53075	65500	68275	55175	179	280	237	148
SiO_2 750	0.215	0.190	0.235	0.210	57625	64375	67900	65475	235	263	270	260
CD (0.05)	0.037				8073.9				123.6			

Table 4.6.4 contd...

Zinc level	Zn (ppm) at MT				Cu (ppm) at MT				Zn (ppm) at PI			
	Zn_0	Zn_{20}	Zn_{40}	Zn_{60}	Zn_0	Zn_{20}	Zn_{40}	Zn_{60}	Zn_0	Zn_{20}	Zn_{40}	Zn_{60}
Silica levels												
SiO_2 0	49.5	57.0	74.5	103.0	10.5	13.0	16.0	18.0	60.0	142.0	225.0	223.0
SiO_2 250	57.5	49.0	102.5	85.5	15.0	12.5	21.0	13.5	47.5	115.5	230.0	345.0
SiO_2 500	47.0	102.5	113.0	107.8	14.5	17.0	12.0	8.5	43.0	63.0	124.5	359.0
SiO_2 750	91.5	60.0	83.0	82.0	10.5	10.5	11.5	12.5	51.5	89.5	136.5	619.0
CD (0.05)	17.52				5.167				118.5			

MT - Maximum tillering PI - Panicle initiation NS - Not significant

Thus the highest content of P in the root at MT stage was recorded due to the combined effect of 750 kg ha^{-1} SiO_2 and 40 kg Zn ha^{-1} and the lowest value of P was recorded at 250 kg ha-1 SiO_2 as sodium silicate and 20 kg Zn ha^{-1} as zinc sulphate. The difference worked out to 31.9 per cent.

Application of Zn @ 60 kg ha^{-1} level, without any sodium silicate increased the Fe content of root from 39363 ppm to 69150 ppm while SiO_2 @ 250 kg ha^{-1} in the absence of Zn increased it from 39363 to 58938 ppm. Both the increases were statistically significant. Silica @ 500 kg ha^{-1} as sodium silicate and Zn @ 40 kg ha^{-1} as zinc sulphate recorded the second highest value of 68275 ppm Fe in the root.

The highest Mn content of the root was recorded due to the combined application of 250 kg ha^{-1} silica and 40 kg ha^{-1} Zn. The lowest Mn content of root was recorded by the combined effect of 250 kg ha^{-1} silica and 20 kg ha^{-1} Zn as zinc sulphate.

Combined application of 500 kg ha^{-1} SiO_2 and 40 kg ha^{-1} Zn gave the highest root content of Zn at MT stage which was significantly superior to the combination of lower and higher levels among the chemicals.

Application of Zn @ 60 kg ha^{-1} and SiO_2 @ 500 kg ha^{-1} gave the lowest content of Cu in the root at MT which was lower than the contents registered due to their individual application. Thus the lowest content of 8.5 ppm was recorded at S_{500} Zn_{60} as against 15 ppm at 250 kg ha^{-1} of SiO_2 and 18 ppm at 60 kg ha^{-1} of Zn. The highest content of 21 ppm of Cu was recorded at 250 kg ha^{-1} silica and 40 kg ha^{-1} Zn.

However at PI stage, combined application of SiO_2 and Zn significantly influenced only the Zn content of the root, while application of Zn @ 40 kg ha^{-1} increased the Zn content of the root from 60 to 223 ppm only in the absence of silica which by itself did not have any effect of its own. At a combined application of silica @ 750 kg ha^{-1} and Zn @ 60 kg ha^{-1}, the root content recorded a Zn content of 619 ppm which was 177.6 per cent more than singular application of Zn @ 60 kg ha^{-1}.

Combined application of SiO_2 and Zn did not have any significant influence on the elemental composition of shoot at MT, culm at PI, leaf at PI, boot leaf or of grain.

4.6.5 Effect of silica and zinc on nutrient uptake

Data on the main effect of SiO_2 and Zn on the nutrient uptake are presented in Table 4.6.5. From the data it can be seen that both the elements failed to significantly influence the uptake of any element in the grain or straw.

Combined effect of these elements also failed to influence the total content of any element either in grain or in straw.

4.6.6 Influence of silica and zinc on nutrient ratios

4.6.6.1 Nutrient ratios of shoot at MT

The data on nutrient ratios of shoot at MT stage are presented in Table 4.6.6a.

The data showed that application of Zn significantly influenced the P/Zn, K/Zn and S/Zn ratio of the shoot and these ratios get narrowed by increasing the levels from zero to 60 kg ha^{-1}. Different levels of SiO_2 did not have any significant effect on nutrient ratios.

4.6.6.2 Nutrient ratios of leaf at PI

At PI stage, application of SiO_2 had a significant effect on modifying the nutrient ratios of leaf. Increasing levels of SiO_2 resulted in a narrow P/K ratio but the ratios K/S, K/Fe, K/Mn, S/Mn and P/Mn widened by SiO_2 application (Table 4.6.6b).

Application of SiO_2 failed to modify the nutrient ratios of leaf at PI stages.

Table 4.6.5 Effect of silica and zinc on nutrient uptake by grain and straw

Treatment	Grain (kg ha^{-1})										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	S_iO_2
Silica											
Si_0	62.04	13.73	15.47	0.509	3.16	7.53	0.692	0.272	0.129	0.023	869.60
Si_{250}	74.09	15.65	17.21	0.501	3.53	7.65	0.851	0.313	0.147	0.028	803.42
Si_{500}	72.28	14.29	14.41	0.497	3.28	7.32	0.823	0.287	0.133	0.023	847.28
Si_{750}	66.67	14.31	15.70	0.492	3.01	7.76	0.635	0.268	0.139	0.022	733.59
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc											
Zn_0	70.63	15.28	16.05	0.507	3.38	7.95	0.744	0.272	0.141	0.026	930.27
Zn_{20}	65.96	13.83	16.04	0.501	3.25	7.23	0.740	0.290	0.135	0.021	731.26
Zn_{40}	60.77	14.23	14.57	0.468	3.24	7.70	0.766	0.278	0.140	0.027	679.97
Zn_{60}	77.71	14.64	16.13	0.523	3.11	7.38	0.752	0.300	0.132	0.023	912.40
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	31.41	13.44	31.78	22.15	18.37	14.48	32.18	34.55	11.55	33.50	28.97

NS - Not significant

Table 4.6.5 contd....

Treatment	Straw (kg ha^{-1})										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	S_iO_2
Silica											
Si_0	35.18	6.98	85.38	10.40	3.82	7.05	6.13	3.96	0.708	0.019	1054.44
Si_{250}	41.17	6.99	84.78	13.71	4.41	7.42	5.16	4.13	0.436	0.019	1287.59
Si_{500}	36.05	6.82	76.57	12.22	4.22	7.05	6.10	4.48	0.814	0.019	1243.72
Si_{750}	32.83	6.61	78.55	10.74	3.97	6.32	4.90	3.89	0.550	0.018	1058.24
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc											
Zn_0	40.58	7.52	92.32	12.17	4.16	7.38	6.48	3.83	0.387	0.020	1381.83
Zn_{20}	36.33	6.26	82.04	13.92	4.56	7.28	5.26	3.73	0.725	0.019	1165.11
Zn_{40}	33.64	6.19	73.72	10.84	3.63	6.30	4.82	4.66	0.780	0.016	1068.80
Zn_{60}	34.69	7.44	77.19	10.13	4.07	6.90	5.73	4.24	0.616	0.019	1028.24
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	22.09	29.75	22.40	36.43	21.44	13.15	33.23	24.74	64.48	17.12	24.62

NS - Not significant

Table 4.6.6a. Nutrient ratios of rice shoot at MT as influenced by Silica and Zinc

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca
Silica																		
Si_0	7.2	0.89	15.0	22.5	12.5	11.0	69.1	618	3047	0.13	2.13	3.2	1.26	1.5	9.7	86.9	427	17.3
Si_{250}	6.7	0.88	16.2	20.0	11.7	9.6	68.5	620	2883	0.13	2.38	3.0	1.26	1.4	10.1	92.9	4.31	18.4
Si_{500}	5.6	0.75	10.3	17.3	10.4	9.9	54.4	503	2349	0.13	1.83	3.0	1.31	1.8	9.9	89.2	416	14.1
Si_{750}	6.6	0.89	19.0	24.2	12.8	11.6	86.6	683	3445	0.13	2.78	3.7	1.47	1.7	12.3	99.3	503	20.4
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc																		
Zn_0	6.1	0.84	15.8	20.5	11.0	9.5	68.9	704	3110	0.14	2.47	3.4	1.45	1.5	11.0	109	429	18.3
Zn_{20}	6.6	0.83.	14.0	17.9	11.3	10.9	80.6	623	2993	0.13	2.07	2.7	1.31	1.6	11.7	95	453	16.7
Zn_{40}	6.4	0.81	13.5	19.1	11.4	9.1	57.0	522	2546	0.13	2.12	3.0	1.26	1.4	8.9	82	402	16.9
Zn_{60}	7.0	0.93	17.2	26.5	13.7	12.2	72.3	576	3076	0.13	2.47	3.8	1.28	1.8	10.5	82	442	18.4
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	20.9	NS	NS
CV (%)	16.14	23.7	51.1	39.7	18.96	45.4	48.4	33.9	38.0	14.8	39.2	393	19.1	33.95	33.0	21.4	27.5	36.2

NS - Not significant

Table 4.6.6a contd...

	K/Mg	K/S	K/Fe	K/Mn	K/Zn	K/Cu	S/Fe	S/Mn	S/Cu	Mn/Fe	Mn/Zn	Ca+Mg / K	Ca+Mg+Fe / P+K+S	Ca+Mg+Fe+k / P+S	Ca+Mg+Fe+K / N+P+S
Silica															
Si_0	25.6	10.1	11.8	78.5	699	3430	1.20	7.8	69.7	0.16	9.2	0.106	0.166	5.14	1.09
Si_{250}	22.7	9.7	11.1	77.7	718	3295	1.14	8.1	74.1	0.15	9.5	0.107	0.167	5.2	1.11
Si_{500}	23.1	10.1	13.9	77.6	687	3207	1.34	7.6	68.6	0.18	9.9	0.118	0.164	5.2	1.27
Si_{750}	29.2	10.9	12.6	92.6	738	3708	1.17	8.5	65.9	0.15	8.7	0.094	0.145	5.2	1.12
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc															
Zn_0	25.5	10.7	10.9	82.2	800	3486	1.03	7.7	74.5	0.15	10.2	0.107	0.170	5.3	1.19
Zn_{20}	21.6	10.4	13.2	95.1	761	3648	1.25	9.0	73.1	0.15	9.1	0.112	0.159	5.4	1.17
Zn_{40}	23.6	9.9	11.6	70.7	651	3158	1.15	7.1	65.6	0.16	9.5	0.108	0.167	5.3	1.18
Zn_{60}	30.0	9.7	13.7	78.4	631	3151	1.41	8.2	65.2	0.18	8.3	0.099	0.147	5.0	
CD (0.05)	NS	NS	NS	NS	112.0	NS	NS	NS	7.9	NS	NS	NS	NS	NS	NS
CV (%)	50.8	12.5	32.8	32.8	14.9	19.4	33.0	29.4	10.7	32.7	23.7	20.8	18.7	9.7	18.12

NS - Not significant

Table 4.6.6b Nutrient ratios of rice leaf at PI as influenced by Silica and Zinc

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca
Silica																		
Si$_0$	6.2	0.86	3.02	12.9	8.4	18.0	20.3	498	2742	0.14	0.48	1.99	1.38	2.92	3.2	81.9	448	3.5
Si$_{250}$	7.7	1.07	3.25	11.8	9.3	18.7	14.8	593	3042	0.14	0.42	1.54	1.21	2.3	1.9	75.6	402	3.1
Si$_{500}$	7.7	1.46	3.38	12.4	9.1	18.7	16.5	630	3135	0.18	0.50	1.75	1.23	2.5	2.3	86.3	429	3.1
Si$_{750}$	6.8	1.13	2.51	12.9	8.2	14.5	14.2	560	2670	0.17	0.39	1.89	1.21	2.1	2.1	83.9	403	2.4
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.83	NS	NS	NS	NS	0.95	NS	NS	NS
Zinc																		
Zn$_0$	6.8	1.12	3.2	11.7	8.7	16.7	19.3	655	2870	0.16	0.47	1.76	1.30	2.6	3.0	96.3	437	3.2
Zn$_{20}$	6.4	1.05	3.0	11.0	8.5	14.2	13.4	548	2623	0.16	0.49	1.83	1.36	2.2	2.2	87.7	431	3.2
Zn$_{40}$	7.3	1.15	3.1	12.7	8.9	18.3	16.1	574	3018	0.16	0.43	1.76	1.22	2.5	2.3	79.8	418	3.0
Zn$_{60}$	7.9	1.20	2.9	13.5	9.0	20.7	17.1	503	3079	0.15	0.40	1.82	1.15	2.6	2.2	64.2	397	2.7
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	28.2	36.3	31.1	25.2	24.8	35.9	32.5	30.7	23.6	16.4	33.8	32.6	18.11	27.6	36.9	28.8	28.2	33.3

NS - Not significant

Table 4.6.6.b contd.....

	K/Mg	K/S	K/Fe	K/Mn	K/Zn	K/Cu	S/Fe	S/Mn	S/Cu	Mn/Fe	Mn/Zn	Ca+Mg	Ca+Mg+Fe	Ca+Mg+Fe+k	Ca+Mg+Fe+K
												K	P+K+S	P+S	N+P+S
Silica															
Si$_0$	13.9	9.3	20.9	23.7	577	3216	2.2	2.5	58.9	0.9	26.6	0.41	0.35	5.9	1.3
Si$_{250}$	11.3	8.9	16.8	13.9	560	2937	1.9	1.6	63.1	1.3	42.1	0.52	0.42	6.1	1.23
Si$_{500}$	10.3	7.1	14.1	13.2	997	2493	2.0	1.9	69.8	1.2	40.1	0.70	0.52	5.1	1.02
Si$_{750}$	11.9	7.4	13.0	13.1	503	2452	1.8	1.8	70.5	1.1	40.1	0.67	0.51	5.5	1.18
CD (0.05)	NS	1.7	4.95	6.67	NS	NS	NS	0.61	NS	NS	NS	NS	NS	0.62	NS
Zinc															
Zn$_0$	13.3	8.4	16.9	19.3	619	2830	2.0	2.4	75.0	0.9	36.4	0.50	0.47	5.6	1.20
Zn$_{20}$	11.7	8.8	14.0	14.1	555	2764	1.6	1.6	64.5	1.09	42.4	0.49	0.43	5.7	1.26
Zn$_{40}$	11.8	8.2	16.6	15.6	526	2766	2.1	1.9	66.7	1.3	40.4	0.53	0.45	5.6	1.15
Zn$_{60}$	12.5	7.8	17.4	14.9	437	2689	2.3	1.9	55.0	1.2	30.1	0.54	0.46	5.7	1.14
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	28.9	19.3	28.7	38.5	29.9	29.9	25.3	30.2	24.2	38.6	34.9	41.3	33.2	10.4	20.3

NS - Not significant

4.6.6.3 Nutrient ratios of boot leaf

The data presented in Table 4.6.6c. showed that the modifying influences of SiO_2 and Zn application observed at MT and PI stages were not obtained at boot leaf stage. Application of SiO_2 or Zn did not show any significant effect on the nutrient ratios at boot leaf stage.

4.6.7 Correlation of growth characters and nutrients with yield of rice

Interrelation between weed dry weight, SiO_2 uptake and SiO_2 and Zn content of different parts of rice with yield are presented in Table 4.6.7.

Correlation between weed dry weight and yield of rice showed a negative relationship with grain yield, straw yield and total biomass and the relation with straw yield was statistically significant. Uptake of SiO_2 by grain, straw and total biomass were also negatively related with grain yield.

The interrelations of SiO_2 content of different parts of rice with yield of rice showed a negative correlation with Zn content of shoot at MT, leaf at PI, boot leaf and grain with grain yield, straw yield and total biomass.

A significant positive correlation was obtained between root and shoot SiO_2 contents with straw and total biomass yield. The relation with grain yield was positive though the relationship was not statistically significant.

Silica content of root at MT and culm at PI were positively and significantly correlated with total biomass production.

4.7 EXPERIMENT VII

The experiment entitled "yield maximisation trial" studied the direct and interactive influences of K, Ca, S and Sio_2, the treatments found to be superior in various experiments, under continuous submergence and irrigation at three days after disappearance of ponded water on improving the productivity of rice in lateritic alluvium.

Table 4.6.6.c Nutrient ratios of boot leaf as influenced by Silica and Zinc

	N/P	N/K	N/Ca	N/Mg	N/S	N/Fe	N/Mn	N/Zn	N/Cu	P/K	P/Ca	P/Mg	P/S	P/Fe	P/Mn	P/Zn	P/Cu	K/Ca
Silica																		
Si_0	10.6	1.51	4.7	22.7	10.5	53.5	35.2	868	3275	0.15	0.44	2.1	1.0	5.05	3.4	85.0	315	3.1
Si_{250}	11.4	1.54	4.6	20.9	10.4	67.0	22.3	881	3433	0.14	0.41	2.0	0.96	6.03	2.1	81.7	318	3.0
Si_{500}	11.8	1.66	4.1	18.8	10.1	63.9	31.2	909	3381	0.15	0.36	1.7	0.89	5.50	2.9	82.0	307	2.5
Si_{750}	10.6	1.40	4.7	20.1	10.8	62.4	25.1	905	4082	0.13	0.44	1.9	1.01	5.8	2.9	87.2	386	3.4
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc																		
Zn_0	10.1	1.48	4.7	21.2	10.1	60.2	36.4	989	3396	0.15	0.46	2.1	1.02	5.92	3.7	101.6	336	3.1
Zn_{20}	10.0	1.53	4.2	18.0	10.0	61.0	30.3	880	3127	0.15	0.41	1.8	1.0	6.07	3.0	89.3	311	2.7
Zn_{40}	12.9	1.65	4.4	19.8	10.7	56.7	27.9	859	3503	0.13	0.36	1.6	0.88	4.38	2.3	71.0	286	2.7
Zn_{60}	11.4	1.46	4.8	23.5	11.0	68.6	25.1	834	4146	0.13	0.43	2.2	0.99	6.00	2.3	73.9	392	3.3
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	28.0	21.9	43.0	43.8	30.4	47.7	38.9	31.5	23.6	NS	35.8	30.8	28.3	39.9	45.0	36.0	30.4	35.1

NS - Not significant

Table 4.6.6c contd.....

	K/Mg	K/S	K/Fe	K/Mn	K/Zn	K/Cu	S/Fe	S/Mn	S/Cu	Mn/Fe	Mn/Zn	$\frac{Ca+Mg}{K}$	$\frac{Ca+Mg+Fe}{P+K+S}$	$\frac{Ca+Mg+Fe+k}{P+S}$	$\frac{Ca+Mg+Fe+K}{N+P+S}$
Silica															
Si_0	15.1	7.1	35.0	24.0	585	2270	4.9	3.3	70.5	1.58	25.9	0.43	0.35	5.03	0.83
Si_{250}	13.9	6.8	43.8	14.5	584	2283	6.3	2.2	77.0	3.11	40.3	0.45	0.36	5.05	0.82
Si_{500}	11.5	6.0	38.7	18.9	552	2040	6.3	3.3	80.9	2.44	35.4	0.51	0.41	5.0	0.78
Si_{750}	14.9	7.8	43.5	22.3	668	3013	5.6	3.0	82.7	2.07	32.2	0.40	0.33	5.46	0.89
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc															
Zn_0	14.3	6.8	40.0	24.4	685	2304	5.7	3.9	89.2	1.86	31.5	0.43	0.35	4.9	0.84
Zn_{20}	11.9	6.6	40.0	19.6	590	2053	6.1	2.9	82.8	2.24	32.7	0.49	0.39	4.9	0.84
Zn_{40}	12.6	6.8	34.2	17.9	551	2223	5.2	2.7	77.5	2.26	34.6	0.47	0.39	5.3	0.80
Zn_{60}	16.6	7.7	46.9	17.9	564	3026	6.1	2.4	60.8	2.84	35.1	0.40	0.31	5.4	0.86
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	39.4	23.5	39.8	40.7	32.5	31.0	22.5	43.3	27.8	47.2	40.4	26.1	23.7	11.1	12.3

NS - Not significant

Table 4.6.7 Correlation coefficient of weed dry weight, silica uptake, silica and zinc content with yield of rice

Characters	Grain yield	Straw yield	Total biomass
Weed dry weight	-0.052	-0.352*	-0.260*
Silica uptake of grain	-0.177	-0.100	0.148
Silica uptake of straw	0.123	0.106	-0.032
Total silica uptake	-0.004	0.025	0.093
Zinc content			
Root at Mt	0.029	0.185	0.107
Shoot at MT	-0.095	-0.044	-0.098
Root at PI	0.030	-0.018	-0.036
Culm at PI	0.156	0.134	-0.060
Leaf at PI	-0.116	0.159	0.013
Boot leaf	-0.319	-0.159	-0.195
Grain	-0.212	-0.074	-0.10
Straw	0.294	-0.045	0.405**
Silica content			
Root at MT	0.180	0.346	0.186
Shoot at MT	0.040	0.458**	0.023
Root at PI	-0.129	-0.019	-0.368*
Culm at PI	0.336*	0.231	0.002
Leaf at PI	0.129	-0.002	0.265
Boot leaf	0.211	0.126	0.308
Grain	0.127	0.127	0.103
Straw	-0.089	-0.060	0.053

4.7.1 Main effects of K, Ca, S and Sio_2 on growth attributes, physiological attributes and yield attributes and yield of rice under continuous submergence

4.7.1.1 Main effects of treatments on morphophysiological and yield characters data are presented in Table 4.7.1a.

a. Growth attributes

Data showed that Potassium applied at 120 kg ha^{-1} significantly increased the height of plants at flowering stage and harvest and tiller count at flowering and the increases were 5.2, 4.8 and 16.9 per cent over control.

Sulphur at 100 kg ha^{-1} significantly decreased the shoot-root ratio only and the decrease was 11.8 per cent.

Silica applied at 250 kg ha^{-1} significantly reduced the tiller counts at flag leaf stage by 13.5 per cent.

b. Physiological attributes

Potassium applied at 120 kg ha^{-1} significantly reduced the chlorophyll `a', `b' and total chlorophyll as well as leaf sap pH of boot leaf and the respective reduction worked out to 20.7, 14.6, 17.1 and 1.5 per cent (Table 4.7.1b).

Sulphur applied at 100 kg ha^{-1} also significantly reduced the chlorophyll `a', `b' and total chlorophyll as well as sap pH of boot leaf by 12.4, 13.4, 10.4 and 1.1 per cent over control.

Calcium applied as lime at 150 kg ha^{-1} reduced chlorophyll `b', total chlorophyll at PI stage and leaf sap pH at MT stage and the reductions were 12.4, 7.8 and 0.6 per cent respectively.

Application of Sio_2 at 250 kg ha^{-1} reduced the total chlorophyll at MT stage by 11.2 per cent. Chlorophyll `b' and total chlorophyll of the boot leaf were also reduced by 9.7 and 9.6 per cent.

Table 4.7.1a Effect of K, S, Ca and Silica on growth attributes of rice under continuous submergence

Continuous submergence	Plant height (cm)				Tillers/hill				Plant dry weight (g plant^{-1})											
									MT				PI				Flg			
	MT	PI	Flg	Harvest	MT	PI	Flg	Harvest	Shoot	Root	Total	S/R	Shoot	Root	Total	S/R	Shoot	Root	Total	S/R
Potassium																				
K_0	41.0	56.9	65.6	65.1	6.99	7.5	7.7	7.9	8.42	2.21	11.25	4.34	19.27	2.53	21.73	7.94	21.39	2.52	23.88	8.85
K_{12}	41.9	58.9	69.0	68.2	6.56	8.0	9.0	8.7	9.89	2.07	11.96	4.89	17.67	2.40	20.07	7.60	19.78	2.53	22.21	8.07
CD (0.05)	NS	NS	2.53	1.78	NS	NS	1.13	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sulphur																				
S_0	41.8	56.9	67.0	66.2	7.06	7.6	8.2	8.3	8.7	2.06	11.36	4.79	18.57	2.33	20.9	8.20	20.70	2.52	23.12	8.75
S_{100}	41.1	58.8	67.6	67.2	6.49	7.9	8.5	8.3	9.6	2.23	11.86	4.44	18.36	2.60	20.9	7.30	20.41	2.53	22.97	8.17
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.06	NS	NS	NS	NS
Calcium																				
L_0	41.3	58.2	67.7	66.7	7.13	7.9	8.3	8.0	8.7	2.09	11.40	4.60	19.50	2.57	22.08	7.95	20.74	2.38	23.12	8.94
L_{150}	41.6	57.5	66.9	66.7	6.43	7.6	8.4	8.6	9.6	2.21	11.81	4.64	17.43	2.36	19.73	7.58	20.37	2.67	22.97	7.98
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Silica																				
Si_0	41.3	58.7	67.4	66.9	6.7	8.2	8.9	8.5	9.3	2.06	11.35	4.67	18.35	2.32	20.62	8.11	20.92	2.47	23.39	8.88
Si_{250}	41.6	57.0	67.2	66.5	6.9	7.3	7.7	8.2	9.0	2.23	11.86	4.56	18.58	2.60	21.19	7.43	20.19	2.58	22.70	8.03
CD (0.05)	NS	NS	NS	NS	NS	NS	1.13	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	5.27	5.18	4.99	3.19	16.84	18.24	18.04	18.14	25.27	30.94	21.39	19.69	20.55	27.97	20.7	18.24	25.12	26.23	23.92	25.37

K - Levels of K (0 and 120 kg ha^{-1}) S - Levels of S (0 and 100 kg ha^{-1}) L - Levels of Ca (0 and 150 kg lime ha^{-1}) S_i - Levels of Silica (0 and 250 kg ha^{-1}) NS - Not significant

Table 4.7.1b Effect of K, S, L and Silica on physiologic attributes of rice under continuous submergence

	Physiologic attributes											
	Chlorophyll (mg/g fresh sample weight)									Leaf sap pH		
	MT			PI			Boot leaf					
	Chl.'a'	Chl.'b'	Total Chl.	Chl.'a'	Chl.'b'	Total Chl.	Chl.'a'	Chl.'b'	Total Chl.	MT	PI	Boot leaf
Potassium												
K_0	1.604	0.538	1.996	1.458	0.377	2.048	1.008	0.383	1.359	6.208	6.213	6.12
K_{120}	1.505	0.584	1.770	1.585	0.327	2.168	0.799	0.327	1.27	6.215	6.247	6.03
CD (0.05)	NS	NS	0.210	NS	NS	NS	0.071	0.024	0.041	NS	NS	0.048
Sulphur												
S_0	1.544	0.578	1.842	1.523	0.363	2.153	0.965	0.381	1.311	6.215	6.239	6.11
S_{100}	1.565	0.544	1.924	1.521	0.341	2.063	0.842	0.330	1.175	6.208	6.220	6.04
CD (0.05)	NS	NS	NS	NS	NS	NS	0.071	0.024	0.041	NS	NS	0.048
Calcium												
L_0	1.57	0.561	1.851	1.510	0.345	2.109	0.911	0.379	1.292	6.229	6.239	6.08
L_{150}	1.54	0.561	1.915	1.530	0.359	2.107	0.896	0.332	1.194	6.194	6.220	6.08
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	0.024	0.041	0.024	NS	NS
Silica												
Si_0	1.611	0.539	1.995	1.490	0.368	2.043	0.931	0.373	1.306	6.205	6.229	6.07
Si_{250}	1.498	0.583	1.771	1.554	0.336	2.173	0.876	0.337	1.180	6.218	6.231	6.08
CD (0.05)	NS	NS	0.210	NS	NS	NS	NS	0.024	0.041	NS	NS	NS
CD (%)	13.16	14.47	14.80	14.16	23.86	12.97	10.78	6.32	4.35	0.42	1.18	0.98

K - Levels of K (0 and 120 kg ha^{-1})
S - Levels of S (0 and 100 kg ha^{-1})
L - Levels of Ca (0 and 150 kg lime ha^{-1})
S_1 - Levels of Silica (0 and 250 kg ha^{-1})
NS - Not significant

c. Yield attributes and yield

None of the main effects affected any yield attribute (Table 4.7.1c).

Potassium applied at 120 kg ha^{-1} increased the grain and total biomass yield by 5.0 and 5.4 per cent and the increases were statistically significant(Fig.4.7.1.)

Main effects of S, Ca and Sio_2 were not statistically significant.

4.7.1.2 Third order interaction effects of K, Ca, S and Sio_2 on growth attributes, physiological attributes and yield attributes and yield of rice

Significant effects of K, Ca, S and Sio_2 observed are presented in Table 4.7.1.2.

The treatment combination $K_{120}S_{100}L_{150}Si_0$ gave the maximum height of 72.3 cm at harvest followed by 70.1 cm in $K_{120}S_0L_{150}Si_{250}$ and they were on par. All other treatment combinations were inferior to these two.

Maximum chlorophyll `b' content of 0.646 mg/g at Mt stage was recorded by the combination $K_{120}S_0L_0Si_{250}$ followed by $K_{120}S_0L_{150}Si_{250}$ combination. The lowest chlorophyll `b' was recorded by $K_0S_{100}L_0Si_0$ and the difference was significant.

Maximum chlorophyll `b' content in the boot leaf was observed in $K_0S_0L_0Si_0$ and the lowest in $K_{120}S_0L_0Si_0$ combination and the significant difference worked out to 113.7 per cent.

Highest total chlorophyll content of the boot leaf of 1.697 mg/g of fresh leaf was observed in $K_0S_0L_0Si_0$ and the lowest in $K_{120}S_0L_{150}Si_{250}$ and the difference worked out to 89.0 per cent. It was also observed that in the absence of K, combining S and Sio_2 significantly reduced the total chlorophyll content whereas in the presence of K combining Ca and Sio_2 significantly reduced it.

A perusal of the data on leaf sap pH showed that combining Sio_2 with K, Ca and S had a general tendency to increase leaf sap pH. Lowest sap pH of 5.84 and the highest sap pH of 6.205 were recorded in $K_{120}S_{100}L_0Si_{250}$ and $K_0S_{100}L_0Si_{250}$ respectively.

ble 4.7.1c Effect of K, Ca, S and Silica on yield attributes and yield of rice under continuous submergence

	Yield attributes and yield							Yield (kg/ha^{-1})			
	Panicles/ hill	Panicle weight (g/10 panicle)	Panicle length (cm)	Branches/ panicle (Nos.)	Filled grains/ Panicle (Nos.)	Unfilled grins/ panicle (Nos.)	1000 grain weight (g)	Grain	Straw	Total biomass	Grain straw
otassium											
$_0$	7.5	19.0	17.3	7.6	59.2	15.1	27.6	5063	3896	8959	1.3
$_{120}$	8.4	18.2	17.2	7.6	60.2	14.4	28.0	5314	4133	9445	1.3
D (0.05)	NS	NS	NS	NS	NS	NS	NS	247.2	NS	429.2	NS
ulphur											
S_0	7.5	18.4	17.3	7.6	58.0	15.8	27.6	5158	3956	9114	1.31
S_{100}	8.4	18.8	17.3	7.6	61.3	13.8	28.0	5219	4071	9290	1.29
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Calcium											
L_0	8.0	18.4	17.1	7.5	57.9	14.0	27.9	5144	3975	9119	1.3
L_{150}	8.0	18.8	17.4	7.7	61.5	15.6	27.8	5232	4053	9286	1.3
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Silica											
Si_0	7.9	18.6	17.3	7.6	59.8	13.5	27.6	5256	4033	9289	1.3
Si_{250}	8.0	18.6	17.3	7.6	59.7	16.1	28.0	5120	3996	9116	1.29
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CD (%)	25.33	7.42	3.94	8.12	11.81	26.15	3.88	6.32	8.57	6.19	8.19

- Levels of K (0 and 120 kg ha^{-1}) S - Levels of S (0 and 100 kg ha^{-1}) L - Levels of Ca (0 and 150 kg lime ha^{-1})

$_1$ - Levels of Silica (0 and 250 kg ha^{-1}) NS - Not significant

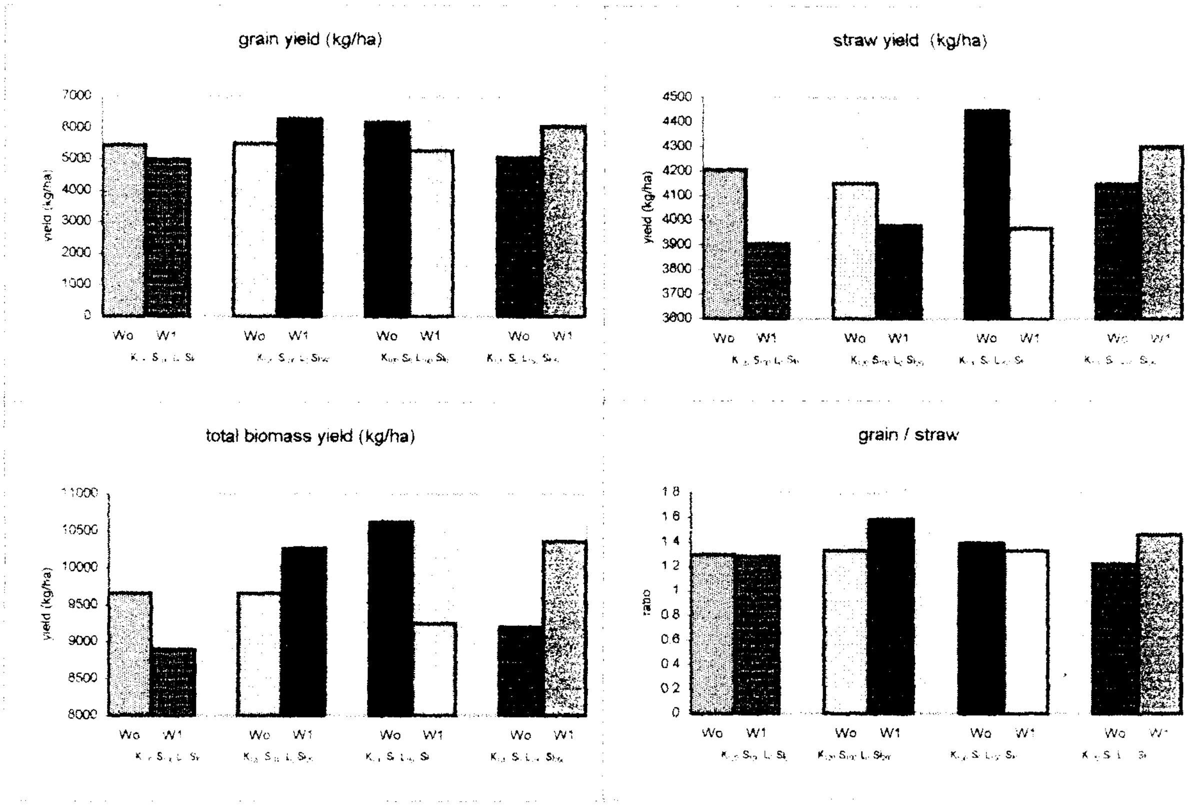


Fig. 4.7.1 Effect of K, Ca, S and Si on grain, straw and total biomass yield and grain / straw under continuous submergence W_0 and 3 DAPAW (W_1)

Table 4.7.1.2 Third order interaction effects of K, S, Ca and Silica on growth attributes, physiologic attributes and yield of rice under continuous submergence

K x S x La x Silica interaction

	Height at harvest (cm)		Chl.`b' at MT		Chl. `b' boot leaf		Total Chl. boot leaf		Leaf sap pH boot leaf	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
$K_0\ S_0\ L_0$	62.9	66.6	0.607	0.529	0.592	0.429	1.697	1.442	5.965	6.180
$K_0\ S_0\ L_{150}$	65.0	63.8	0.569	0.533	0.340	0.362	1.350	1.282	6.125	6.090
$K_0\ S_{100}\ L_0$	66.7	65.6	0.371	0.607	0.433	0.292	1.713	1.095	6.200	6.205
$K_0\ S_{100}\ L_{150}$	64.6	65.7	0.555	0.532	0.295	0.319	1.092	1.199	6.055	6.140
$K_{120}\ S_0\ L_0$	68.4	66.2	0.521	0.646	0.277	0.345	0.975	1.317	6.140	6.140
$K_{120}\ S_0\ L_{150}$	66.4	70.1	0.597	0.624	0.413	0.287	1.522	0.898	6.175	6.085
$K_{120}\ S_{100}\ L_0$	68.7	68.2	0.611	0.597	0.322	0.339	1.025	1.068	5.940	5.840
$K_{120}\ S_{100}\ L_{150}$	72.3	65.6	0.480	0.598	0.314	0.322	1.074	1.137	5.940	5.995
CD (0.05)	2.54		0.178		0.067		0.117		0.135	

	Grain yield (kg ha^{-1})		Total biomass (kg ha^{-1})		Shoot/root at MT	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
$K_0\ S_0\ L_0$	5274	4773	9276	8516	5.02	5.15
$K_0\ S_0\ L_{150}$	5054	4997	8908	8926	3.54	4.95
$K_0\ S_{100}\ L_0$	4941	5278	9018	9373	3.23	4.37
$K_0\ S_{100}\ L_{150}$	5166	5026	9002	8657	3.93	4.55
$K_{120}\ S_0\ L_0$	5278	4661	8762	8702	4.08	5.94
$K_{120}\ S_0\ L_{150}$	6177	5054	10624	9204	6.58	3.08
$K_{120}\ S_{100}\ L_0$	5447	5503	9653	9654	4.88	4.14
$K_{120}\ S_{100}\ L_{150}$	4717	5671	9071	9896	6.12	4.32
CD (0.05))	699.2		1213.9		1.984	

Highest grain yield of 6177 kg ha^{-1} was recorded in $K_{120}S_0L_{150}Si_0$ combination which was significantly superior to all other treatment combinations except $K_{120}S_{100}L_0Si_{250}$ and $K_{120}S_{100}L_{150}Si_{250}$. The results further showed that all those treatment combinations without K and those with K alone recorded significantly lower yields than that obtained in $K_{120}S_0L_{150}Si_0$ combination. The results further showed that combining S and Sio_2 together in the presence of K will only reduce the yield.

A perusal of the data showed that the total biomass yield also followed the same pattern. Highest biomass yield of 10624 kg ha^{-1} was recorded in $K_{120}S_0L_{150}Si_0$ treatment combination and all the treatment combinations with 120 kg K and S or Ca were on par. All the other treatment combinations recorded significantly lower biomass yield.

Data on shoot-root ratio revealed that the same treatment combination which gave the highest yield of grain and biomass also gave the highest shoot-root ratio of 6.58. Here again all those treatments receiving number K and receiving S or Ca alone with and without Sio_2 registered a significantly lower ratio. The results further revealed that application of Sio_2 at 250 kg improved the grain-straw ratio to levels on par with that of $K_{120}S_0L_{150}Si_0$ combination.

4.7.2 Main effects of K, Ca, S and SiO_2 on growth attributes physiological attributes and yield attributes and yield of rice under irrigation at 3 days after disappearance of ponded water

4.7.2.1 Main effects of treatments on morphophysiological and yield characters data are presented in Table 4.7.2a.

a. Growth attributes

It can be seen from the table that the main effect of K applied at 120 kg ha^{-1} in affecting growth characters was confined only to increasing height at PI stage. At this stage the height increased by 2.7 per cent.

ble 4.7.2a Effect of K, S, Ca and Silica on growth attributes of rice under irrigation at 3 days after disappearance of ponded water

ontinuous ubmergence	Plant height (cm)				Tillers/hill				Plant dry weight (g plant^{-1})											
									MT				PI				Flg			
	MT	PI	Flg	Harvest	MT	PI	Flg	Harvest	Shoot	Root	Total	S/R	Shoot	Root	Total	S/R	Shoot	Root	Total	S/R
otassium																				
$_0$	42.57	58.7	67.1	66.6	6.81	7.7	7.1	7.9	8.9	2.02	10.92	4.8	20.3	3.19	23.6	7.32	20.8	2.4	23.12	8.9
$_{12}$	42.91	60.3	67.6	67.3	7.1	7.3	7.0	7.8	8.6	1.92	10.60	4.7	19.0	2.40	21.4	8.32	22.8	2.5	24.62	9.4
D (0.05)	NS	1.34	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ulphur																				
$_0$	43.19	58.7	67.0	66.7	6.8	7.6	6.9	7.6	8.9	2.25	11.16	4.2	20.0	2.6	22.7	8.23	21.7	2.5	24.06	9.0
$_{100}$	42.29	60.3	67.7	67.1	6.7	7.4	7.1	8.1	8.6	1.69	10.35	5.3	19.3	3.0	22.3	7.41	21.9	2.4	23.67	9.4
D (0.05)	NS	1.34	NS	NS	NS	NS	NS	NS	NS	0.392	NS	0.729	NS	NS	NS	NS	NS	NS	NS	NS
alcium																				
$_0$	42.16	59.5	67.4	67.1	6.61	7.5	7.0	8.1	8.6	1.92	10.57	4.8	20.6	2.9	23.4	8.1	21.5	2.4	23.15	9.4
$_{150}$	43.33	59.4	67.4	66.8	6.88	7.4	7.1	7.7	8.9	2.02	10.94	4.7	18.8	2.7	21.6	7.5	22.1	2.5	24.58	9.0
D (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ilica																				
i_0	42.15	59.0	67.4	67.2	6.74	7.4	7.4	8.2	9.1	1.90	11.05	5.0	19.5	3.0	22.5	7.2	21.4	2.4	23.65	9.3
i_{250}	43.33	59.9	67.4	66.7	6.75	7.5	6.7	7.5	8.4	2.04	10.46	4.5	19.8	2.6	22.5	8.4	22.2	2.5	24.10	9.1
D (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V (%)	5.80	2.98	3.23	3.81	12.03	9.01	11.39	14.85	14.20	26.50	14.01	20.44	18.01	43.60	19.97	31.45	17.52	23.39	20.2	21.71

- Levels of K (0 and 120 kg ha^{-1}) S - Levels of S (0 and 100 kg ha^{-1}) L - Levels of Ca (0 and 150 kg lime ha^{-1}) S_1 - Levels of Silica (0 and 250 kg ha^{-1}) NS - Not significant

In the case of S, significant effect was observed in height as well as shoot root-ratio. Application of S at 100 kg ha^{-1} significantly increased both the above attributes and the increases were 2.7 and 26.2 per cent over control.

Main effects of Sio$_2$ and Ca did not influence any growth attribute.

b. Physiological attributes

Data on physiological attributes studied in the experiment are furnished in the Table 4.7.2b.

Main effects of K on chlorophyll at boot leaf and sap pH of leaves at MT and PI stages were significant.

Potassium increased the chlorophyll `a', chlorophyll `b' and total chlorophyll contents by 8.0, 6.9 and 8.7 per cent. Application of K significantly reduced the pH of the leaf sap pH at MT and increased it at boot leaf stage. The differences worked out to 0.49 and 1.6 per cent.

Main effect of S was also significant in influencing the chlorophyll and sap pH. Sulphur reduced the chlorophyll `a', `b' and total chlorophyll of boot leaf by 26.3, 24.0 and 26.7 per cent. Sulphur applied @ 100 kg ha^{-1} reduced the pH of the sap at MT and boot leaf stages by 0.49 and 0.64 per cent respectively.

Main effects of Ca reduced the chlorophyll a, b and total chlorophyll of the boot leaf by 10.1, 13.8 and 12.0 per cent. Reaction of the sap was reduced by 0.8 and 1.6 per cent during MT and of the boot leaf.

Silica also reduced the chlorophyll content by 2.4, 6.5 and 4.4 per cent respectively. The pH of the leaf sap was reduced only at MT stage by 0.48 per cent over control.

None of the other characters were significantly affected.

Table 4.7.2b Effect of K, S, Ca and Silica on physiologic attributes of rice under irrigation at 3 days after disappearance of ponded water (DADPW)

	Physiologic attributes											
	Chlorophyll (mg/g fresh sample weight)									Leaf sap pH		
	MT			PI			Boot leaf					
	Chl.`a'	Chl.`b'	Total Chl.	Chl.`a'	Chl.`b'	Total Chl.	Chl.`a'	Chl.`b'	Total Chl.	MT	PI	Boot leaf
Potassium												
K_0	1.593	0.607	1.991	1.520	0.399	2.064	0.995	0.404	1.390	6.19	6.19	6.18
K_{120}	1.515	0.716	1.886	1.640	0.361	2.319	1.075	0.432	1.511	6.16	6.29	6.20
CD (0.05)	NS	0.101	NS	NS	NS	NS	0.024	0.024	0.034	0.024	0.024	NS
Sulphur												
S_0	1.536	0.650	1.878	1.542	0.382	2.128	1.192	0.475	1.673	6.19	6.23	6.20
S_{100}	1.571	0.673	1.999	1.618	0.377	2.255	0.878	0.361	1.27	6.16	6.25	6.16
CD (0.05)	NS	NS	NS	NS	NS	NS	0.024	0.024	0.034	0.024	NS	0.034
Calcium												
L_0	1.567	0.669	1.934	1.573	0.379	2.143	1.090	0.449	1.543	6.20	6.24	6.24
L_{150}	1.541	0.654	1.943	1.588	0.380	2.240	0.980	0.387	1.358	6.15	6.23	6.14
CD (0.05)	NS	NS	NS	NS	NS	NS	0.024	0.024	0.034	0.024	NS	0.034
Silica												
Si_0	1.588	0.642	2.024	1.531	0.404	2.099	1.047	0.432	1.483	6.19	6.25	6.18
Si_{250}	1.520	0.681	1.852	1.629	0.355	2.284	1.022	0.404	1.418	6.16	6.23	6.20
CD (0.05)	NS	NS	NS	NS	NS	NS	0.024	0.024	0.034	0.024	NS	NS
CD (%)	18.58	20.24	15.41	15.58	26.04	12.79	2.68	6.90	3.27	0.46	0.50	0.69

K - Levels of K (0 and 120 kg ha^{-1})
S - Levels of S (0 and 100 kg ha^{-1})
L - Levels of Ca (0 and 150 kg lime ha^{-1})
S_i - Levels of Silica (0 and 250 kg ha^{-1})
NS - Not significant

c. Yield attributes and yield

None of the main effects affected any yield attribute (Table 4.7.2c).

Potassium applied at 120 kg ha^{-1} increased the grain and total biomass yield by 5.0 and 5.4 per cent and the increases were statistically significant(Fig.4.7.1.)

Main effects of S, Ca and Sio_2 were not statistically significant.

4.7.2.2 Third order interaction effect of K, Ca Ca, S and SiO_2 on growth and yield of rice

Data are presented in Table 4.7.2.2. It can be seen from the table that the lowest number of tillers per hill was recorded in $K_{120}S_{100}L_0Si_{250}$ and highest in $K_{120}S_0L_0Si_0$ which was on par with the treatments receiving K at 120 kg ha^{-1} with or without Ca, S or Sio_2.

Data on shoot dry weight at MT revealed that the combination of $K_{120}S_0L_{150}Si_0$ gave the highest dry weight of shoot as well as total dry weight at MT stage. Shoot dry weight at MT stage was significantly superior to all other combinations and total dry weight was on par with $K_0S_0L_{150}Si_0$ and $K_0S_0L_{150}Si_{250}$ and was superior to all others.

The highest leaf sap pH of 6.36 was recorded at $K_{120}S_{100}L_0Si_0$ and it was significantly superior to all other treatment combination except $K_{120}S_{100}L_0Si_{250}$. In the case of boot leaf the highest leaf sap pH was in $K_{120}S_{100}L_0Si_{250}$ and it was significantly superior to all other treatment combinations.

Data on the chlorophyll content of the boot leaf showed that the highest contents of chlorophyll `a', `b' and total chlorophyll were recorded in $K_{120}L_0S_0Si_{250}$ combination and it was significantly superior to all other treatment combinations.

Data on grain yield showed that the highest grain yield of 6289 kg ha^{-1} was recorded in $K_{120}S_{100}L_0Si_{250}$ followed by $K_{120}S_0L_{150}Si_{250}$ combination.

Highest grain-straw ratio of 1.58 was recorded by $K_{120}S_{100}L_0Si_{250}$ which was significantly superior to the corresponding one without Sio_2.

Table 4.7.2c Effect of K, Ca, S and Silica on yield attributes of rice under irrigation at 3 days after disappearance of ponded water (DADPW)

	Yield attributes							Yield (kg ha^{-1})			
	Panicles/ hill	Panicle weight (g/10 panicle)	Panicle length (cm)	Branches/ panicle (Nos.)	Filled grains/ Panicle (Nos.)	Unfilled grains/ panicle (Nos.)	1000 grain weight (g)	Grain	Straw	Total biomass	Grain straw
Potassium											
K_0	7.5	17.6	16.8	7.5	58.4	14.1	27.4	5326	4081	9395	1.315
K_{120}	7.4	18.0	17.0	7.3	58.3	12.6	27.8	5364	4049	9413	1.331
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
sulphur											
S_0	7.0	17.6	16.8	7.3	57.4	12.4	27.8	5314	3998	9318	1.341
S_{100}	7.8	18.1	17.0	7.5	57.3	14.4	27.4	5376	4132	9489	1.300
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Calcium											
L_0	7.5	17.8	16.8	7.4	58.2	13.7	27.8	5307	3919	9232	1.362
L_{150}	7.3	17.8	16.9	7.4	58.5	13.1	27.5	5383	4211	9574	1.284
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Silica											
Si_0	7.6	18.0	17.1	7.4	59.1	14.6	27.7	5202	4049	9251	1.293
Si_{250}	7.2	17.6	16.7	7.4	57.6	12.1	27.6	5487	4081	9556	1.353
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CD (%)	11.63	10.80	3.89	6.27	15.17	20.62	2.74	7.21	11.67	8.12	9.93

- Levels of K (0 and 120 kg ha^{-1})

- Levels of Silica (0 and 250 kg ha^{-1})

S - Levels of S (0 and 100 kg ha^{-1})

NS - Not significant

L - Levels of Ca (0 and 150 kg lime ha^{-1})

Table 4.7.2.2 Third order interaction effects on growth attributes, physiological attributes and yield of rice under irrigation at 3 DADPW

K x S x Ca x Silica

	Tillers/hills at PI		Leaf dry weight at MT (g plant^{-1})		Total dry weight at MT (g plant^{-1})		Leaf sap pH at PI		Leaf sap pH boot leaf	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
$K_0\ S_0\ L_0$	8.0	7.6	8.2	8.17	10.1	10.2	6.14	6.18	6.2	6.26
$K_0\ S_0\ L_{150}$	6.4	8.1	10.19	9.3	12.7	12.8	6.26	6.15	6.14	6.06
$K_0\ S_{100}\ L_0$	7.2	7.8	8.02	10.18	9.4	12.2	6.24	6.17	6.24	6.26
$K_0\ S_{100}\ L_{150}$	8.0	8.1	9.46	7.68	10.9	9.3	6.22	6.20	6.13	6.18
$K_{120}\ S_0\ L_0$	8.2	8.1	8.16	6.46	10.1	8.3	6.25	6.28	6.08	6.16
$K_{120}\ S_0\ L_{150}$	7.3	7.0	13.23	7.54	15.7	9.5	6.30	6.29	6.13	6.23
$K_{120}\ S_{100}\ L_0$	7.5	5.9	9.78	9.73	12.3	12.1	6.36	6.34	6.31	6.41
$K_{120}\ S_{100}\ L_{150}$	6.8	7.6	6.10	7.87	7.4	9.4	6.29	6.19	6.21	6.09
CD (0.05)	1.43		2.649		3.211		0.067		0.095	

	Chl`a' boot leaf		Chl.`b' boot leaf		Total Chl. boot leaf		Grain yield (kg ha^{-1})		Grain/ straw	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
$K_0\ S_0\ L_0$	1.407	0.927	0.627	0.374	2.046	1.300	5279	5284	1.36	1.26
$K_0\ S_0\ L_{150}$	1.026	1.028	0.383	0.363	1.409	1.391	5447	4997	1.44	1.19
$K_0\ S_{100}\ L_0$	0.949	1.131	0.419	0.446	1.353	1.576	5391	5054	1.38	1.33
$K_0\ S_{100}\ L_{150}$	0.824	0.664	0.362	0.258	1.186	0.856	5447	5708	1.10	1.48
$K_{120}\ S_0\ L_0$	0.929	1.603	0.391	0.631	1.359	2.232	4941	5222	1.41	1.32
$K_{120}\ S_0\ L_{150}$	1.339	1.278	0.569	0.523	1.848	1.800	5278	6065	1.33	1.41
$K_{120}\ S_{100}\ L_0$	0.993	0.781	0.393	0.309	1.386	1.090	4998	6289	1.28	1.58
$K_{120}\ S_{100}\ L_{150}$	0.911	0.767	0.369	0.331	1.275	1.098	4841	5278	1.06	1.24
CD (0.05)	0.067		0.067		0.095		821.6		0.278	

4.7.3 Main effect of water management on nutrient uptake

Data on nutrient uptake by grain and straw due to continuous submergence and irrigating 3 DADPW are presented in Table 4.7.4.

The data showed that continuous submergence of the crop recorded a higher uptake of almost all elements by grain except Fe, Zn, Cu and Sio_2. Irrigating the crop once in 3 DADPW recorded 20.1, 0.4, 6.0, 0.21 and 0.54 kg less N, P, K, Mg and S respectively than continuous submergence.

As against this, in straw, irrigating the crop 3 DADPW recorded 4.7 and 0.5 kg more uptake of N and Mn than continuous submergence. Continuous submergence recorded a higher uptake of P, K, Ca, Mg, S, Fe, Zn, Cu and silica in straw.

4.7.4 Combined effect of Ca x Silica and S x Silica on nutrient uptake by rice in grain and straw

It can be seen from the Table 4.7.5. that application of silica brought about 7 kg increase in N and 287 kg in silica over control in the uptake combining S with silica reduced K and Mg and increased S marginally and reduced silica uptake by grain. When Ca was combined with silica instead of S, it increased K, Ca and Mg marginally and decreased silica by 176 kg over application of silica alone.

Application f silica @ 250 kg ha^{-1} reduced N, P, S, Mn and Cu uptake and increased Ca, Mg, Fe and SiO_2 uptake by the straw and the respective mean decreases compared to control were 2.2, 0.6, 0.83, 0.9 and 0.019 and the corresponding increases were 1.4, 0.28, 0.82 and 167 kg respectively.

Table 4.7.3a Effect of K, Ca, S and Silica on elemental composition of grain under continuous submergence and irrigation at 3DADPW

	N (%)				P (%)				K (%)			
	Continuous submergence		Irrigation at 3 DADPW		Continuous submergence		Irrigation at 3 DADPW		Continuous submergence		Irrigation at 3 DADPW	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
K_0 L_0 S_0	1.05	1.14	1.14	1.31	0.27	0.26	0.29	0.29	0.50	0.55	0.30	0.38
K_0 L_0 S_{100}	1.23	1.23	1.49	1.14	0.30	0.22	0.27	0.28	0.38	0.58	0.30	0.38
K_0 L_{150} S_0	1.14	1.23	1.31	1.31	0.28	0.27	0.26	0.27	0.48	0.33	0.43	0.35
K_0 L_{150} S_{100}	1.05	1.31	1.14	1.75	0.30	0.34	0.29	0.29	0.65	0.35	0.30	0.30
K_{120} L_0 S_0	1.14	1.14	1.31	1.14	0.29	0.30	0.27	0.28	0.58	0.58	0.33	0.33
K_{120} L_0 S_{100}	1.49	1.49	1.23	1.05	0.28	0.27	0.26	0.28	0.38	0.38	0.30	0.40
K_{120} L_{150} S_0	1.23	1.93	0.88	1.05	0.28	0.28	0.27	0.25	0.58	0.50	0.35	0.33
K_{120} L_{150} S_{100}	1.05	1.49	1.40	0.70	0.29	0.27	0.28	0.26	0.43	0.28	0.45	0.25

	Ca (%)				Mg (%)			
	Continuous submergence		Irrigation at 3 DADPW		Continuous submergence		Irrigation at 3 DADPW	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
K_0 L_0 S_0	0.015	0.013	0.012	0.012	0.070	0.062	0.075	0.073
K_0 L_0 S_{100}	0.013	0.009	0.011	0.013	0.064	0.043	0.062	0.075
K_0 L_{150} S_0	0.14	0.021	0.011	0.011	0.066	0.034	0.065	0.066
K_0 L_{150} S_{100}	0.012	0.014	0.011	0.014	0.062	0.074	0.067	0.078
K_{120} L_0 S_0	0.013	0.026	0.011	0.010	0.068	0.068	0.063	0.063
K_{120} L_0 S_{100}	0.011	0.011	0.011	0.010	0.062	0.061	0.055	0.058
K_{120} L_{150} S_0	0.013	0.011	0.011	0.010	0.066	0.070	0.065	0.061
K_{120} L_{150} S_{100}	0.013	0.012	0.010	0.011	0.071	0.072	0.064	0.060

Contd....

Table 4.7.3b Effect of K, Ca, S and Silica on elemental composition of straw under continuous submergence and irrigation at 3DADPW

	N (%)				P (%)				K (%)			
	Continuous submergence		Irrigation at 3 DADPW		Continuous submergence		Irrigation at 3 DADPW		Continuous submergence		Irrigation at 3 DADPW	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
K_0 L_0 S_0	0.61	1.05	0.96	0.70	0.16	0.15	0.18	0.15	2.10	2.00	3.75	1.80
K_0 L_0 S_{100}	0.76	0.53	0.96	0.70	0.16	0.15	0.15	0.14	2.40	3.25	1.95	1.80
K_0 L_{150} S_0	0.88	0.76	0.96	0.88	0.15	0.15	0.15	0.17	2.85	1.75	2.25	1.90
K_0 L_{150} S_{100}	0.53	0.61	1.14	0.79	0.14	0.18	0.13	0.12	2.45	2.75	1.85	2.35
K_{120} L_0 S_0	0.61	0.70	0.53	0.96	0.14	0.14	0.13	0.15	3.40	3.90	2.35	2.30
K_{120} L_0 S_{100}	0.88	0.96	0.79	0.70	0.17	0.15	0.14	0.14	2.25	2.70	2.30	2.35
K_{120} L_{150} S_0	0.61	0.70	1.31	0.96	0.17	0.18	0.14	0.12	2.90	2.55	2.30	2.25
K_{120} L_{150} S_{100}	0.96	1.05	0.53	0.88	0.14	0.14	0.14	0.16	2.10	1.90	2.55	2.10

	Ca (%)				Mg (%)				S (ppm)			
	Continuous submergence		Irrigation at 3 DADPW		Continuous submergence		Irrigation at 3 DADPW		Continuous submergence		Irrigation at 3 DADPW	
	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}	Si_0	Si_{250}
K_0 L_0 S_0	0.184	0.502	0.565	0.256	0.120	0.074	0.111	0.087	3146	1729	2085	3322
K_0 L_0 S_{100}	0.112	0.355	0.290	0.356	0.125	0.082	0.153	0.086	1820	1671	2080	1448
K_0 L_{150} S_0	0.419	0.363	0.348	0.319	0.113	0.119	0.092	0.092	1755	2015	2433	1958
K_0 L_{150} S_{100}	0.363	0.294	0.369	0.312	0.108	0.109	0.124	0.142	2932	1762	3604	1517
K_{120} L_0 S_0	0.436	0.289	0.240	0.207	0.162	0.075	0.077	0.099	2828	1521	2943	1680
K_{120} L_0 S_{100}	0.366	0.430	0.366	0.459	0.079	0.119	0.073	0.050	1742	1762	1536	1530
K_{120} L_{150} S_0	0.371	0.368	0.325	0.314	0.092	0.109	0.078	0.070	2743	2080	1582	1517
K_{120} L_{150} S_{100}	0.479	0.581	0.955	0.513	0.095	0.084	0.104	0.114	2007	1922	1613	1530

Contd....

Table 4.7.4 Effect of water management of nutrient uptake by rice

Treatment	Grain kg ha^{-1}										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO$_2$
Continuous submergence	79.5	15.4	25.7	0.64	3.59	10.12	1.9	0.43	0.13	0.074	998.6
3 DADPW	59.4	15.0	19.7	0.59	3.38	9.58	2.1	0.32	0.15	0.077	1043.8

Treatment	Straw kg ha^{-1}										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Sio$_2$
Continuous submergence	33.3	7.1	110.4	16.3	4.23	8.9	3.61	3.94	0.32	0.046	1029.0
3 DADPW	38.0	5.3	92.9	14.9	2.74	6.4	2.68	4.44	0.18	0.026	989.0

DADPW - Days after disappearance of ponded water

Table 4.7.5 Combined effect of Ca x Silica and S x Silica on nutrient uptake by rice

Treatment	Grain kg ha^{-1}										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO_2
Ca+SiO_2	70.9	15.2	24.9	0.64	3.87	9.24	2.0	0.38	0.12	0.078	988.9
S+SiO_2	67.9	15.2	20.5	0.60	3.23	10.46	2.0	0.37	0.15	0.075	1053.4
Si_0	66.3	15.0	22.5	0.63	3.23	9.79	1.84	0.37	0.12	0.075	877.8
Si_{250}	72.6	15.5	22.9	0.60	3.56	9.91	2.2	0.37	0.16	0.077	1165

Treatment	Straw kg ha^{-1}										
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	SiO_2
Ca+SiO_2	44.9	6.5	105.7	14.6	3.69	8.41	3.23	3.60	0.27	0.046	1044.5
S+SiO_2	33.9	5.9	97.5	16.6	3.28	6.69	3.07	4.79	0.23	0.026	974.6
Sio	36.7	6.5	101.2	14.9	3.34	7.96	2.74	4.20	0.23	0.045	925.0
Si_{250}	34.5	5.9	102.0	16.3	3.62	7.13	3.56	3.40	0.27	0.026	1092.6

Discussion

DISCUSSION

The project entitled "Nutritional balance analysis for productivity improvement of rice in iron rich lateritic alluvium" was carried out during 1995-97 at Agricultural Research Station, Mannuthy. The experiments in the project aimed to identify the yield limiting influences and measures of overcoming them have evaluated all the management inputs except N and P which were maintained at recommended levels of 90 and 45 kg ha^{-1} respectively. As such the results have been discussed in this context in the morphological, physiological and nutritional diamensions. A general discussion summing up the results of all the experiments also is included so as to serve as the base to facilitate formulation of a comprehensive production technology for rice culture.

5.1 EXPERIMENT I

Farmers's field yields

Extreme variation in realised yields within and over the three soil groups had been the striking feature of the results obtained from the study in farmers plots. Inspite of comparable levels of application of nutrient inputs, the general yield range had been 2860 to 9000 kg ha^{-1}. The respective values for the soil groups were 2860-8200, 4500-7500 and 4500-9000 kg ha^{-1} in the laterite, kole and black soils respectively (Table 4.1.1). Primarily this variation shall be attributed to the environmental influence. Menon *et al.* (1997) have reported that the effect of environmental influence classified between soil and atmosphere worked out to be six and ten folds. Results of adaptive trials (Anon. 1988) showed similar results.

Primarily, growth and yield are plant characteristics. As such an objective approach should take into account variations in yield as direct effects of inhibitory influences. Thus progressive reductions from the maximum realised yields are really expressions of progressive intensities of inhibitory influences. Thus management for yield improvement should be to diagnose the inhibitory influences and adopt measures to ameliorate or circumvent them.

Nutritionally high yield is considered to be the capacity of the plant to dilute nitrogen (Wilcox, 1936). As such, poor yields are the results of metabolic failure in the plant. Data presented in Table 4.1.2 will show that the lowest N content of 1.98% in the leaf in laterite soil at PI stage was associated with a yield of 6000 kg grain as against 3.68 per cent associated with 3000 kg grain ha^{-1}. These results confirmed that low yields are resultants of inhibitory influences. At the same time they also pointed out that their influences are physiological ie. within the plant system and prompted by some elements or their interaction.

A comparative evaluation of the leaf content of N and yield studies (Table 4.1.5 and 4.1.1) revealed that high leaf N is not accompanied by high yields. This result indicated that high leaf content of any nutrient is not an index of high yield. High contents also restrict absorption. Thus inhibited yield, consequent to metabolic disorder may primarily be arising from soils.

A perusal of the data on the mean yield and yield range of rice (Table 4.1.1) in the laterite, kole and black soil groups (Fig. 5.1.1, 5.1.2 and 5.1.3) have shown that inspite of variation in mean productivity expressions, many plots of these three soil groups fall within a common range of 5000 to 7000 kg ha^{-1}, though the nutritional

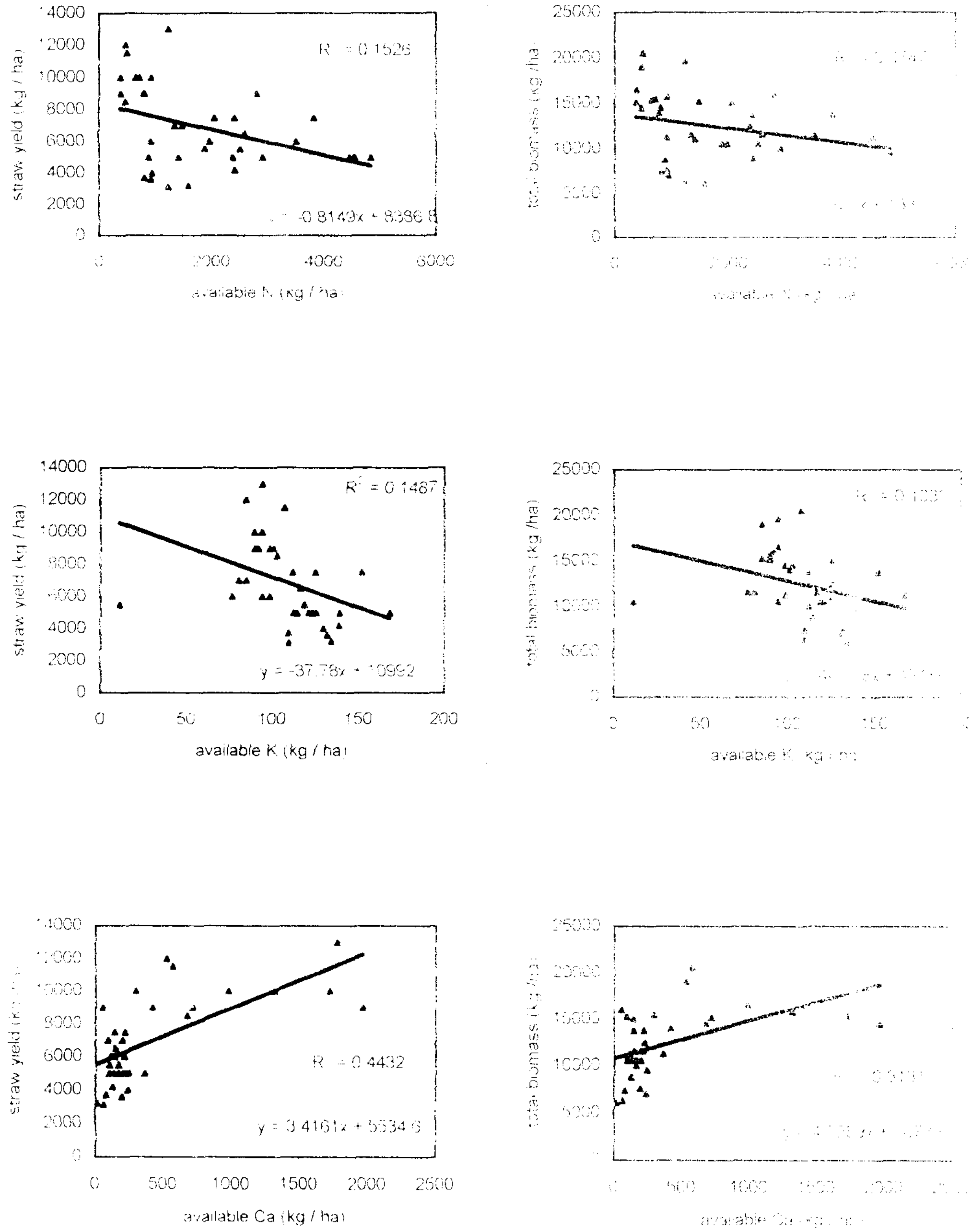


Fig. 5.1.1 Influence of available N, K and Ca content of soil on yield of rice

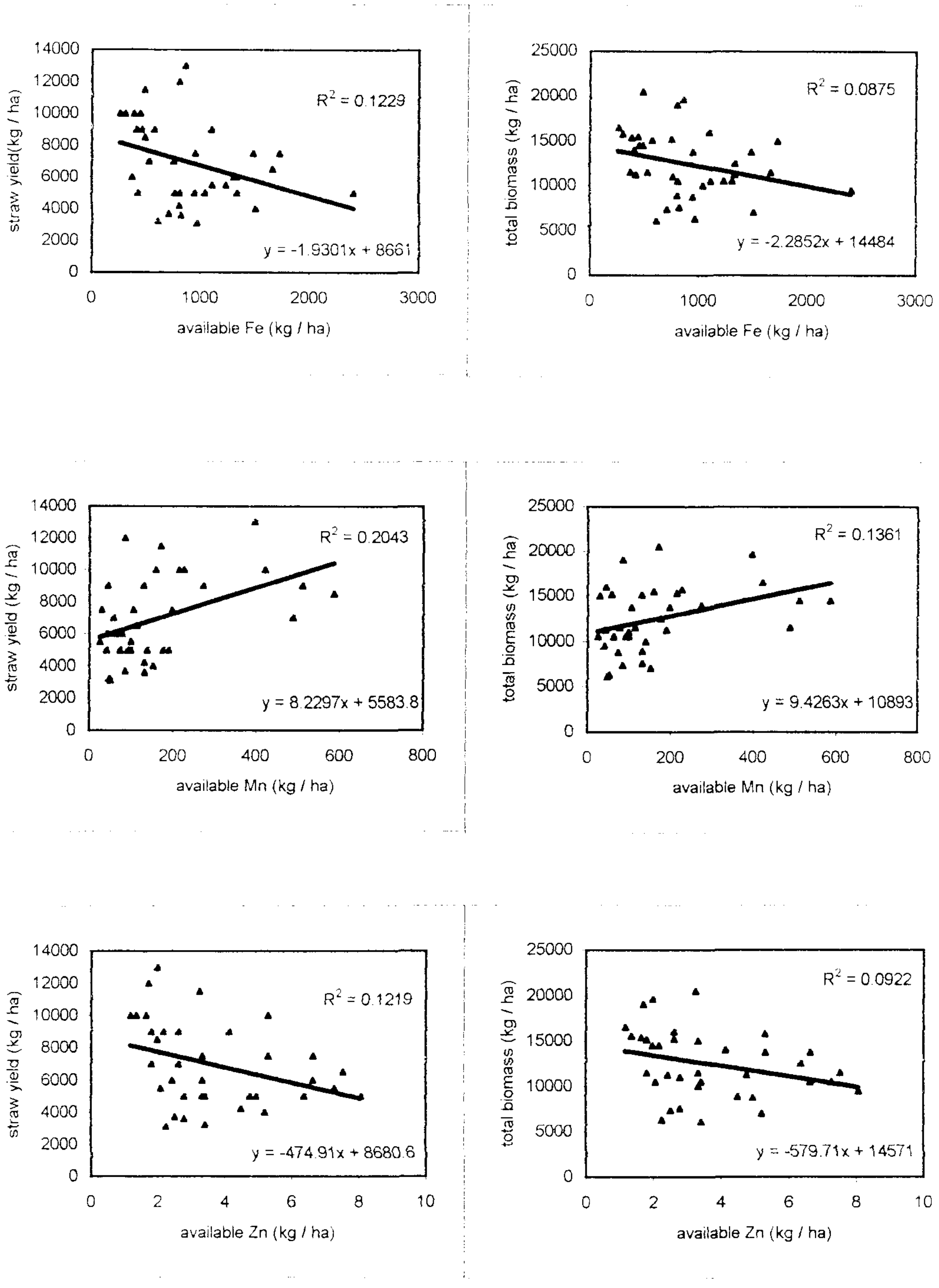


Fig. 5.1.2 Influence of available Fe, Mn and Zn content of soil on yield of rice

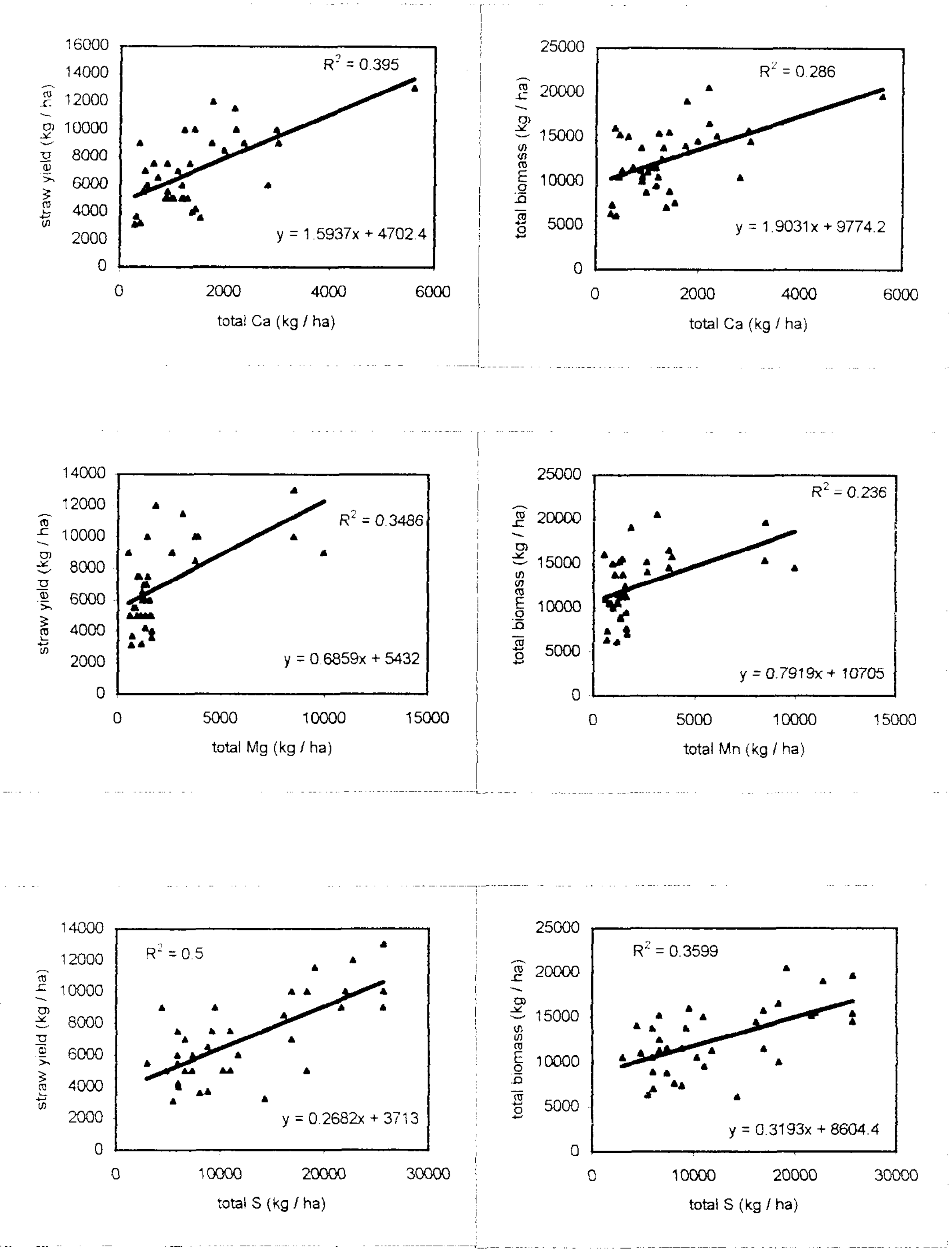


Fig. 5.1.3 Influence of total Ca, Mg and S content of soil on yield of rice

environment were very much different. Thus same yield levels in different soil chemical environments suggest that any particular realised yield level shall not be due to any individual element but only due to the product of the total environment. As such analysis of the cause of low yields or measures for improving the yield should be based on the total environment and not singular element.

The above contentions can be seen to get further strengthened from the data in Table 4.1.2. This depicts the individual minimal levels of nutrients over the soil groups for a yield above 7000 kg ha^{-1} as well as the plant minimum levels of individual elements in the three soil groups. A yield level of 7000 kg in laterite and kole lands had been linked to high content of S, Fe, Mn and Zn as against a high calcium content in black soils. Possibly higher than required N and P content in laterite soils and N in black soils may be required to neutralise the excess effect of elements which are not applied.

An observation on the range of plant elemental composition in the three soil groups further revealed that plants are not deficient in any element as to cause yields below 7000 kg. Almost all the elements especially Fe, Mn, Zn and Cu are in excess of critical levels. Low yields inspite of high contents is a further evidence to the contention that more than the content of individual elements it is the net effect that affect the yield. These results also mean that leaf contents of individual elements need not necessarily be the indices of productivity. Sreekumaran (1998) have found that individual content of elements fail to explain yield relations. Possibly a "Content Balance Combined Approach" will be useful.

Generalised relationships of available and total nutrient (element) contents to yield (Table 4.1.6 and Fig. 5.1.1, 5.1.2, 5.1.3 and 5.1.4) showed that the elemental relations in rice is confined to production of biomass as well as straw. Absence of significant correlations suggests that individual contents of elements can not explain the grain yield. Musthafa (1995) and Beena Jacob (1995) have also recorded similar results. Total biomass includes grain and straw. Grain yield is the product of differentiation, translocation to the earhead from structural components (vegetative components) and post anthesis photosynthesis (Mureta, 1969). Strongest correlation for straw yield, their declining effects in total biomass and absence of significant relationship to grain yield suggest that individual elements by themselves progressively weaken themselves in their influence on the metabolic process, with advance in growth.

Negative and positive effects of simple correlations of individual elements lead to a stalemate situation where yield or yield process cannot be explained. This calls for a critical and detailed evaluation of the direct and indirect effects of elements. Data on path coefficient analysis presented in Table 4.1.10 showed that individual elements by itself fail to explain the yield as the high residual values obtained indicated. High residual values probably are due to the high availability of elements like Fe, Mn and Zn as well as the interacting influences of each element with all the others.

Inter-correlation matrix in root, culm and leaf at PI stages taken together (Table 4.1.7, 4.1.8 and 4.1.9 and Fig. 5.1.5) provides clues on how possibly the correlation values are built up as well as how the negative influences could be overcome. Thus a significant positive correlation of Zn content in the root but its

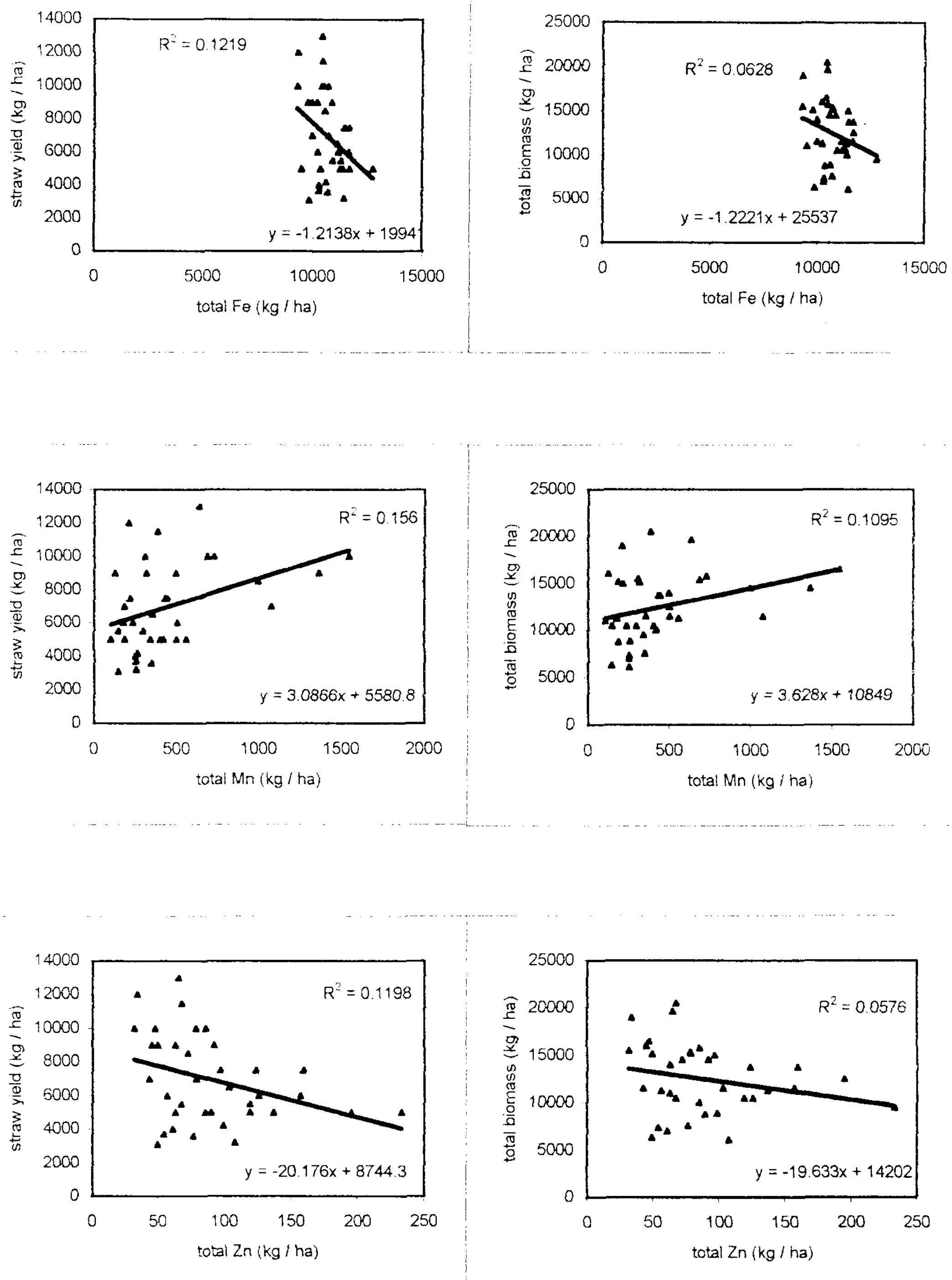


Fig. 5.1.4 Influence of total Fe, Mn and Zn content of soil on yield of rice

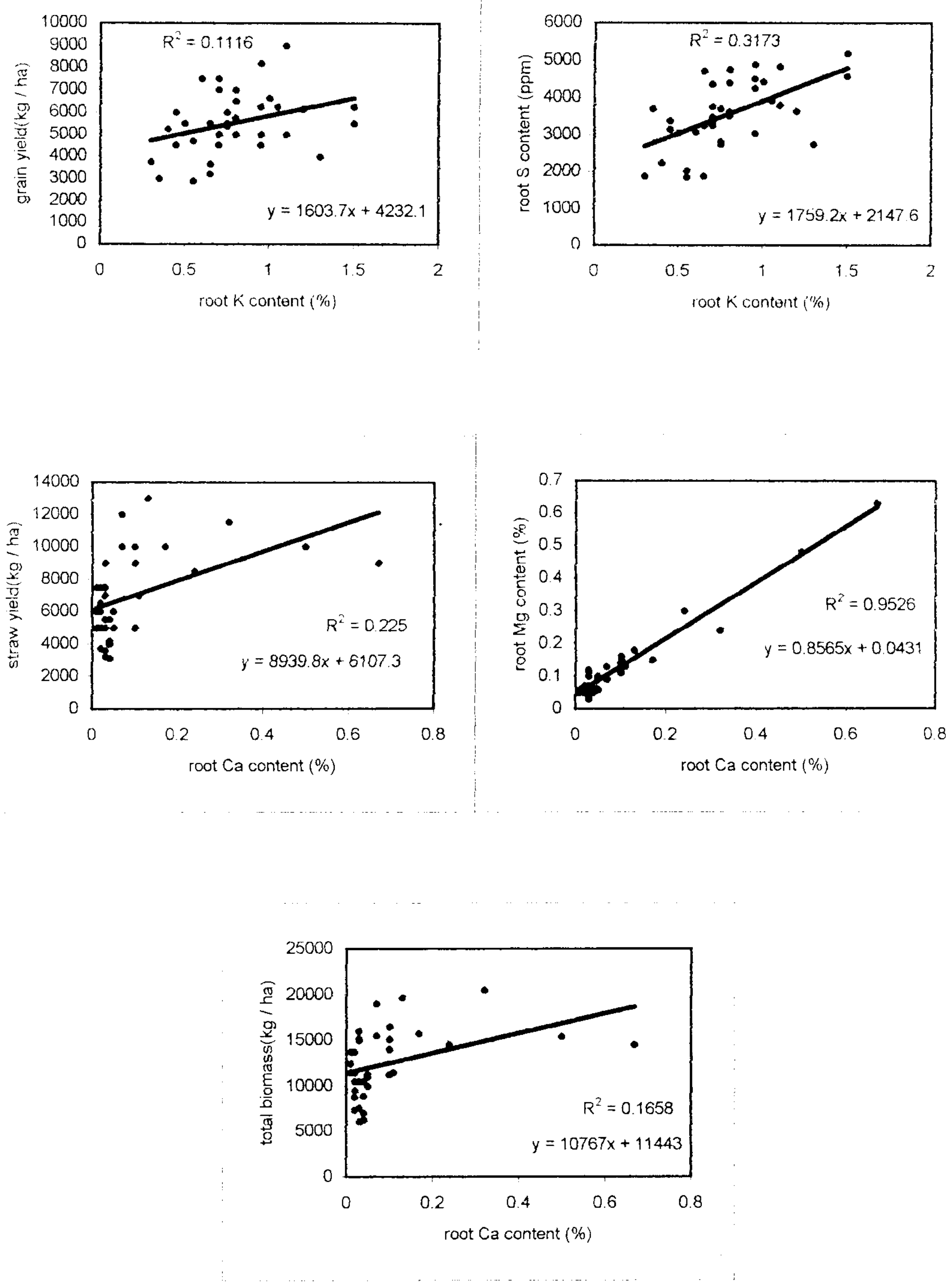


Fig.5.1.5 Influence of root K and Ca content on yield and other nutrients

significantly negative relations subsequently would imply that Zn should not get translocated to the above ground portions of the plant. Similar but less pronounced relationship of Cu on the one side and the highly significant relationship of Cu with Zn would mean that means of containment of Zn will automatically contain Cu also. Yoshida (1981) has reported that leaf content of Zn and Cu beyond 15-20 and 6 ppm respectively are harmful.

Similarly significant positive relationship of Ca and Mg in the root is likely to be at least in part due to their negative effects on Fe. The data also show that Ca and Mg are not very effective in containing Zn and Cu in the root level (Fig. 5.1.6 and 5.1.7)

In the culm of the plant positive relationship of P with Zn may be the cause of negative relationship with yield. In the same way positive relationship of Ca and Mg may be at least in part due to their significantly negative influence on Zn. However the data showed that negative effect of Ca and Mg was not evident in the culm. But higher content of P in the culm was negatively related with iron content. May be that P retains iron in the leaf.

In the leaf Ca and Mg could counteract Fe and Cu.

Thus the effect of Ca and Mg might have been by reducing Ca in the root and Zn and Cu in all parts of the plant at PI stage. The apparent negative effect of P could have been due to its positive effect on Zn.

Positive influence of S on Mn content in root and culm and absence of any relationship in the leaf suggested that Mn may be contained in the root by S.

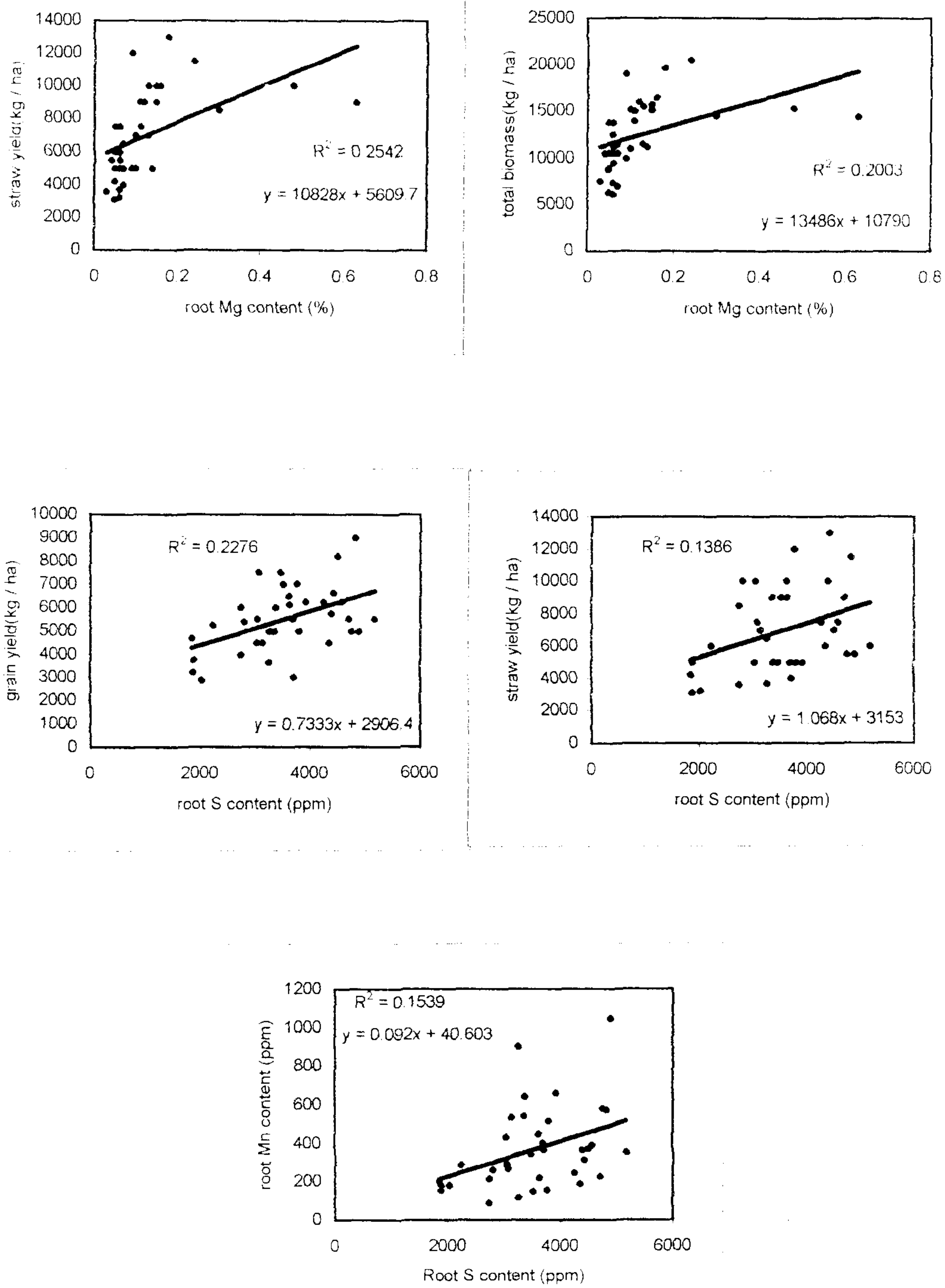


Fig.5.1.6 Influence of root Mg and S content on yield and other nutrient

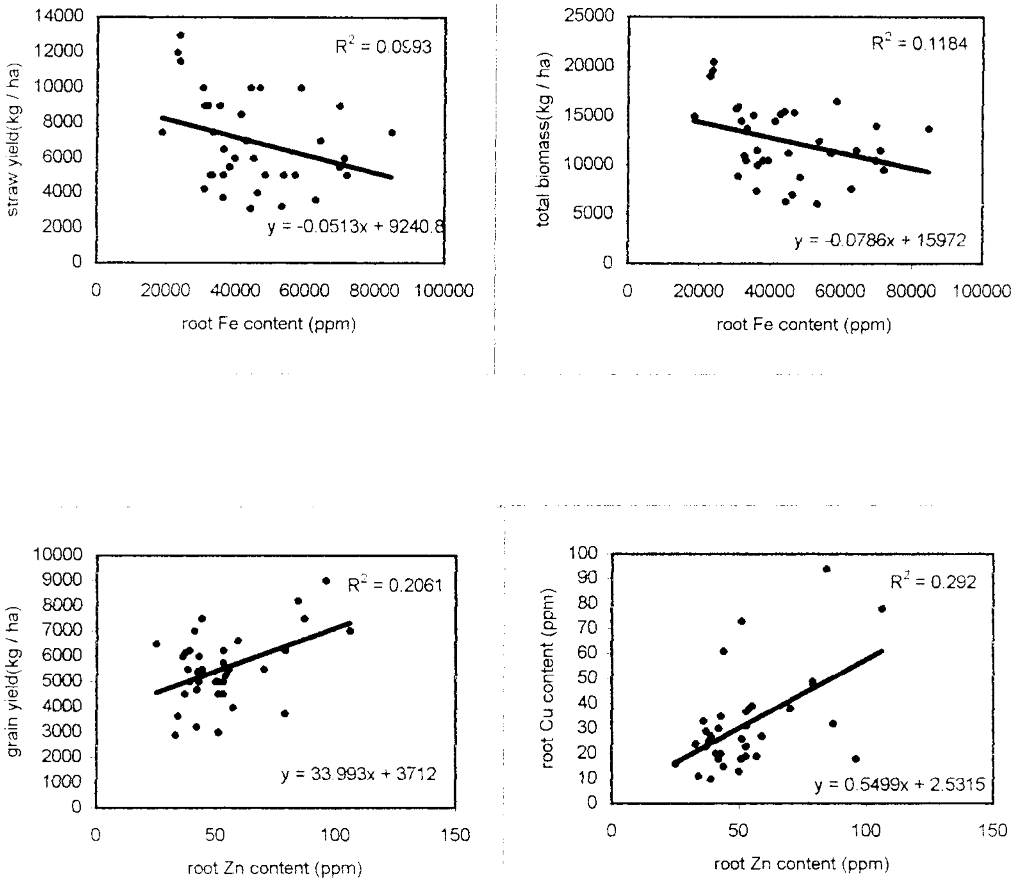


Fig.5.1.7 Influence of root Fe and Zn content on yield and other nutrient

Thus the results suggest that increasing Ca levels in the plant shall contain Zn and Cu virtually completely. Calcium shall also contain Fe in the root. Positive relationship of S with Mn indicates that S may be able to contain Mn to some extent. However all these requires further investigation. Results showed that Ca and S will be required though they are negatively interacting. Interactions are a function of levels. As the expressed results themselves are products of direct effects and effects through some other elements a "Content Balance Combined Approach" appears to be better than content based approach alone.

Split up correlation of elements in Table 4.1.11 revealed that root contents alone showed significant relation. From the negative relation of iron contents of the root at PI in both laterite and black soils, it may be concluded that iron effect on yield is at root level.

Sulphur had positive relationship with yield. The positive relationship of Zn content of the root but the negative relation in leaf at PI stage may possibly mean that forced root accumulation of Zn with restricted supply is desirable and possible.

The declining strength of relationship as evidenced by the declining values in general progressively suggest accumulation of elements in the root. Positive effect of elements in the root and their negative trends in above ground portion may broadly point out that in addition to out translocational variations of elements, rice plant tend to contain excess levels of native elements in the root.

Negative relation of almost all elements in the leaf unequivocally suggest excess of elements (Fig. 5.1.8, 5.1.9, 5.1.10 and 5.1.11). Since many of the elements are native and non applied, the only alternative will be to tilt the balances for productivity

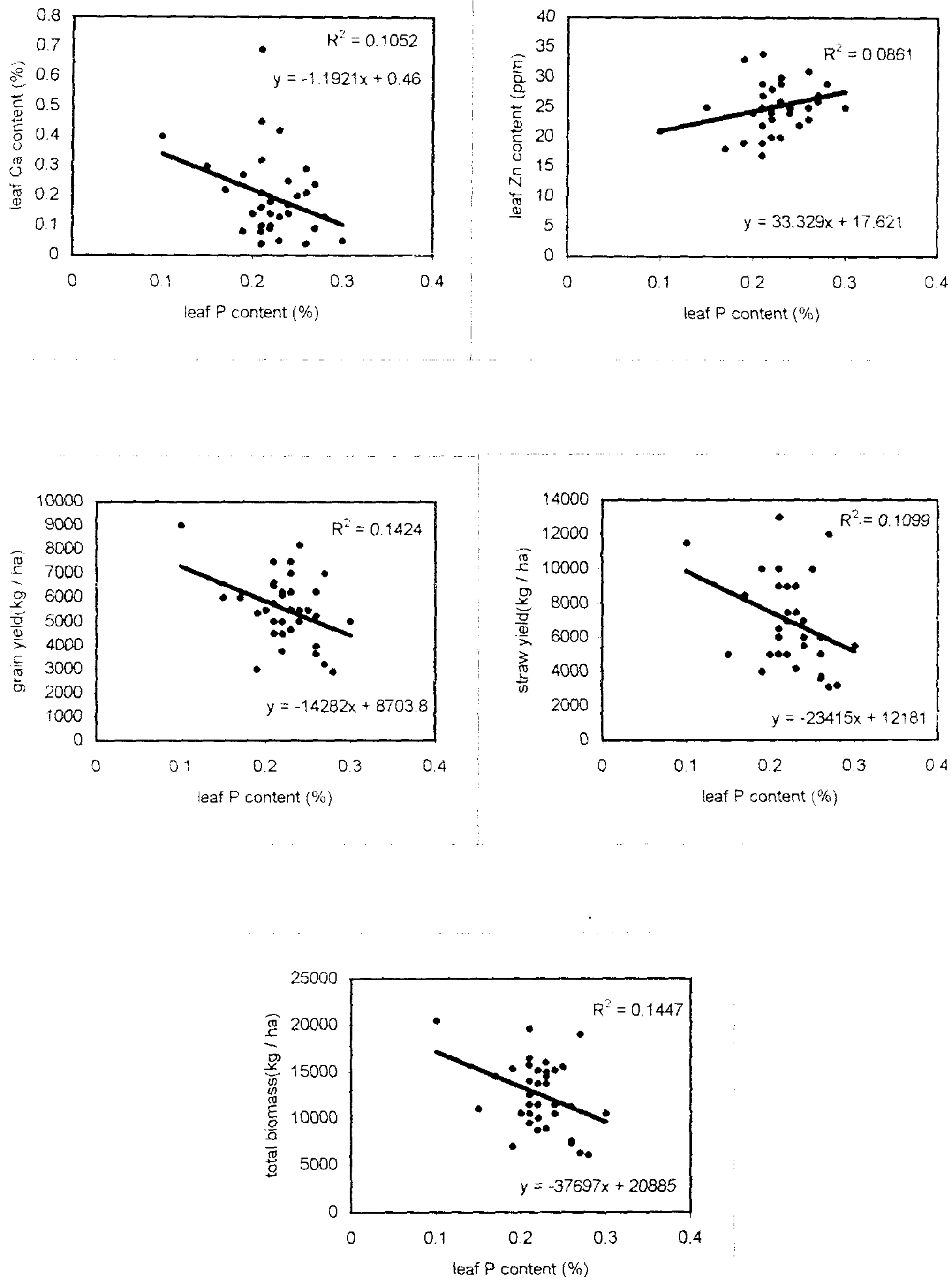


Fig. 5.1.8 Influence of leaf P content on yield and other nutrients

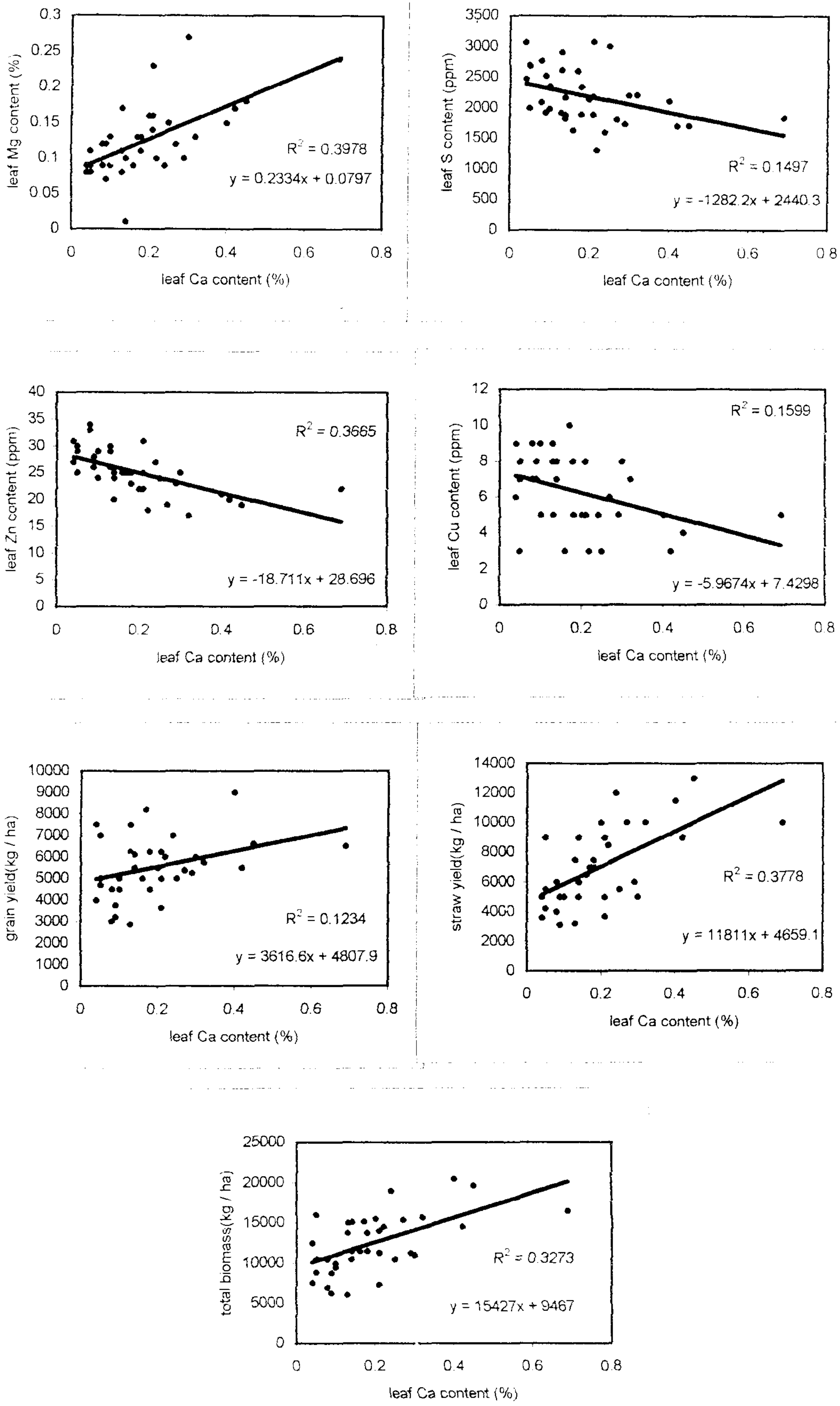


Fig. 5.1.9 Influence of leaf Ca content on yield and other nutrients

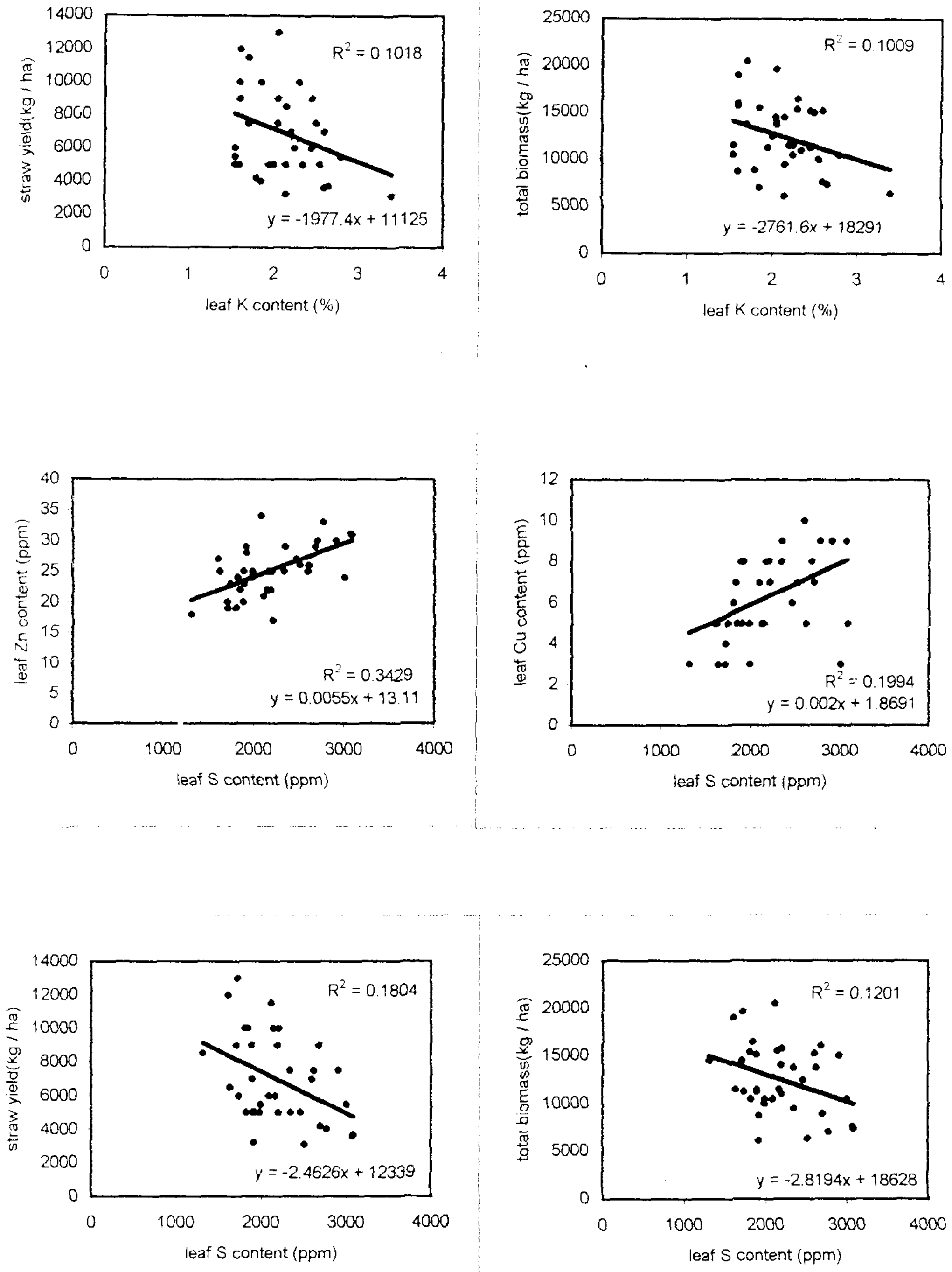


Fig. 5.1.10 Influence of leaf K and S content on yield and other nutrients

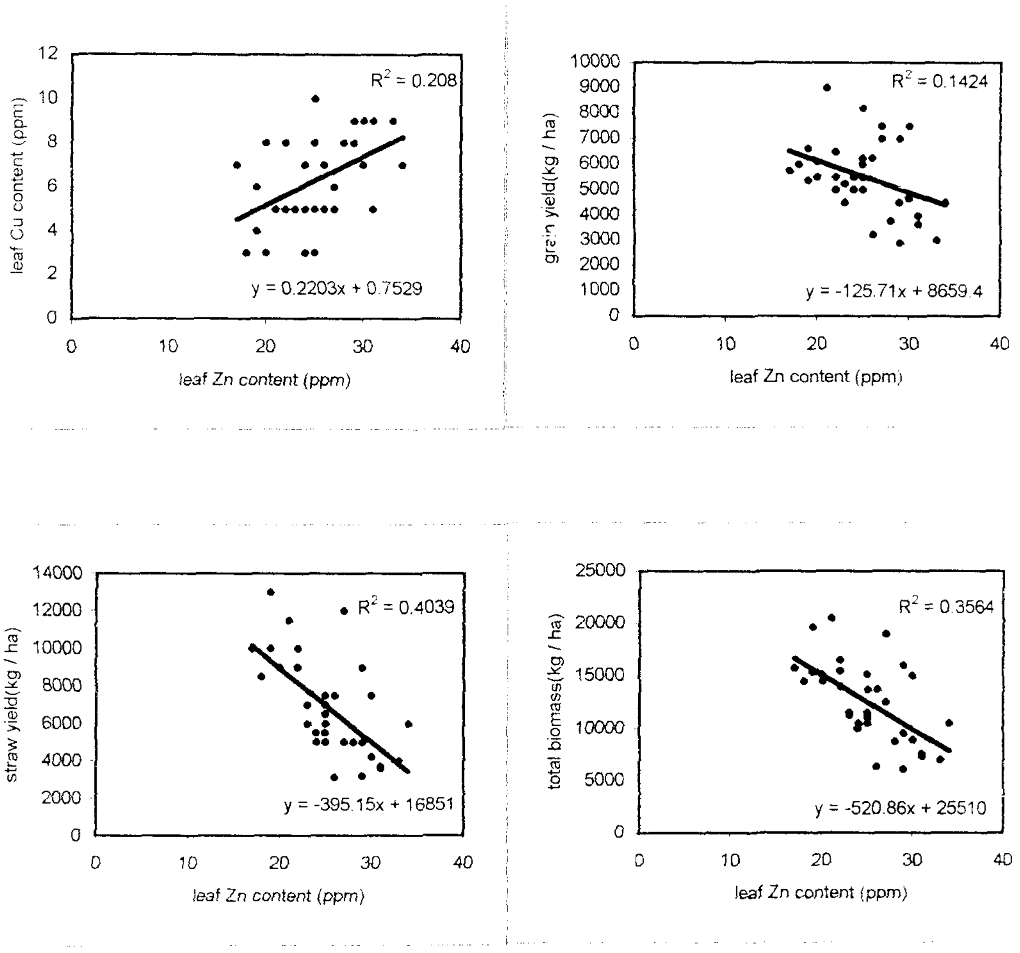


Fig. 5.1.11 Influence of leaf Zn content on yield and other nutrients

advantage. This also means that working out an optimum for any or every element will be impossible and ratio dependant approach alone shall be adoptable to productivity improvement.

Significant variation in plants among the sub groups also suggest that the problems are soil specific and calls for soils specific recommendations.

5.2 EXPERIMENT II

Pot culture studies differ from the actual field trials in three respects. There is the absence of sub soil influence, avoidance of effect of weather variations super imposing on plant-soil interaction and variations due to fluctuations of water regime. Unlike sand culture studies, a pot culture study with three soil groups may not be advisable for basic and fundamental information but that alone can provide information on relative nutrient relations to yield in the three different soil plant systems and their potential capabilities and weaknesses in yield formation. Such an information is a pre-requisite in formulation of corrective management programmes.

The yield data from the pot culture studies revealed extreme variability in yield expression. The variability range compared well with field data (Table 4.2.1 and 4.1.1). Comparable range of variability suggested the acceptability of pot culture results, in any further evaluation of field results.

A critical perusal of the data across and within the soil type revealed that while variation in grain yield amounted to 250 per cent, variation in straw yield was within 100 per cent only. This wider variability suggested that grain yield is a function of production and translocation to the earhead together while straw yield is virtually a residue and is the product of production minus translocation to the grain. These trends suggested that a high yield management programme should have the twin objectives of ensuring high photosynthesis throughout as well as an uninterrupted translocation in the post flowering phase to the panicle. A wide grain straw ratio as observed in traditional varieties would appear to be due to elemental involvement resulting in inhibited translocation.

Data presented in Table 4.2.2 will give an idea on the functional progressive pattern of rice in the three soil types. Thus in laterite soil only 66 per cent of the tillers produced panicles as against 75 per cent in `kole' lands and over 90 per cent in black soils. Tiller numbers were also more in laterite and `kole' land soils and the range between minimum and maximum was less. Over different locations in black soils, the range was more. But conversion of vegetative tillers to producutive tillers was highest in black soils.

Wider range in tiller production accompanied by over 80 per cent of their conversion to productive tillers would appear as an expression of response to favourable additive inputs (De Datta, 1981 and Lai Ding *et al.*, 1993) whereas heavy tiller production with limited conversions to productive tillers appears to be the expression of domineering influence of unfavourable factors. Musthafa (1995) have found heavy declines of non productive tillers as an unfavourable influence of Fe. He found that it is a mechanism of avoiding excess accumulation of Fe and found that to shed one kg Fe the crop loses 14 kg N which in turn leads to absence of response to N. Thus it appears safe to assume that black soils require additive inputs and `kole' lands and laterite soils require ameliorative management to increase production.

Observations on developmental pattern of yield attributes further confirm the above contention. The data showed that the influence of negative factors do not cease with panicle formation. Against a 66 per cent variation in panicle weight in black soils variation in panicle weight was 250 and 148 per cent respectively in laterite and kole soils. Variation in filled grains and total grains per panicle was similar to panicle. Comparatively lower variation between total and filled grains in laterite soils possibly point out to the interference of the negative factors in the process of differentiation.

`Kole' lands and black soils produced equal number of total grains which were nearly 20 per cent more than that in laterite soils. Thousand grain weight was also comparable in these soil. These results point out to the possibility of variation in the negative factors and their differential extent of nfluences in the laterite soil. Musthafa (1995) and Menon (1996) have obtained similar results.

The lower range of thousand grain weight of rice obtained in laterite soils as compared to the other two soil types points out that negative factors affect not only the processes of defining productive tillers and floret numbers but also translocation to the panicles.

Inter-relations of morphophysiologic and yield attributes presented in Table 4.2.4 will serve as indirect indices of concurrent and progressional operation of yield negating processes along with normal growth process.

Absence of correlation of number of tillers at MT, PI, flowering and harvest with grain yield showed that differentiation of grain is unrelated to growth in this study. Coupled with this, absence of relationship of straw yield to tiller counts and even negative tendencies are indirect indications of tiller decline at all these stages. Straw is the residual vegetative mass at harvest and only left overs can contribute to straw.

This can be termed as "adjusted protective self management". Musthafa (1995) and Beena Jacob (1995) have reported similar results.

Existence of exclusive relationship of number of grains per panicle to straw suggested that only those minimum vegetative portion required to support grains per panicle survives till the end. This observation coupled with the observation that the panicle bearing tillers were not correlated with straw points out to the very high magnitude of operational powers of negative factors.

The data further showed that even physiologial parameters failed to relate to yield. Chlorophyll \`a' is the photosynthetic unit and chlorophyll \`b' is the receptor pigment. Chl \`b' is formed from chlorophyll \`a'. Absence of relationship of Chl.\`a' to yield may suggest that yield of grain is probably, only the result of translocation to the florets from the earlier formed vegetative portions. Beena Jacob (1995) and Musthafa (1995) also have reported that the entire Chl \`a' get destroyed by flowering in rice grown in the laterite soil. Absence of significant relationship of chlorophyll \`a' to total biomass or its components appeared to be an indirect resultant of tiller decline observed throughout growth.

Data on the requirements of nutrient elements for a yield above 120 g per pot revealed that the minimum amount for the same yield of every element varied with soils and also in the various plant parts (Table 4.2.10).

A comparison of mean yields in the soil types showed that laterite soils gave the mean yield of 112.8 g pot^{-1} which was followed by black soils and \`kole' lands in that order. The variation in minimal requirements of any element with soil types can only be related to specific chemical composition of the soil types; which inturn will mean that even critical level has to be linked to soil. As the chemical constitution of the same soil type itself varies from place to place critical plant content will have to vary. Yoshida (1976) and Tandon (1991) have reported different critical levels for the same element. Sreekumaran (1998) have also found that critical concentration is not a reliable index of nutritional needs.

Variations in the requirements of an element especially applied ones like N, P and K depending upon chemical composition would mean that the level of an applied input is governed by the nature and content of native elements. Thus it is possible that the variation in leaf nitrogen content between 1.97 to 3.66 per cent (Table 4.2.10) has been due to the variations in the content and magnitude of nonapplied elements. Mathewkutty *et al.* (1994) have reported similar results in coconut. These results would indicate that simple correlations of elements with yield will be governed by the influence of other elements and as such will not be reliable.

In the same way as any element will not be limiting absolutely and productivity is the result of combined effects, correlations may be sometimes spurious. Absence and inconsistency in the correlations in Table may be explained in this context.

The data presented in Table 4.1.10 further reveal that no nutrient element is actually and absolutely limiting in any of the three soil types. Increases over the minimal level of applied input possibly is to neutralise the ill effects of some native elements. Thus higher leaf content of N may more effectively counteract Fe in laterite and black soils. Similarly higher K counteracted the ill effects of excess $\frac{\mathrm{Ca} + \mathrm{Mg}}{\mathrm{K}}$. Marykutty *et al.* (1992) and Musthafa and Potty (1996) have reported that ratios explain better the yield expression in rice.

Yoshida (1976) fixed the critical level of Fe, Mn, Zn and Cu as 300, 2500, 20 and 6 ppm. The present data shows that all these were in excess of the critical levels. Nitrogen, P and K content of leaf in laterite soils were 2.4, 0.28 and 2.4 per cent respectively (Table 4.2.3). Thus it is possible that higher content of N and K were required to neutralise higher contents of some other excess elements. Thus at least in part yield expression is the net neutralising effect of unfavourable influence of some elements by the favourable influence of others. These results would lead to the conclusion that low yields are often instanccs of failure to neutralise the unfavourable influences. The fact that the unfavourable influences are plant borne (as they are due to excess contents), and thus the causes of low yield can be designated as internal chemical effects. As the excess absorption is due to excess content in the soil and its availability, it can be referred to as "Soil through plant" cause.

Yield is the metabolic end product of growth and development. Metabolic utilisation of elements is a pre-requisite for growth. Low yield of crop inspite of high contents appears to be a direct evidence of physiologic unavailability. Indirectly it would indicate that chemical function preceeds physiological utilization. Singh (1970) have found that such a situation is the cause of low yield of cowpea in alkaline calcareous soils. This has been subsequently proved in other crops like rice (Pillai, 1972), groundnut (Dungarwal *et al.*, 1973). Wider protein N - Protein S ratios and narrower total N - total S ratios differentiating metabolic and non metabolic contents have also been reported (Dev and Saggar, 1974).

A comparison between iron content of the root on one side and other plant parts on the other (Table 4.2.3) showed that root iron is improportionally very high. Marykutty *et al.* (1993) found that a very large quantity of iron is seen as surface deposition. Iron deposition probably destroy the root system through chocking (Plate 1 and 2) necessitating further and progressive development of roots. One possible cause of low yield may be this forced diversion of photosynthesis. Leaf content of Fe at all stages were also beyond critical levels. Bridgit and Potty (1992) have reported that the high iron contents in the leaf have led to low content of chlorophyll a and a wide chl. \`a' : chl. \`b' ratio which also contribute to low yields.

Thus the data indicated that combined influence, external physical effects and internal chemical and biochemical effects contribute to poor productivity of rice and thus call for ameliorative soil management and corrective physiologic management. Rising tendencies in cell sap pH have been identified as index of physiologic malfunctioning and treatment to keep down pH levels of leaf sap have been found to reduce stress effects of excess content of elements and increase the yield. (Dungarwal *et al.*, 1973). Marykutty *et al.* (1992) have reported that pH of leaf sap of rice should not rise beyond 6.2.

Necessity of physiologic correlations is further indicated by content Fe, Mn, Zn and Cu which were higher than the upper critical levels proposed by Yoshida (1976).

Thus the study showed that low yield and marginal response of rice to nutrients has been due to high iron deposition in the root and excess plant contents of Fe, Mn, Zn and Cu. A management programme to contain them shall improve the nutrient use efficiency and increase the yield profoundly.

5.3 EXPERIMENT III

Crop growth and yield are the result of metabolic process and as such variation in yield is to be viewed as the product of variation in the rate of metabolic processes. Cultural and nutritional managements alter the rate of metabolic processes through modifying the soil plant interactions. Hence a variation in yield of the tune of 30 per cent observed in the present study has to be attributed to this variation.

Data presented in Table 4.3.1 showed that the dry seeding has given an yield of 11884 kg ha^{-1} biomass partitioned between 6496 kg of grain and 5388 kg of straw ha^{-1} and the improvement in grain yield over transplanting and wet seeding were 37.8 and 40.8 per cent respectively. Superiority of dry seeding over wet seeding and transplanting has been reported (Anon, 1990) from RARS, Pattambi.

As different methods of crop establishment have received uniform management practices a high yield in dry seeded crop will mean a higher nutrient use efficiency and vice versa. Thus low yield in wet seeded and transplanted crops are due to some variations probably in the soil or plant or both.

Morphological development is the expression of metabolic process as well as their rate. A significant superiority manifested in the tiller counts height and dry weight during the three phases of crop growth viz., MT, PI and flowering stage pointed out that the high yield in the treatment has been due to a higher metabolic activity manifested through better morphological development throughout the growth of the crop (Table 4.3.1a).

A significant observation in this context is that in wet seeding and transplanting the dry matter accumulation was not only below 40 per cent of the dry seeded crop but dry matter accumulation process virtually ceased at PI stage while the process continued further in dry seeding. It appeared that the higher rate of accumulation of dry matter as well as the continuance of the growth process onwards further have been the cause of the high yield and vice versa.

Incidently the marginal and declining dry matter accumulation in the post PI stage preceeded by very slow growth rate in the early stage in WSR and TPR and the early inhibition reached the maximum in the post PI stage (Post PI cessation) to arrest the crop growth. High yielding varieties are known to accumulate drymatter till harvest (Yoshida, 1981). The variety Jyothi used in the experiment is a high yielding variety produced by crossing TN1 x Ptb10. The results thus suggests that even high yielding varieties fail to express itself in these situation due to the inhibition. It is also possible that metabolic products are diverted from final accumulation as a mean of escaping from inhibiting influences for survival. Bridgit and Mathew (1995) and Mustafa (1995) have reported similar results. Photosynthetic functionality of the leaves at PI and flowering stage (boot leaf) as observed in the present study add further evidence to the above observation (Table 4.3.1b).

The significance of post PI cessation is evidenced further by the number of grains per panicle. Though the yield variation was of the order of 30 per cent, number of grains per panicle had been almost the same in all the treatments and the advantage of continued dry matter accumulation beyond PI stage was confined to number of filled grains as well as 1000 grain weight.

The fact that the number of grains/panicle has been constant irrespective of the method of crop establishment, points out to the significance of early growth leading to higher number of tillers and panicles per plant. Mureta (1969) have reported that the number of florets is the most important parameter in deciding a high yield. Thus the very low yield in transplanted and wet seeded crops are due to the combined effect of low productive tillers, filling percentage and thousand grain weight. Thus wet seeding and transplanting are affected in all the yield contributing components.

A direct observation of the metabolic rate as evidenced by chlorophyll content revealed that dry seeding had registered a higher content which might have contributed to high dry matter accumulation and yield in this treatment. It is also pertinent to note that dry seeding was conspicuous in the stability of chlorophyll `a' throughout. Unlike the dry seeded crop, in the other two treatments, the balance between chlorophyll `a' and `b' have shifted in favour of `b' thereby reducing the size of the real photosynthetic unit. This also appears to have contributed to the lower number of filled grains and grain weight in these treatments.

Leaf sap pH is considered as a physiologic index of crop productivity. Marykutty *et al.* (1992) have reported that leaf sap pH should be around 6.2 for maximum productivity. Results in the present study has indicated that in wet seeding and transplanting the sap was highly acidic which tended to increase progressively as against a near steady state in dry seeding. A steady sap pH about 6.2 appears to a biochemical index for high yield.

Metabolic inhibition in a crop subjected to the same atmospheric but varying soil environments evidently is related to soil situation and roots are the best morphologic indices. Data in the Table 4.3.1a. will show that number of roots were almost 45 per cent less in wet seeding and transplanting compared to dry seeded crop. Average length of root was also low in them. Poor morphologic development and low dry matter accumulation shall thus be a direct function of the ramification of the root system which in turn decides nutrient removing power of the plant. The poor development of the root system can only be the effect due to saturation and submergence of the soil as well as their duration. Basically the system differed only in the commencement of submergence and saturation with dry seeding having an initial phase of unsaturated environments in the early stage. Evidently this hydrophilic crop required an unsaturated environment in the early phase to trigger off and then maintain a higher root development at least in the lateritic environment. De Datta (1981) have stated that rice can grow well with 1 mm moisture a day in the early phase.

As roots are the absorbing organs, development of root is evidently an index of the vigour of the above ground portion also. Yoshida (1981) have stated that the ideal balance of shoot : root ratio is 10 at the MT stage. The best ratio in the present trial has been only 7.4 implying that even dryseeding has not escaped the harmful effects of the soil environment totally.

March of shoot root ratio from PI to flowering stage showed a decline at PI and flowering stages in dry seeding while it steadily increased in wet seeding and transplanting. A closer scrutiny of the data shows that the ratios alone are misleading and the higher ratios are the results of lower number of roots, tillers and productive tillers. Number of roots and ratio together will be better and shall serve as a morphological index of future realisable yield. Prabhakaran and Rani John (1992) have suggested the feasibility of predicting yield based on early growth.

Effectiveness of depth of digging when viewed in the context of plant development showed that digging to a depth of 30 cm instead of 15 cm significantly increased the yield by 621 kg ha^{-1} grain and 319 kg ha^{-1} of straw over 5786 and 4222 kg grain and straw ha^{-1} respectively. Increasing the depth of digging naturally increases the soil volume for root ramification which in turn facilitate better nutrient absorption, plant growth and yield. Increase in yield due to deep digging in rice have also been reported by Mosand *et al.* (1993).

Observations on the morphological parameters showed that deep digging had increased the number of roots at MT, had registered a steady and continuous increase in root dry weight from MT stage and increased the total dry matter accumulation. These observations had been in identical pattern with that observed in the system which substantiate that root number at MT and post PI accumulation are two important determinants of the ultimate yield.

Exclusive confinement of significant influence of digging on number of roots at MT, root dry weight at PI stages indicated that effect of deep digging on yield was mainly through facilitating root growth, ensuring their survival as well as increasing growth as against in wet seeding and transplanting. It would imply that deep digging minimises the root damage probably by removing some harmful factors though affecting the plant by washing them down to some extent.

Concurrent with this advantage is the significantly low leaf sap pH of the leaf both at PI and boot leaf stages. Data on the leaf sap pH in the systems indicated that a pH level above 6.2 is an index of high productivity (Table 4.3.1b). Leaf sap pH below 6.2 in deep digging points out to the possibility of some carry forward unfavourable effect into the metabolic system. Thus the yield of 5645 kg ha^{-1} grain is the net result of the balance between its favourable effect through the root system and unfavourable effect through the leaf sap pH.

Increasing levels of FYM has increased the yield and at 10 t ha^{-1} FYM, the increase had assumed significant level. Here again the characteristic increase in root number at MT stage, root dry weight at MT and PI stages and shoot dry weight at PI and flowering stages were evident. Also evident was the circumventing effect of FYM on post PI cessation of growth. This confirms that they are definite indices of productivity. However, the yields higher than 5465 kg ha^{-1} recorded in treatments viz., dry seeding and in 10 t ha^{-1} of FYM and the significant influence of average root length (Table 4.3.7) on yield pointed out that average root length has a significant role in boosting the yield, though it is only second to root number.

Application of 10 t ha^{-1} of FYM significantly increased the number of filled grain as well as percentage of filling (Table 4.3.1c). Physiologically filling is a function of translocation and the high yield obtained due to application of 10 t ha^{-1} of FYM is possibly the result of facilitated translocation.

Organic manures are soil ameliorants and sources of nutrients. But the fact is that application of 10 t ha^{-1} of FYM could not affect the chlorophyll and leaf sap pH at any stages of growth in rice compared to control (Table 4.3.1b). Lower root number, mean root length, dry matter accumulation rate and dry matter increase in the post PI stage suggest that deep digging or FYM are inadequate to correct the malady. The superiority of dry seeding further indicate that the malady is linked to moisture regimes.

Data on the interaction effect between crop establishment and depth of digging, crop establishment and FYM levels and depth of digging FYM levels showed high levels of significance in morphological and yield attributes but yield has not shown any significant increase. This apparent contradiction can be explained from three angles. One is that the statistical significance is overall significance and not uniformly system specific. Thus deep digging increased root number and dry weight in dry seeded crops but reduced shoot/root at Pi. In wet seeding and transplanting depth of digging did not affect. The data have shown that in the system, variation had been marginal due to the combined effects.

Advantage of depth of digging had been confined only in roots in dry seeding. In wet seeding, the advantage in number of panicles was offset by a reduction in other yield attributes. It would also mean that the early positive effects did not carry forward to the yield of grain.

This is well expressed as is evident from Table 4.3.2d. of second order interaction.

Combined effects however manifested a significant disadvantage in the metabolic part as is evident from the data on pH (Table 4.3.1b). Reactivity of the sap had been either low or high and not in the optimum range. All these results imply that beneficial effect of cultural management, though system specific, had been at least unable to favourably modify the metabolic process.

Elemental composition of the various plant parts have served as a pointer to the morphological variations. Increasing concentration of Fe in the root at MT stage appears to be the cause of lowest root number and average root length in the crop. As against 10619 ppm of iron in DSR it had been 28979 ppm in WSR and 42504 ppm in TPR (Table 4.3.3a). Investigating on the Fe effect on rice, Marykutty *et al.* (1993) have reported that large scale deposition of iron in the roots worked out to be 2.00 kg day^{-1} in one hectare. The high P and K content may be accompaniments of this high Fe in the roots. Significant correlation observed (Table 4.3.7) confirm that Fe content and/or deposition was the pre disposing cause of low root development. Significantly increasing iron content from dry seeding to transplanting further indicate that Fe deposition is a function of soil moisture regime. In the light of the above it will be reasonable to assume that deeper digging though reduced the iron content of the root, did not ameliorate the moisture effect as the lower yields in these treatments is the reflection of the inefficiency of this amelioration.

Distinguishing features of tiller production process has been a continuous production of tillers at all the stages of observation. Continuance but undesirable increase in tillers in the post vegetative phase in wet seeding and transplanting crop was followed by a post flowering decline against a steady tiller decline in dry seeding from PI stage. Percentage reduction of tillers after flowering had been lowest in dry seeding also. Being a growth phenomenon, higher number of tillers in dry seeding can be explained by the higher N content in the plant at MT and PI stages but it can not explain either the increase of tillers in the post vegetative phase in wet seeding and transplanting or tiller decline in dry seeding. More over it may also mean that root content or shoot content of Fe and Mn *per se* have no relations to tiller production.

The ratios of N/Fe and N/Mn will explain this phenomenon (4.3.8a, 4.3.8b, 4.3.8c) A wider N/Fe and N/Mn ratio indicating a relatively higher content of N has been the deciding factor. Wider ratios facilitated tiller production at MT and the normally expected decline whereas a narrow ratio inhibited tiller production but lead to a steady but undesirable increase in tillers upto flowering and these result is a pointer to the fact that more contents of elements in tissues can not explain always a phenomenon which can be done by ratios. The above hold good for the tiller production process observed under cultural and manurial treatments of the experiment. A comparative perusal of the data on elemental composition and nutrient ratios also have shown that widening of the ratios has been brought about by reduction in the content of Fe and Mn and not by increase in N content (Table 4.3.3c. and 4.3.11). This suggested that the management to reduce the Fe and Mn contents in the root and plant parts held the key to improved productivity.

The influence of these ratios on physiologic process of dry matter accumulation brought about by the chlorophyll content at MT, PI and flowering stages as well as the leaf sap pH at these three stages as well as their significant correlations are shown in Table 4.3.9 and Table 4.3.11. The regulatory effect of the ratios on the physiological observations is a direct index of the interfering influence of excess iron on the metabolic process and regulating the productivity expression of rice.

Analysing the causes of low productivity of rice in laterite soils Potty *et al.* (1992) have stated that high iron content of leaves including the boot leaf is the principle cause of low expressed yields in high yielding varieties in laterite soil.

The non-significance of FYM and depth of digging on the N/Fe and N/Mn and N/Zn ratios appears to be the cause of their inability to influence the yield of rice to any marked extent. Bridgit and Potty (1992) have reported that heavy absorption and high tissue contents of Fe tilts the balance between chlorophyll `a' and chlorophyll `b'.

Data (Table 4.3.5) on the interaction effects of various treatment combination showed that they failed to show any consistent positive progressive effects on nutrient content from root to boot leaf and on yield. This is probably because of the unfavourable influence of high content of Fe and Mn in the soil which increases with increasing the depth of digging. Thus even dry seeded crop become subjected to the unfavourable influence of these elements more when other management measures increase Fe and Mn contents.

Iron and Mn are elements which increase their availability in the soil and absorption by plant under saturation and submergence. Thus combining digging and methods of crop establishment did not show beneficial effects.

Direct effect of FYM levels (Table 4.3.3e. and 4.3.3f.) showed its inability to significantly modify the Fe, Mn and Zn contents which in turn had lead to absence of positive effects of interaction (Table 4.3.9 and 4.3.11). Results of the Permanent Manurial Trial at RARS, Pattambi, showed that yield of rice could not be improved beyond 4000 kg ha^{-1} even by application of 36 t ha^{-1} of FYM for over 20 years (Anon, 1990).

These results thus reveal that deep digging or increased levels of application of FYM are not the panacea to rectify the low yield condition in the laterite soils.

Correlation between biometric differentials and yield presented in Table 4.3.7 and Fig. 5.3.1 will show that root numbers per plant at MT stage is the best index of future yield, which in turn suggest that inhibited root growth and or root decay is the best index of low yield. Conversely it means that unfavourable nutrient ratios affect yield by affecting root growth.

Significant correlation between yield attributes, root dry weight and total dry weight between MT and PI stages is naturally to be expected because this is the dry matter that affect the panicle and floret number (Fig. 5.3.1). Mureta (1969) has also reported that dry matter accumulation before heading decides floret number and dry matter accumulation between flowering and PI stage contributes to floret development and hence the positive correlation.

Shoot dry weight was found to be unrelated with grain, straw and total biomass. This may be because of the possible tiller decline after maximum tillering stage. Musthafa (1995) has reported severe tiller decline in rice in laterite soils.

The ratios among elements and their significant differences among the different treatments in the context of yield realised give an indication of the relative excesses, dificiencies and optimum levels of elements which were responsible for the yield. In turn they will also help in identifying the limiting factors in the process of yield formation.

Critical analysis of the data on nutrient ratios in plant at MT, PI and boot leaf stage showed that the yield levels in transplanting and wet seeding had been low due to unfavourable ratios among them (Table 4.3.8a, b and c and Fig. 5.3.2, 5.3.3., 5.3.4 and 5.3.5). The ratios indicated that the applied nutrients N, P and K had to be increased or decreased in relation to some nonapplied elements in the plant. P has to increase in relation to Ca, S, Mn and Fe and decrease in relation to K and Mg; Nitrogen has to increase in relation to P, K, Mg and Cu and K has to increase in relation to Mg and Cu and decrease in relation to S, Fe, Mn and Cu. It may apparently appear that the yield is low because of the deficiency of these elements in the plant. But conversely the result that P has to increase in relation to Ca, S, Fe and Mn for a higher yield would mean Ca, S, Fe and Mn are very high and as such they limit the yield because of the unfavourable ratio and the statement means that either P has to increase or Ca, S, Fe and Mn are in excess in the plant naturally due to higher content in the soil and that their higher contents are responsible for low yield through induced ineffectiveness or inactivation of P. These in turn would mean that amelioration of excess influence of Ca, S, Fe and Mn will increase the yield by increasing efficiency of P.

A perusal of the data will also show that this has not been the case for P alone. Contents of S, Fe, Mn and Zn have to decrease in relation to K in the plant. Phosphorus, K, Mg and Ca have to decrease in relation to N in wet culture of rice to get comparable yields as in dry seeding. This is confirmed from the data on the actual content of these elements in the plant tissue at various growth stages.

A high content of the elements considered as micronutrients is characteristic of lateritic soils. Saturation or submergence increases the availability of these elements (Hassan, 1978).

Failure of the crop to increase the yield due to digging deeper or increasing levels of organic manure shall also explained in the very same way.

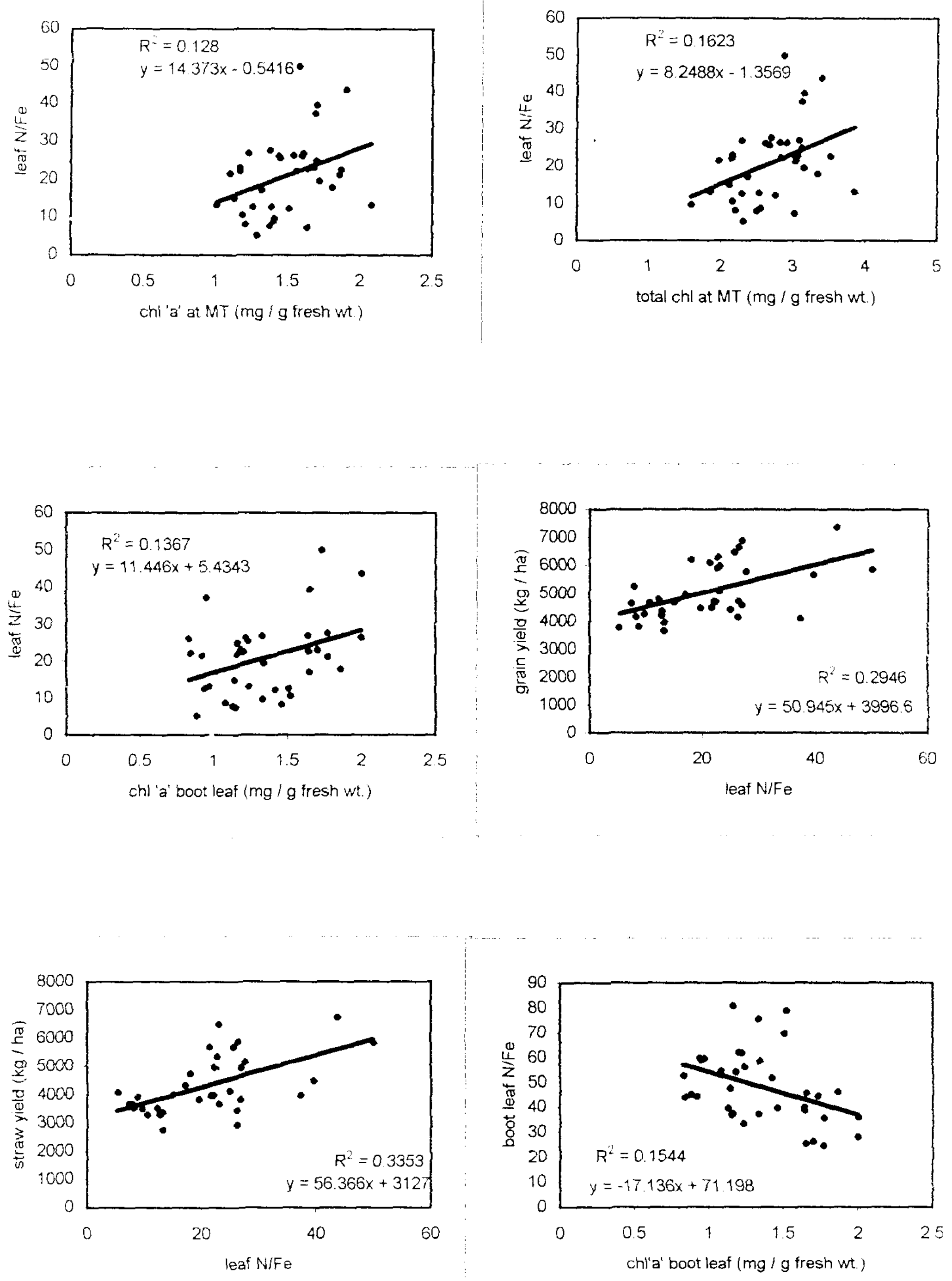
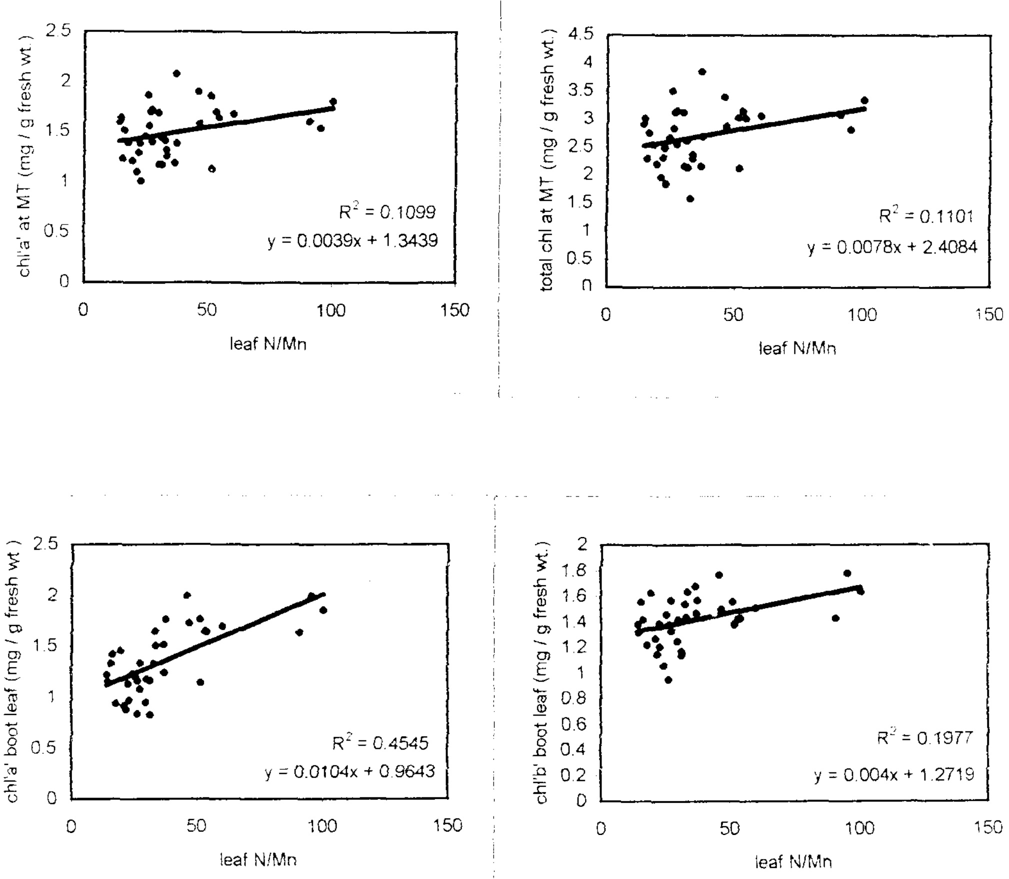


Fig. 5.3.2 Influence of leaf nutrient ratios on yield and physiologic attributes

Fig. 5.3.2 contd......



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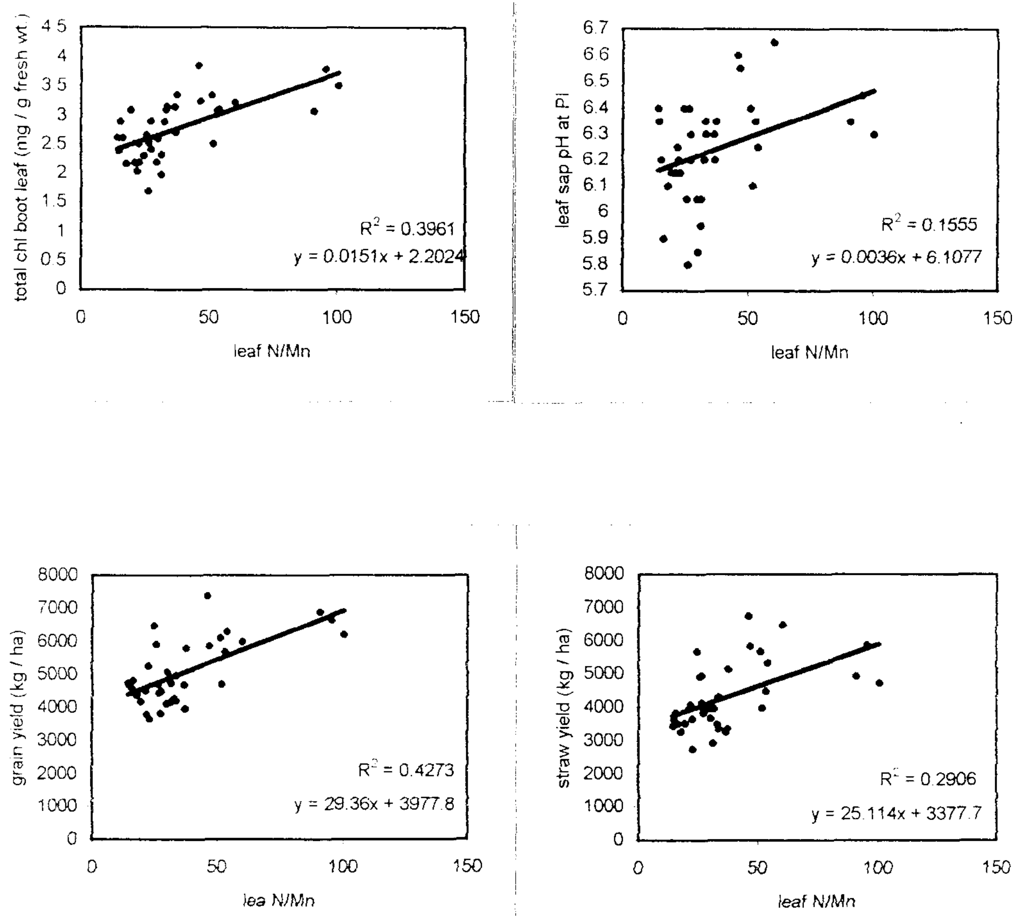


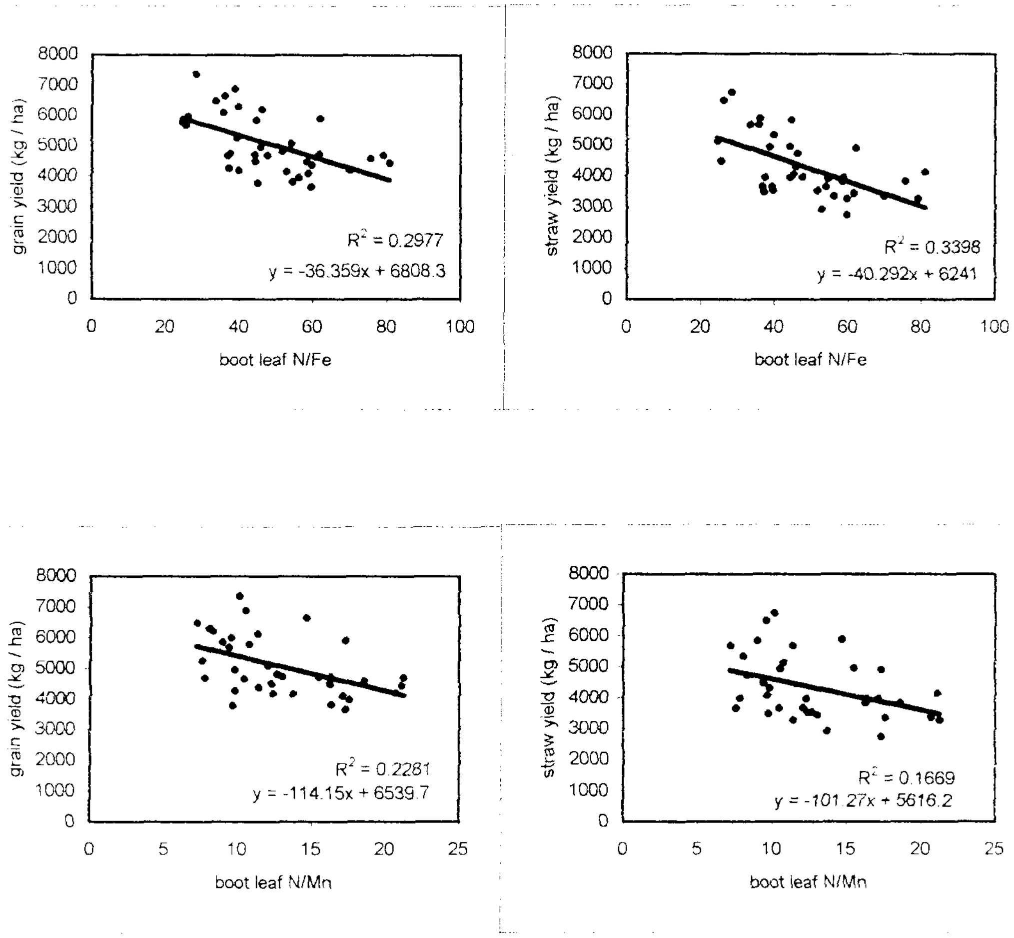


Fig. 5.3.3 Influence of boot leaf nutrient ratios on yield

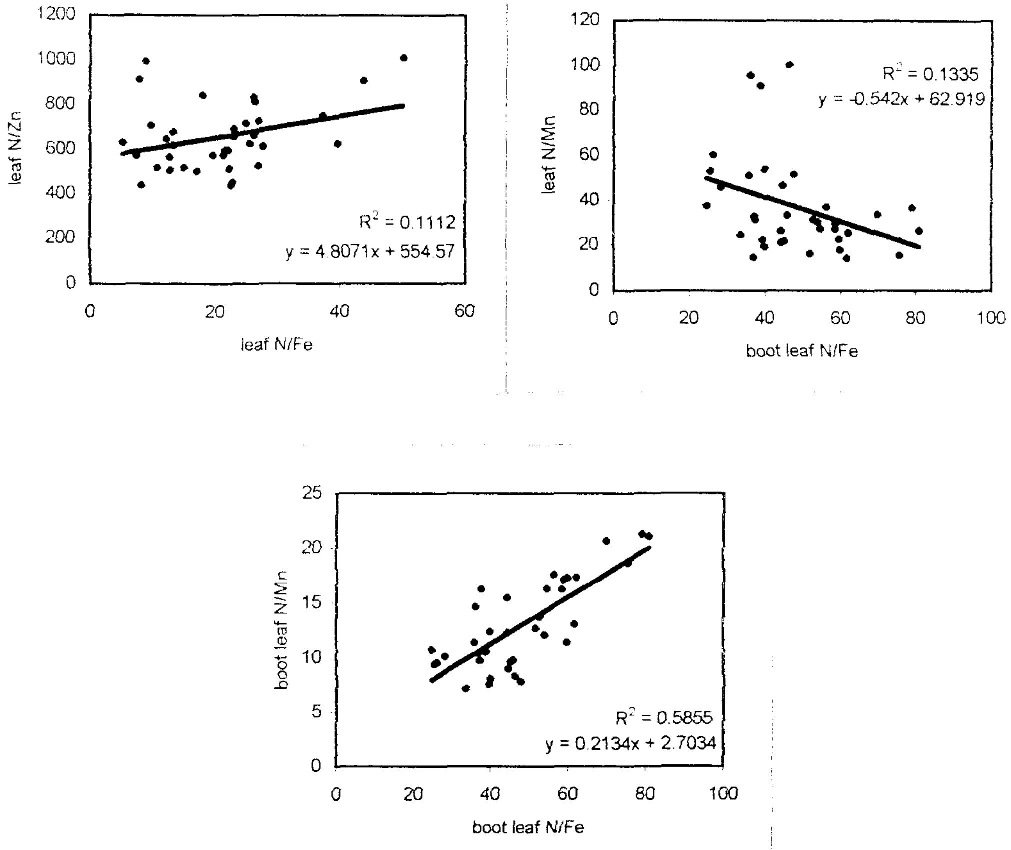


Fig. 5.3.4 Inter relation of leaf and boot leaf nutrient ratios - first crop (May - September)

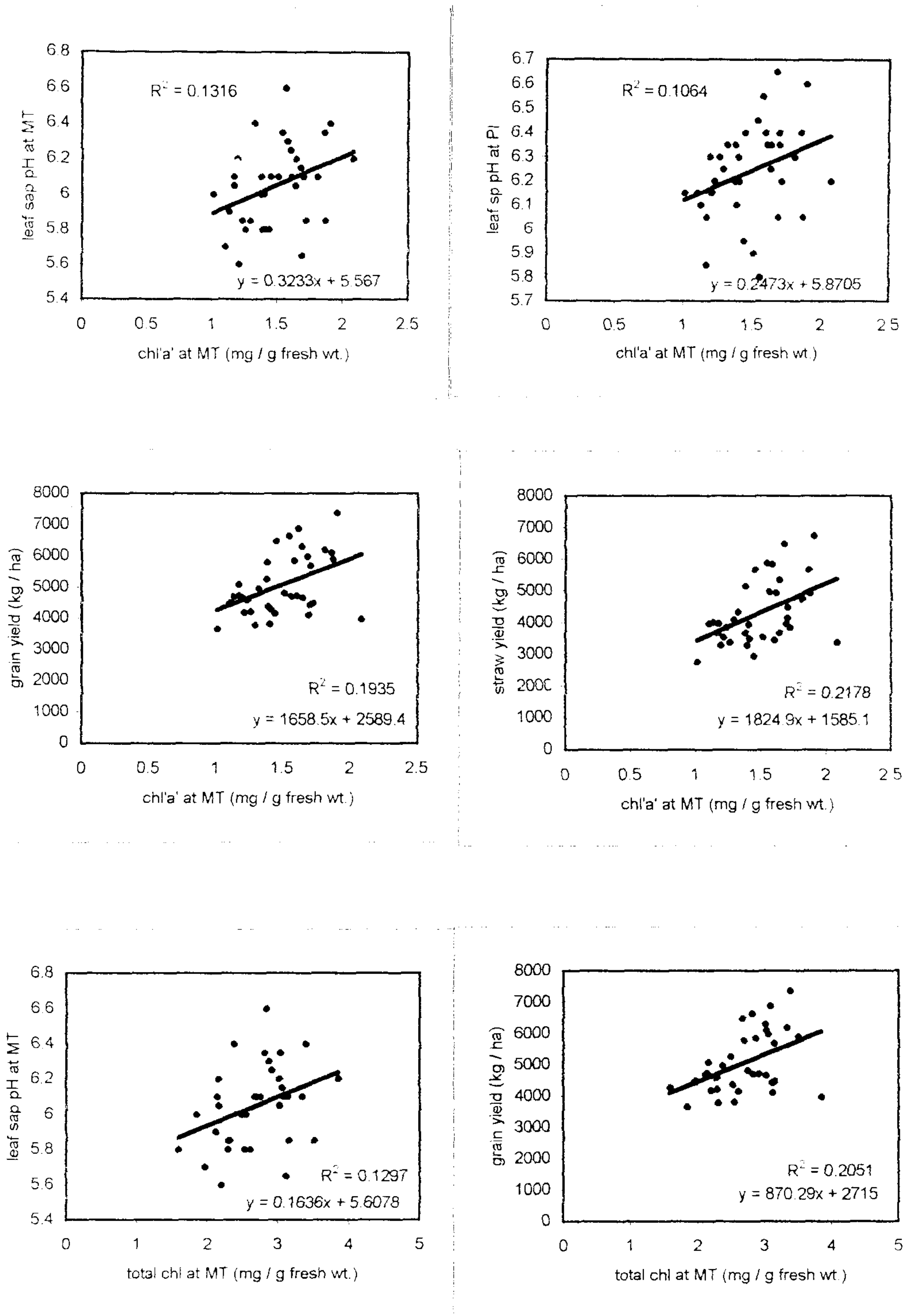


Fig. 5.3.5 Inter relation of physiological attributes with yield- first crop(May-September)

Fig. 5.3.5 contd.......

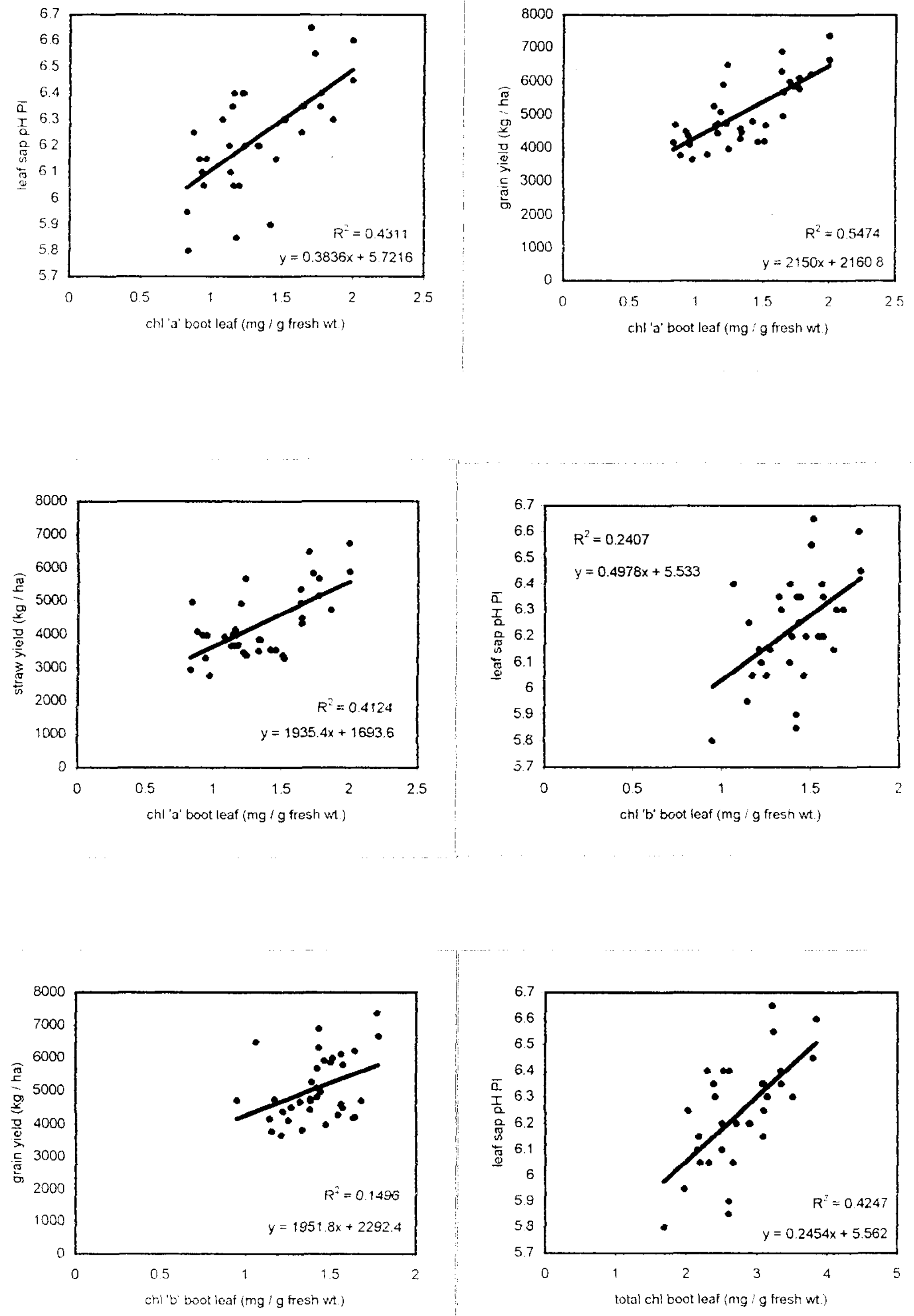


Fig. 5.3.5 contd......

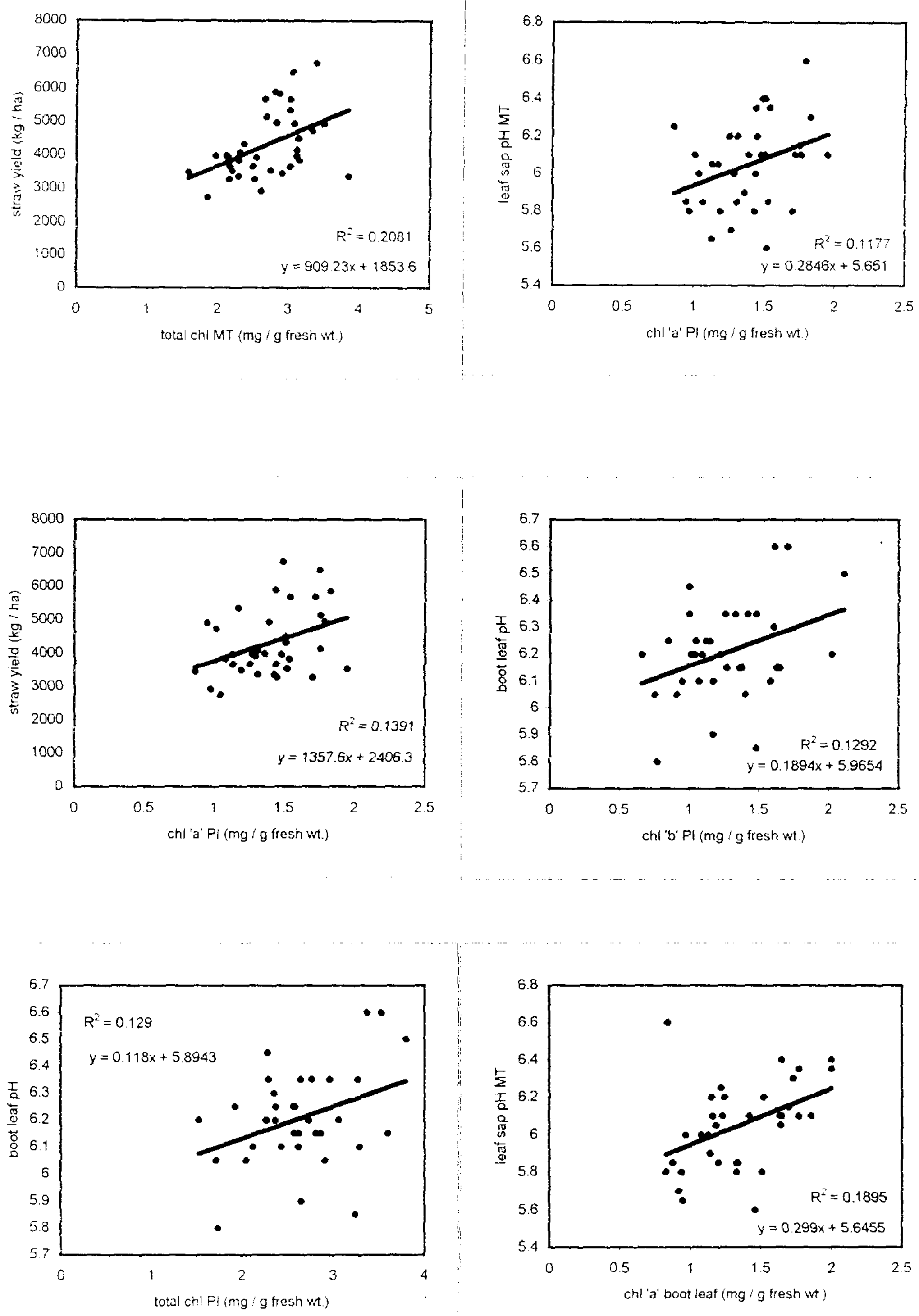
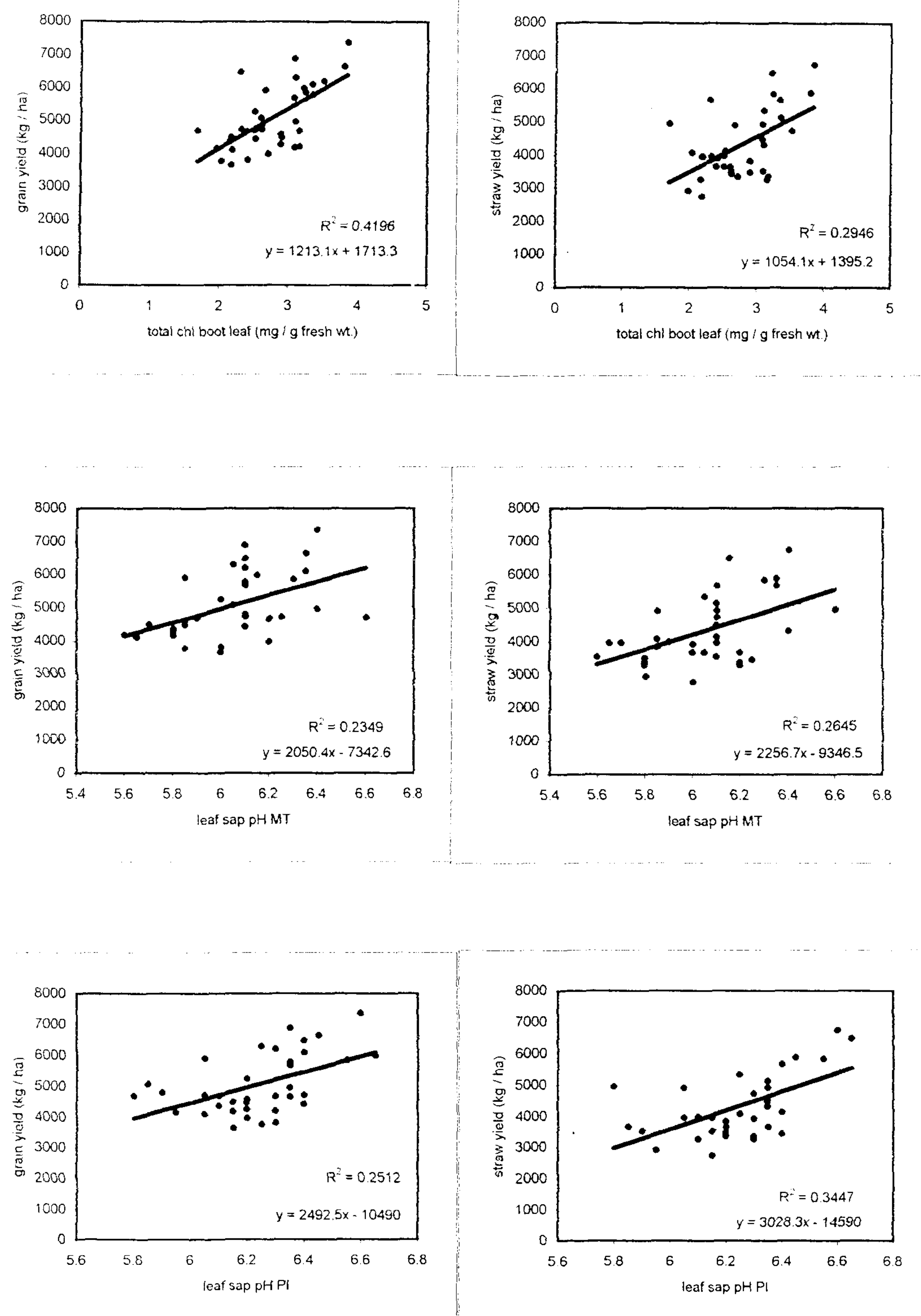


Fig. 5.3.5 contd........



Deep digging increases the volume of soil for root ramification and better absorption of elements. But in a situation wherein excess elements limit growth, deep digging will also increases the excess elements. Absence of significance in majority of the ratios confirms this.

In the case of increasing levels of FYM also, the effect has been more or less the same. It had failed to affect the balances among the nutrients at any stage. This is evident because of the fact that manures are derived from organic residues which also contain these unfavourable elements as they are basically products of this environment.

A comparative perusal of the ratios at the three stages viz., MT, PI and boot leaf showed a progressive shift in the ratios (Table 4.3.8a, 4.3.8b and 4.3.8c). As an example N/Fe ratio at the above three stages had been 17.7, 28.5 and 35.4 in dry seeded crop. A perusal of the data on contents will show that this shift has been the result of differential translocation of elements in this case reduced translocation of iron and higher translocation of N. The rate of translocation may be the characteristic of the element, its mobility as well as their interactions. Differential translocation would imply accumulation of some elements in early vegetative parts probably due to formation of complexes. This would mean that neither content nor ratio alone will be adequate to arrive at a judicious recommendation but a `combined content ratio approach' may be required.

A comparison of the efficacies of progressive shift in ratios also in the different treatments showed that methods of crop establishment, depth of digging or organic manure levels are not equally efficient. Progressive shift had been low in wet seeding and transplanting. There was not much change by depth of digging. Thus it is probable that rate of shift also may affect the yield process and the effect of treatments as manifested by yield will be a function of translocation also.

5.4 EXPERIMENT IV

The experiment on methods of crop establishment, land preparation and organic manure/FYM levels conducted in the first crop season was repeated in the second crop season avoiding the dry seeding treatment. Significant results of the experiment have been the positive effects of deep digging and organic matter/FYM and their combined influence on grain yield though the best grain yield obtained in the season was 900 kg lower than that obtained in the first crop. Crop performance in the second crop season (October - March) has been reported to be poor in the national level. Poor yield in the second crop compared to first crop is a direct indication of inhibitory influences causing the yield reduction and calls for a management programme to ameliorate or circumvent them.

The second crop is situationally subjected normally to a progressively decreasing moisture regime since November-December which is preceeded by a possible excess moisture level in the early phase. This is due to withdrawal of monsoon after early November as is evidenced from data in Appendix I and Fig.3.1. The situation is just the opposite in the first crop season. The response variations to treatments appears to be primarily due to this subjective influence of situational effect.

Data presented in Table 4.4.1b have shown that digging to a depth of 30 cm have significantly increased the yield from 4339 to 5211 kg ha^{-1}. Results further showed that a significant increase in 1000 grain weight had been the contributing component. Almost near constant straw yield and significant increase in grain yield would suggest that increased grain weight and grain yield have been due to the enhanced rate of post flowering photosynthesis. Yoshida (1981) have reported that significant photosynthate share in grain is contributed by post flowering photosynthesis.

A further perusal of the data will show that the above beneficial effect was the positive function of the decline in leaf sap pH which inturn might have been due to marginal reduction of Fe in the boot leaf (Table 4.4.3c).

Application of FYM @ 5 t ha^{-1} has also significantly increased the yield of grain from 4031 to 5176 kg ha^{-1} but without much change in straw yield (Table 4.4.1b). A perusal of the data will show that this yield improvement had been through an increase in the number of florets and filled grains which inturn contributed to a higher panicle weight. Increase in grain yield due to increase in the number of florets and weight of grain have been reported by De Datta (1981). Thus effect of FYM had been unlike that of deep digging and might have started at least from earlier phases of growth as evidenced by increased root number and dry matter differentials and their correlation as in first season crop. However the dry matter accumulation was lower than what was obtained in the dry seeded crop. Comparable levels of dry matter differentials and yield in wet seeding and transplanting both in the first and second crops which were lower than the dry seeded crop appear to be an evidence in favour of inability of these systems of crop establishment to supersede these inhibitions. Comparable values of wet seeding and transplanting over both seasons suggest that low yield in second crop is not a weather effect but a soil effect.

A comparative perusal of the data on nutrient content and uptake in grain and straw will reveal that though both deep digging and FYM have increased the yield, the mechanism of yield improvement has been different. Data showed that deep digging makes a larger soil volume available for root growth (Table 4.4.1.a) and facilitate larger absorption as evidenced by increased contents of the elements in grain and straw as well as uptake (Table 4.4.3d, 4.4.6a and 4.4.6b). Digging has increased the uptake of N, P, K etc.

Farm yard manure on the other hand has increased the yield by reducing contents and uptake per unit yield. This would mean that yield improvement has been through dilution and not due to increased nutrient supply. Musthafa and Potty (1996) have reported that *in situ* green manuring in semi dry rice increased the yield of grain not through additional supply of nutrients. The fact that additional uptake is prevented implies a soil role for organic manures also. Subramaniyan *et al.* (1993) and Sekharan *et al.* (1996) have reported that main role of organic manure/FYM is to improve the soil environment. The reason for the failure of incremental levels of FYM beyond 5 t ha^{-1} appeared to be imbedded in the data. Failure to increase yield had been associated with significant reduction of Ca in the straw and an increase in K and S contents as well as a reduction in the Fe and Zn contents to that of M_0 level. Significant increase in the straw yield without an increase in the yield of grain may thus be due to reduction in Ca content. Thus increasing the Ca level to 0.3 per cent in the straw by application of Ca coupled with FYM would raise the yield further. Results due to deep digging also confirm the above results and suggested possible further yield improvement due to deep digging if combined with Ca supplements. This is further substantiated by the data in Table 4.4.4.c which have described the Ca - Mn and Ca - Zn relations.

Differential pathways of deep digging and FYM in increasing the yield would suggest compatibility and synergesic effects of their combination. This is substantiated by the data in Table 4.4.2.c which showed that the yield due to the combined effect increased to 5692 kg ha^{-1}.

Transplanting and wet seeding primarily differ between themselves in the number of plants per unit area employed to produce yields. Wet seeding employs almost 3-4 fold more number of plants so that harmful influences are distributed over a larger population and lower yields from a larger population will out weigh the larger yields from a smaller population. Approaches based on this concepts have proved itself true in the experiments of Rao and Raju (1987), Shah *et al.* (1991), Trivedi and Kwatra (1983), Paraye *et al.* (1996) and Srivastava and Tripathi (1998).

In the present experiment the data presented in Table 4.4.1. will reveal that wet seeding manifested significant advantages in number of roots per/tiller, panicle weight, percentage filling and thousand grain weight. Progressive increase in dry matter accumulation during the pre-flowering phase was favourable. A perusal of the data on physiological attributes will show that the morphological expressions were not an accident but is the product of favoured metabolism. Bridgit and Mathew (1995) have also reported the advantage of wet seeded rice over transplanted crop. But inspite of a favoured physiological set up and morphological expression extending to the terminal point of the life cycle of the plant, the data showed that grain/straw ratio had been the lowest in this treatment in the entire project and the grain yield had been lower than that of transplanting. Wind velocity in the post flowering phase of the wet seeded crop and shattering nature of the variety may provide the answer. Velocity of the dry desiccating winds had been above 8 to 13 km hr^{-1}. Viswambaran (1989) have reported that wind is the cause of low yield during second crop season.

Data on interaction between land preparation and crop establishment (Table 4.4.2a) showed that wet seeding produced more number of roots as well as better longevity of roots in shallow digging. This is naturally because when seeding is surface sowing which will be less affected by the reduced conditions in the deeper layers and consequently excess Fe and Mn effects. However the high yield obtained in wet seeded crop in deep digging might be due to the higher chlorophyll content in the treatment.

Superiority of wet seeding combined with shallow digging in the early stages of growth has been found turned to deep digging at later stages (4.4.2a). This change appeared to be due to the pH reduction due to deep digging and also due to the beneficial effect of deep digging manifesting in the later stages possibly because of progressive reduction in water content with lime.

Better efficiency of FYM with deep digging would suggest that a combination of deep digging and FYM application at 5 t ha^{-1} with wet seeding ensuring a larger population will be better, provided that the crop does not face the harmful wind effects. Failure to get significance for this combination might have been due to the wind effect.

Nutritional evaluation of the methods of crop establishment showed that transplanting the crop inspite of a higher boot leaf content of N and P and comparable content of K has recorded a lower panicle weight and filling percentage than wet seeding which implied that these nutrient contents of the leaf *per se* are not involved at least fully in the grain development. The lower filling percentage, panicle weight and thousand grain weight inspite of favourable weather relations (Alexander *et al.*, 1991) could naturally have been only due to the significantly higher content of Ca, Fe, Mn and Zn in the boot leaf.

Another possible cause of low panicle weight lower filled grains and thousand grain weight in the transplanted crop appeared to be the steadily increasing non productive tillers even after the panicle initiation stage. The increase in such tiller was 19 per cent in transplanted crop as against less than 12 per cent in a wet seeded crop.

Nutritionally this appeared to be the result of highly excess contents of Fe, Mn, Zn and Cu content of the root upto PI stage and culm and leaf (Table 4.4.3). This high content of Fe, Mn, Zn and Cu content of the root and plant can be traced to average root length which was 4.7 cm in transplanting as against 2.4 cm in wet seeding. Differential root lengths may be related to surface placement of seeds in wet seeding and deep placement of seedlings in transplanting. Musthafa (1995) have reported that post PI tiller production is an iron exclusion mechanism and that in this process major nutrients are wasted. From the nutritional point of view transplanting suffered from higher rooting depth leading to higher root and plant content of Fe, Mn, Zn and Cu. Nutritionally deep digging had contributed to a higher yield inspite of comparable root length through a higher root number both at MT and PI stages. This higher root number has resulted probably in a higher root activity as iron content per root had been 50 per cent less at MT and 10 per cent less in PI stage. This effect can be seen to have carried forward to a lower Fe and Mn content at PI stage.

Yield increase due to application of FYM also can be seen to have been due to a reduction of Fe content in leaf at PI and boot leaf stages. Though marginal, these reductions in turn have come possibly due to the increased root formation after MT stage (Table 4.4.1).

Failure of the yield increase beyond 5100 kg ha^{-1} due to deep digging or FYM appeared to be due to their failure to contain Mn and Zn in the plant and points out that alternate means to reduce them will have to be resorted to.

Seasonal influence on mineral nutrition of rice

Comparatively low productivity characterises the yield and yield process of rice in the second crop season (Oct-Feb.) throughout the state and the real cause has eluded so far. This fact that low yield inspite of a gradual retrieval of rain and floods from November and improving weather influences like longer hours of sunshine and wider day night temperature differences points out that nutritional causes will be the pre-disposing factor. Data presented in Table 5.1 depict the mean elemental composition in the two seasons.

Elemental composition of the leaf at PI stage and boot leaf showed that among applied elements K had been associated with lower yield in both the situations implying that a relative deficiency in the leaf and boot leaf may be the cause of low yield. The correlation is supported by the significantly low content of K in the straw as well as grain as the natural resultant of lower absorption. Significantly higher content of Fe in the root both at MT and PI stages as well as shoot at MT stage followed by significantly lower contents in leaf at PI and flowering stage suggested a low content of K in later developing parts, at least in part, is due to some inhibition for its translocation upwards from the culm; probably the obstruction acting at the culm level. This translocational inhibition also probably affect further absorption even if the element is present in available from in soil, which in turn is associated with low contents in grain and straw as well as lower uptake of the element. Thus the cause appears to be an internal one and hence physiological. This can be an induced relative K deficiency.

Equally important as the induced relative K deficiency is the very high content of Zn and Mn in root, culm and leaf each observed at two phases. Yoshida (1981) have reported that rice plant can tolerate Manganese and Zinc upto 2500 and 15 to 20 ppm respectively. Levels of both elements have exceeded these limits making them fatal for the plants. This fatal absorption and accumulation of Mn and Zn might have a direct bearing on the low productivity of rice in second crop season. Probably the very high levels of Mn and Zn in the leaf at PI and flowering stages interferes with both the process of floret formation and floret filling thereby reducing the yield.

Table 5.1 Seasonal effect on elemental composition of rice

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Grain yield (kg ha^{-1})
Season	Root at MT stage										Shoot at MT stage										
1st crop	1.14	0.22	1.58	0.026	0.068	2970	35741	278	18.7	66.8	1.72	0.28	3.03	0.111	0.098	2309	1933	433	5.0	35.3	4838
2nd crop	0.91	0.23	1.96	0.031	0.076	2251	38383	1384	90.7	46.8	2.93	0.33	3.57	0.082	0.106	2828	980	2262	31.0	14.8	4751
CD (0.05)	0.12	NS	0.23	NS	0.008	194.5	NS	236.3	8.58	8.6	0.23	0.02	0.51	0.018	NS	202.9	211.8	279.4	2.63	4.76	NS
CV (%)	19.3	21.2	21.5	92.2	19.5	12.5	25.0	47.6	26.3	25.4	16.3	11.7	16.8	38.2	16.8	13.2	24.2	34.7	24.6	31.8	10.8
Season	Root at PI stage										Culm at PI stage										
1st crop	0.78	0.21	0.67	0.026	0.051	2430	49375	227	12.3	57.9	0.92	0.28	2.59	0.033	0.084	1719	2044	618	3.6	58.4	
2nd crop	0.91	0.19	1.15	0.023	0.069	2343	40108	1197	80.3	48.9	0.99	0.26	2.16	0.065	0.108	1746	614	1937	64.1	8.0	
CD (0.05)	0.11	0.012	0.14	NS	0.006	NS	3750	130.8	10.6	6.59	NS	NS	0.19	0.018	0.019	NS	1208	360.5	11.1	11.1	
CV (%)	22.3	10.3	25.2	27.3	16.9	17.5	14.0	30.8	38.0	20.7	27.5	11.7	13.5	53.1	23.7	24.3	152.1	47.25	54.9	55.9	
Season	Leaf at PI stage										Boot leaf at PI stage										
1st crop	1.86	0.22	2.10	0.25	0.100	1834	1232	684	3.7	26.5	2.05	0.19	1.6	0.23	0.128	1784	388	1459	4.1	26.0	
2nd crop	1.72	0.18	1.48	0.32	0.116	1846	689	3609	26.6	6.3	2.43	0.21	1.41	0.26	0.105	2066	2709	2768	25.1	9.4	
CD (0.05)	NS	0.02	0.20	0.018	0.012	NS	318.1	142.0	1.40	1.64	0.17	NS	0.16	NS	0.019	162.4	109.6	228.0	2.04	3.0	
CV (%)	20.3	16.4	18.7	10.6	19.5	12.2	55.5	11.8	15.4	16.7	12.4	14.7	18.4	25.0	27.3	14.1	11.9	18.1	23.3	28.4	
Season	Grain										Straw										
1st crop	1.19	0.24	0.48	0.005	0.055	1404	86.0	89	2.4	21.2	0.82	0.15	2.60	0.19	0.092	1340	299	1470	4.0	48.7	
2nd crop	1.08	0.26	0.37	0.017	0.086	1345	2452.0	257	23.5	6.2	0.87	0.23	2.19	0.30	0.130	1492	2667	3452	51.2	6.0	
CD (0.05)	NS	0.018	0.05	0.006	0.004	51.7	57.8	12.8	1.9	2.0	NS	0.012	0.19	0.042	0.018	68.5	70.6	237.1	8.5	6.33	
CV (%)	19.9	12.9	18.9	12.8	8.0	6.3	7.6	12.4	24.2	24.8	19.3	10.44	13.3	29.8	21.4	8.11	8.0	16.1	51.3	38.8	

First crop (Kharif) - May-September Second crop (Rabi) - October-February

The observation that K content was lower and Mn and Zn contents were high from the culm at PI stage onwards suggest that the probable cause of inhibited translocation of K is Mn and Zn. Thus it appears safe to assume that lower yield of rice in the second crop rice is caused by direct effect of Mn and Zn as well as through their indirect effect on inhibiting K translocation.

Though the iron content of the leaf at PI had been above the proposed upper critical level, it was less in leaf and was only 55 per cent of that observed in the first crop season. Thus it appeared that Fe is not the more serious menace to productivity.

Another interesting observation is that high uptake of Mn and Zn and low yield were linked to low uptake of silica in relation to other elements. Thus it seems possible that silicate application may be the solution to minimise the Zn and Mn injury.

5.5 EXPERIMENT V

The most significant aspects of the results of the experiment has been a positive and convincing response for the application of K @ 120 kg ha^{-1} on the one side and the mechanics of interactions regulating the response behaviour of the crop.

Data on the process of crop development as expressed by the biometric observation (Table 4.5.1a, 4.51b and 4.5.1c) showed that the yield improvement had been the result of enhanced development of all the yield attributes viz., branches/panicle, panicle weight, filled grains/panicle and 1000 grain weight reflected by the differentials of the mean dry matter accumulated between MT stage and flowering which probably is due to the role of K in internal water relations of the plant (Tanaka, 1977).

More or less exclusive influence in post vegetative phase is further indicated by the observation on physiologic characteristics (Table 4.5.1b) Though the leaf sap reaction has declined in the boot leaf, K applied at 120 kg ha^{-1} has recorded the highest pH value both at MT stage and boot leaf of the plant. Marykutty *et al.* (1992) have reported an optimum pH of 6.2 in rice plant for high yield. In the same way, chlorophyll `a' significantly differed between the mean effects only in the boot leaf. Potassium applied at 120 kg ha$^{-1}$ had recorded the highest chlorophyll `a' content. More over it was only at this stage that chlorophyll `a' : chlorophyll `b' ratio has been positive which in turn has contributed to the better development of the yield attributes. Bridgit *et al.* (1992) have reported that instability of chlorophyll `a' reflected through a higher content of chlorophyll `b' than chlorophyll `a' is the physiologic cause of low yield of rice in laterite soil. It is possible that in a transplanted crop manifestation of physiologic effects may take a longer time.

Nutritionally, a positive response for increased level of K appeared to be a direct function of increase in the K content in all the plant parts viz., root at MT and PI stage, shoot at MT stage and culm and leaf at PI stages (Table 4.5.3a, 4.5.3b, 4.5.3c, 4.5.3d and 4.5.3e). An increase in yield due to the direct effect would mean a real absolute deficiency of the element in the soil which could not be compensated by the normally recommended dose of 45 kg k ha^{-1} for rice. Menon (1987) have also reported that higher yield of rice in the first crop of rice is due to the enhanced release availability of K due to the temperature effect from fallowing in the previous season.

Data on the main effect of K on the content of elements in the grain and straw (Table 4.5.3g and h) will show that contents of Mg, S, Fe, Mn and Cu have reduced with increase in yield. Increase in yield with a reduction in percentage content evidently point out to dilution. In other words K inhibited the uptake of these elements and increased the yield or K deficiency lead to excess accumulation of these elements.

These results point out to the fact that there is a real K deficiency and relative excess of Mg, S, Fe, Mn, Cu etc.

Crop response to K only at 120 kg ha^{-1} and above will need further explanation in the light of the fact that present recommendation is only 45 kg k ha^{-1} and laterite soils of the state are designated as one which did not give response to application of K. The cause of this rather abnormal behaviour is evident from the way by which K has increased the yield (Table 4.5.1c) as well as the principle governing availability of K. The foregoing paragraph showed that response of K at least in part is by limiting the uptake of cations like Fe, Mn, Cu etc. which in turn implied that a relatively high content of K will be required. Yoshida (1981) have also reported that deficiency of K increased the uptake of iron by rice plant. More over the principle governing the availability of K is not merely its content or availability in the soil. Its availability is governed by the activities of K in relation to other ions by ratio law enunciated by Schofield (1957). Thus the lack of response to K at lower doses will only mean sufficiency of K but insufficiency in relation to divalent ions like Ca, Mg, trivalent ions like Fe etc. Marykutty *et al.* (1992) have also reported that yield governing factor in rice is the narrowing down of $\frac{Ca + Mg}{K}$ ratio and not the individual components.

A further scrutiny of the data will show that application of 120 kg K ha^{-1} significantly increased the content of silica both in grain and straw. It is also probable that at least in part the increased yield might have been brought about by K through increasing the silica content of the plant.

Another significant observation in the present study has been that increasing levels of K has not affected the iron or Mn content of the root or shoot (Table 4.5.3a, 4.5.3b and 4.5.3c). The effect of K on Fe and Mn was confined only in the boot leaf (Table 4.5.3f). This will mean that yield increase due to K was mainly direct and indirect if any, confined only at the boot leaf stage and after. This probably would suggest a role on selective translocation of elements by K.

Data on nutrient uptake (Table 4.5.5a and 4.5.5b) studies confirm these observations.

An incidental but an important observation on the nutrient content and uptake of grain and straw is that content of elements like S, Ca, Zn, Mg etc. in the grain was not affected by an increase of K from 60 to 120 kg K ha^{-1}. But in the content of straw they showed profound increases. This probably is the result of selective translocation on the one side and on the other side would mean that vegetative portion serves another purpose of accommodating the excess elements.

A perusal of the data showed that the crop did not manifest any significant positive influence on yield of rice due to the application of Ca and S though S applied at 100 kg ha^{-1} had brought about a numerical increase of 334 kg grain ha^{-1}. Calcium had failed even to manifest any numerical increase.

A perusal of the data (Table 4.5.1a, 4.5.1b and 4.5.1c) will show that the absence of response has been in tune with morphophysiologic expressions. The difference between Ca and S was evident in chlorophyll content. The significant increase due to S application in chlorophyll `a' both at MT and PI stages appeared to be responsible for the numerical increase in yield which was significantly manifested in total dry matter at MT, branches/panicle and panicle weight.

From the nutritional point of view absence of response to calcium would mean that Ca was not necessary and that a content of 0.36 per cent in the leaf may be sufficient which is met from the native contents in the soil.

Data on the nutrient content of grain revealed that as an ameliorant, Ca applied as 150 kg lime ha^{-1} failed to increase the content of silica in the plant significantly.

Sufficiency of Ca as nutrient coupled with its ineffectiveness to increase silica appeared to be the cause of lack of response.

Sulphur, though increased the silica content of grain and straw significantly, failed to improve the yield. It had also resulted an increase in chlorophyll `a' both at MT and PI stages and panicle weight and branches/panicle among the yield attributes.

Influence of elements are two fold viz., direct effect and indirect effects manifested through interactions. Data on the content of nutrient elements in the various plant parts revealed that the worked out direct effects, though one is a cation and another is an anion, were similar pattern but for marginal differences in Mg and S content in the culm. Both Ca and sulphur significantly reduced the iron content of the root at MT by 19.9 and 17.8 per cent, increased it at PI by 2.9 and 8.1 per cent and again increased it in the culm and reduced it in the boot leaf evidently leading to an yield improvement. Even then absence of response as obtained here points out to the possibility of interfering interactions.

This would suggest that low yield is not a function of iron but a real deficiency of K which in turn leads to Fe and Mn accumulation in plants. This is further confirmed by the data on uptake of elements in the grain and straw which showed that yield increase due to K application has been achieved with a reduction in K uptake. Thus probably a real deficiency will be one where yield increases with increase in uptake of those elements.

Early dose of Ca will have the advantage of reducing Fe and also Mg and a smaller subsequent dose of S may further reduce Fe in leaf. Thus spaced application of small dose of Ca and S appeared a sure possibility of reducing Fe which however needs further investigation.

Apart from increasing its own content and thereby its relative status with other elements, K application increased the yield by widening the balances of N and P with Ca, Mg, S, Fe and Mn by reducing these elements in the leaf and boot leaf. Thus function of K appears to be two fold namely its direct function as an essential element in the metabolic process and its ameliorative function deriving from reducing the excess elements like Fe, Mn, Zn etc. in the metabolic system. Thus the element can be designated as a metabolic modulator or metabolic refiner.

A comparative perusal of the ratios at MT and PI stages further showed that the ratio had been much narrower in the shoot than the leaf in respect of N/Fe. Data on the content of Fe in the various plant parts also suggested that the element has progressively decreased probably by retention in roots, culm and early leaves. Similar was the case of Ca. These results imply that K has acted as a metabolic refiner through discriminatory translocation.

Lack of response to Ca which, in addition to being a nutrient, is an ameliorant of acidity can be explained in the very same way. At PI stage application of Ca could not influence any balances involving nitrogen except that with Ca. Musthafa (1995) has reported that N/Fe was a critical determinant in deciding the yield of rice in laterite soil. Calcium had influenced P/Ca, P/Fe and P/Zn but was less effective compared to K. Probably P/Ca and P/Fe may not be very important in the laterite soil. Another critical factor appeared to be K/Fe where also Ca was found to be less effective. These results showed that K is a more efficient metabolic refiner than Ca.

In the case of S, the data showed that the element was higher in relation to N and K. N/S ratio for cereals is considered to be 15 to 20:1. Hence lack of response to S has been probably due to excess S.

Relatively higher status of S and Ca in relation to N and K and its comparative ineffectiveness in modifying balances of elements would point out to an absolute and relative deficiency of K as the yield limiting factor. Significant superiority of K in widening all ratios involving Fe with N, P and K coupled with increased yield and lower iron uptake point out that iron accumulation is the resultant of a real deficiency of K.

5.5.2 Interaction effect between K, Ca and S

A perusal of the data on interaction (Table 4.5.2) has brought out the nature and pattern of interacting influences and their relation to growth and yield expressions.

Absence of interacting influences between K and Ca at 60 kg ha^{-1} and 150 kg lime ha^{-1} but significant interaction at 120 kg ha^{-1} and 150 kg ha^{-1} lime showed that levels of the interacting elements govern the interaction. Explaining the factors affecting availability of K (Buckett, 1972) while investigating potential relations of elements say cations, have stated that availability for absorption of any cation is dependant not merely on the activity of that element, but by the activities of other cations which inturn depends on the valency of the other elements involved. Additive advantage of the two cations then will naturally have to depend on the levels of the elements. This is further confirmed by the data (Table 4.5.2) from the same table were K at 180 kg ha^{-1} and lime at 150 kg ha^{-1} had manifested a lower extent of influence. It is possible that the levels of Ca had marginally raised the grain number and the increase would have been higher than that obtained at $K_{120}L_{150}$ treatment.

Another significant observation from K and Ca interaction is that the increase in floret number to the tune of 36.6 per cent. This would suggest that combining Ca as 150 kg lime ha^{-1} with 120 kg K ha^{-1} had its effect at PI stage. Effectiveness of

Ca in reducing Fe in the root and plant content at early stages would suggest the possibility of the effect of lime is indirect - that is it reduces Fe and facilitate higher initiation of floret number.

A perusal of the data on grain straw ratio and panicle weight (Table 4.5.2) under the same treatments showed that increase in floret number was not associated with increase in panicle weight but was linked to narrowing down the grain straw ratio. A 36.6 per cent increase in floret number was progressively linked to 29 per cent narrowing down in grain straw ratio and eight per cent increase in panicle weight. Mureta (1969) have reported that carbohydrate in the plant before PI stage contributes to the floret number. A 36.6 per cent increase in floret number by narrowing down the grain straw ratio naturally leads to the conclusion that Ca increased floret number by facilitating (removing the inhibitors) the floret initiation. Its failure to increase the yield inspite of increase in floret number further indicate that influence of Ca was confined to facilitation and not on increasing the rate of photosynthesis.

A further perusal of the data also showed that variations in the levels of elements involved in the interaction functional leads to variation in functional roles also. This is evident from the functional changes when levels of K was enhanced from 120 to 180 kg ha^{-1}. The increase in K levels reduced grain number from 36.7 to 20 per cent and raised panicle weight from 8 to 28 per cent. These results along with the observation that direct effect of K on yield was positively significant, point out to the fact that the role of Ca has been internal amelioration for K use.

Another important observation in the present trial is the significant negative correlation of $\frac{Ca + Mg}{K}$ to yield (Table 4.5.13). This ratio showed that Ca has a role on suppressing K effect when its level is high. This results suggest that interactions

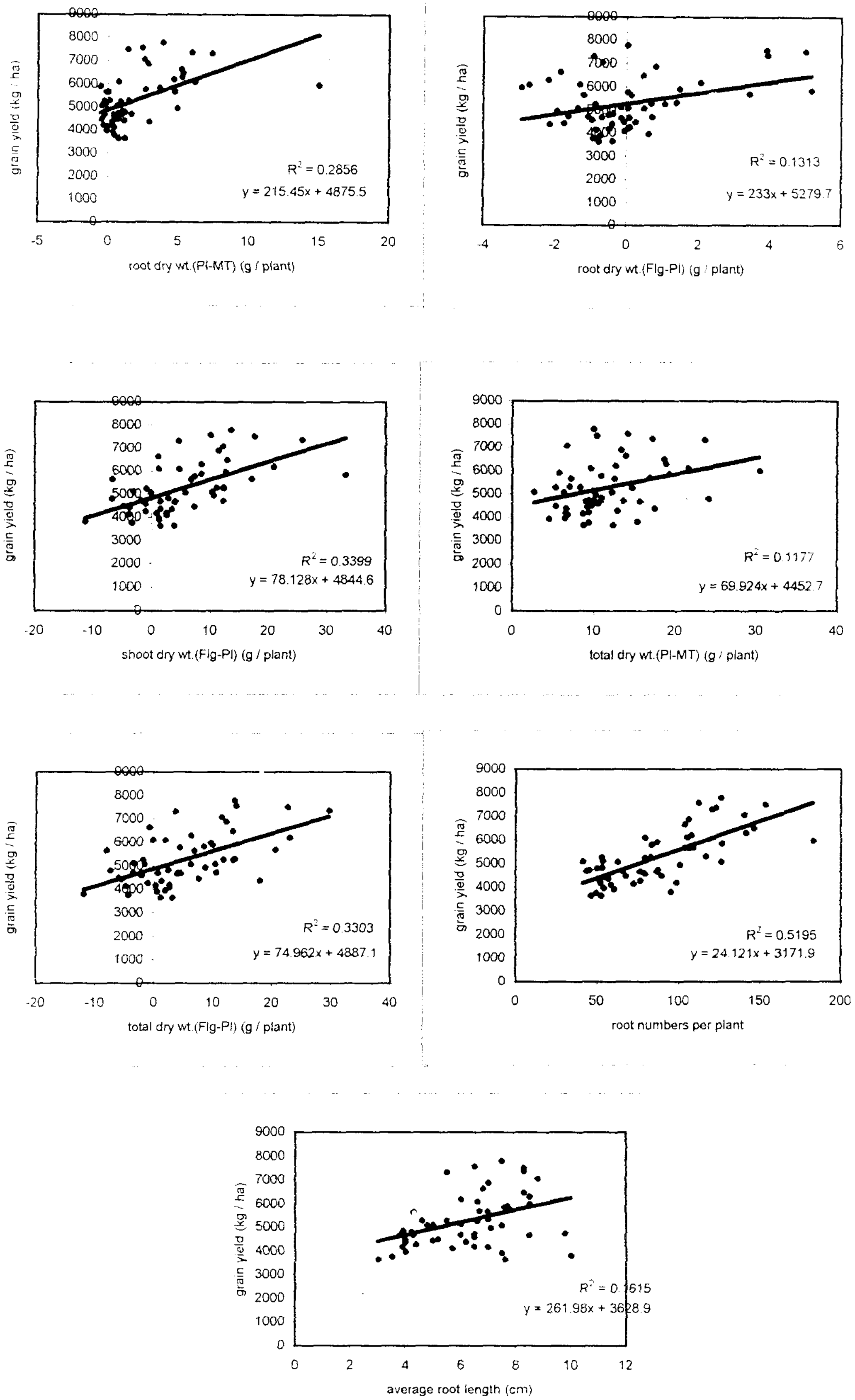


Fig. 5.3.1 Influence of some growth differentials, root number, average root length and root iron content on yield of rice

Fig. 5.3.1 contd.........

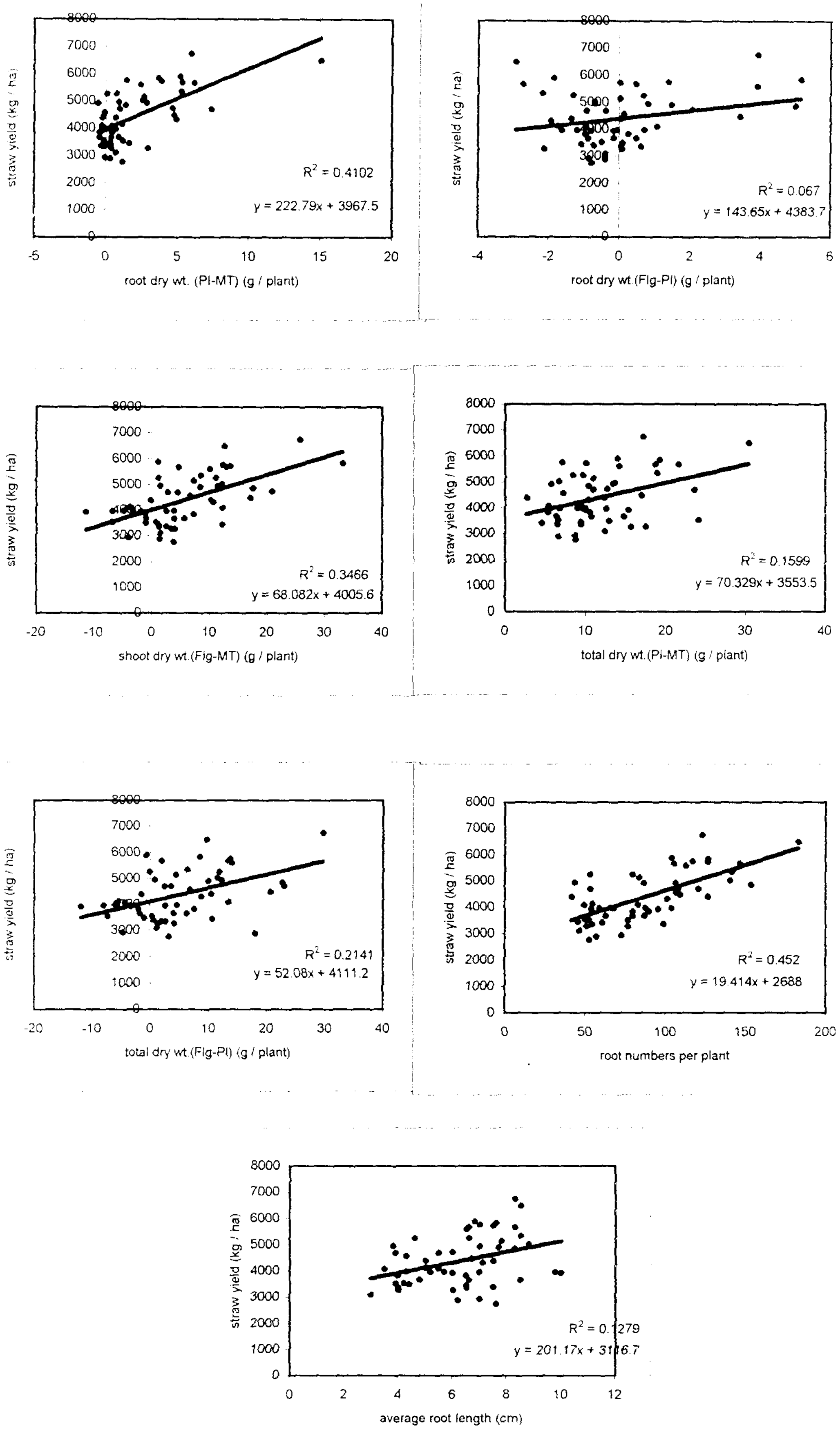


Fig. 5.3.1 contd……….

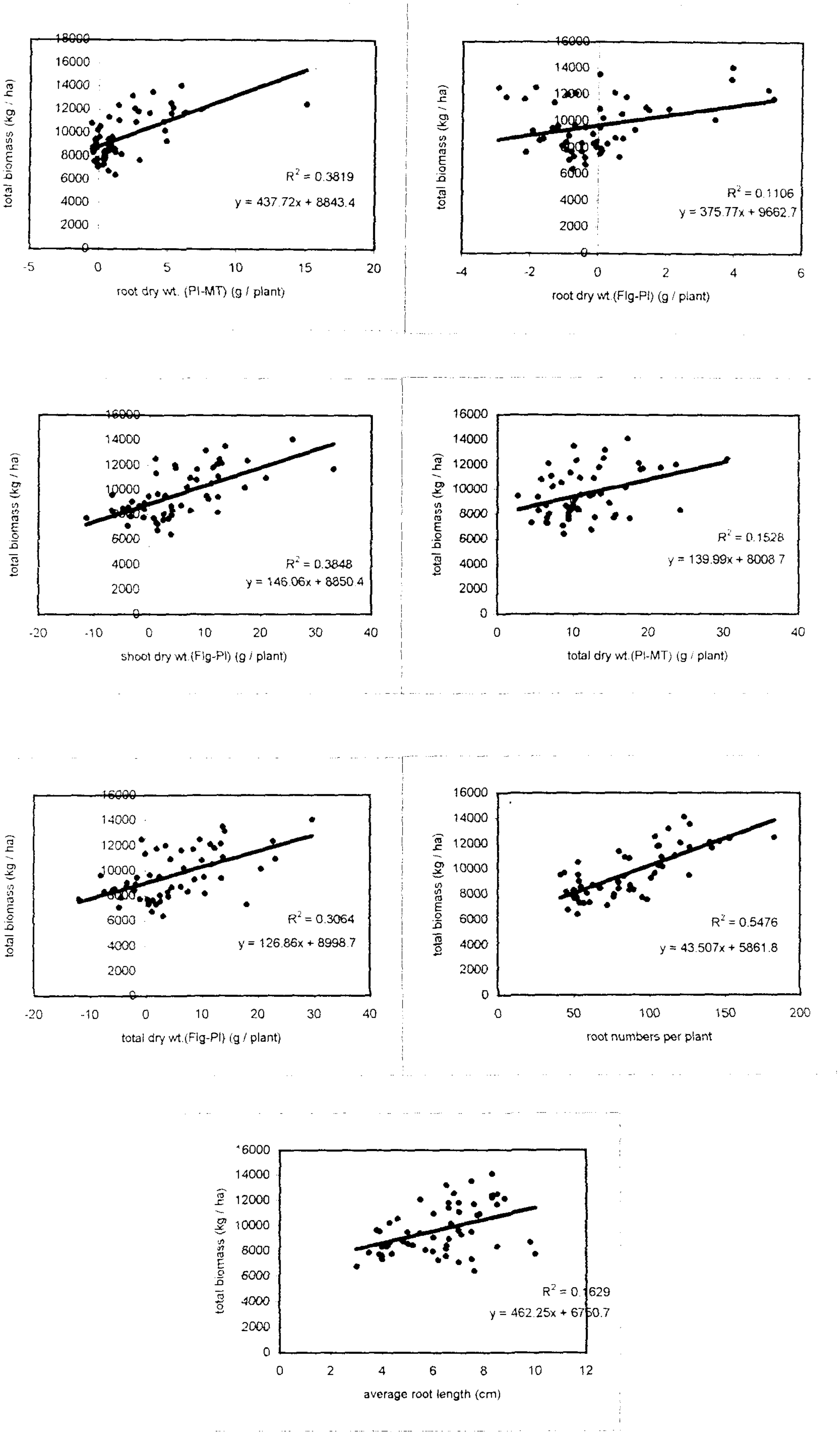
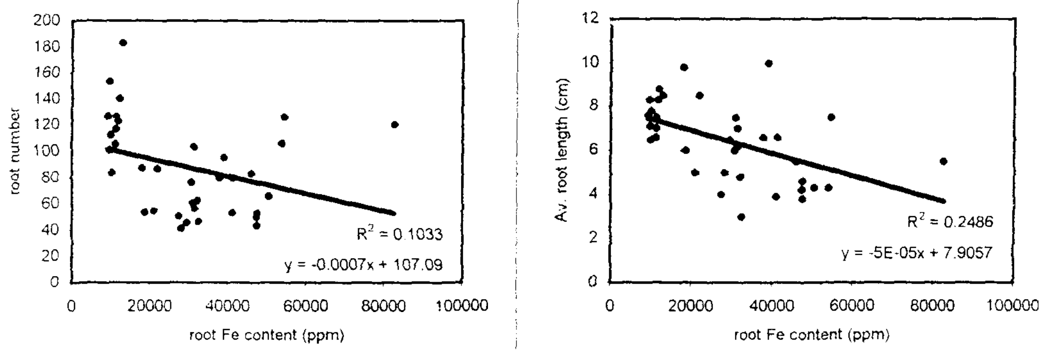


Fig. 5.3.1 contd......



are specific to quantitative ranges of elements involved and this vary depending on the elements themselves.

The over all results of K, Ca interaction in the context of yield process is that at optimal levels this interaction may increase either floret number or panicle weight and not both.

Interaction of K with S show that at 180 kg ha^{-1} S addition @ 100 kg ha^{-1} also could increase the floret number by 20 per cent.

This suggest that the same effect can be brought about by two differential combinations of elements.

Behaviour of K x Ca and K x S combinations are similar and can be seen by a comparison at 120 kg K level. Increasing the dose of elemental S from 100 to 200 kg ha^{-1} increased the floret number by 5 per cent but increased the panicle weight by 16.5 per cent.

When combined interactions of K, Ca and S are considered, it can be seen that the effects get neutralised. As example can be seen in the interaction at 180 kg K, 100 kg S and 150 kg Ca ha^{-1}. First order interactions significantly increased the floret number when second order interactions did not have any effect. This may be because one is cation and another is an anion and the reaction between them possibly lead to a neutralising effect. The necessity of an increase in both floret number and panicle weight for higher yield would suggest that both are required. A temporal separation is possible as pre-panicle initiation phase and grain filling phase are separated by time. The present situation of Ca and S neutralising between themselves can be overcome by temporally separating them. Calcium being more effective shall be applied basallly. Changing the sources of S from elemental S to soluble S and applying in the post PI stage.

This shall be achieved by substituting urea with ammonium sulphate. However, this requires field testing.

A closer scrutiny of the plant content of elements at and through the specific growth phases have thrown light on what, why and how of the crop response to nutrient inputs. The concept of nutrient addition itself is application of a factor or factors over the base level of those factors in the soil to make up its deficiency. The data (Table 4.5.6e) however showed that addition of any inputs brings about changes in the absorption level of not only that factor but also almost all other factors. Moreover the changes in that particular factor is a function of the level of application and stage of observation. Thus at 120 kg ha^{-1} level of K (Table 4.5.6e) which increased the yield by 1457 kg ha^{-1} had not increased the K content but increased Ca and Fe and reduced S, Mn and Zn by 190.0 and 31.8 and 23.6, 2.2 and 6.8 per cent respectively. This would indicate the inter dependant influence of nutritional inputs on yield and that its magnitude varies with level of input as well as the element affected and stages of observation. This is the interaction effect.

The fact that it is the interaction and not absolute direct effect of the elements that decides the yield is further confirmed by a comparison of elemental composition in K_0S_0 and $K_{120}S_0$ which have recorded comparable yields (5249 and 5308 kg ha^{-1} respectively) though their elemental composition were uncomparable as the content of P, K, Ca, Mg, S and Fe varied by 16.7, 73.4, 190.0, 50.0, 19.1 and 31.9 per cent.

Data in Table 4.4.6e on variation in elemental composition under $K_{60}Ca_{150}$ and $K_{120}Ca_{150}$ showed that magnitude of change varied with the levels. At lower level of K,

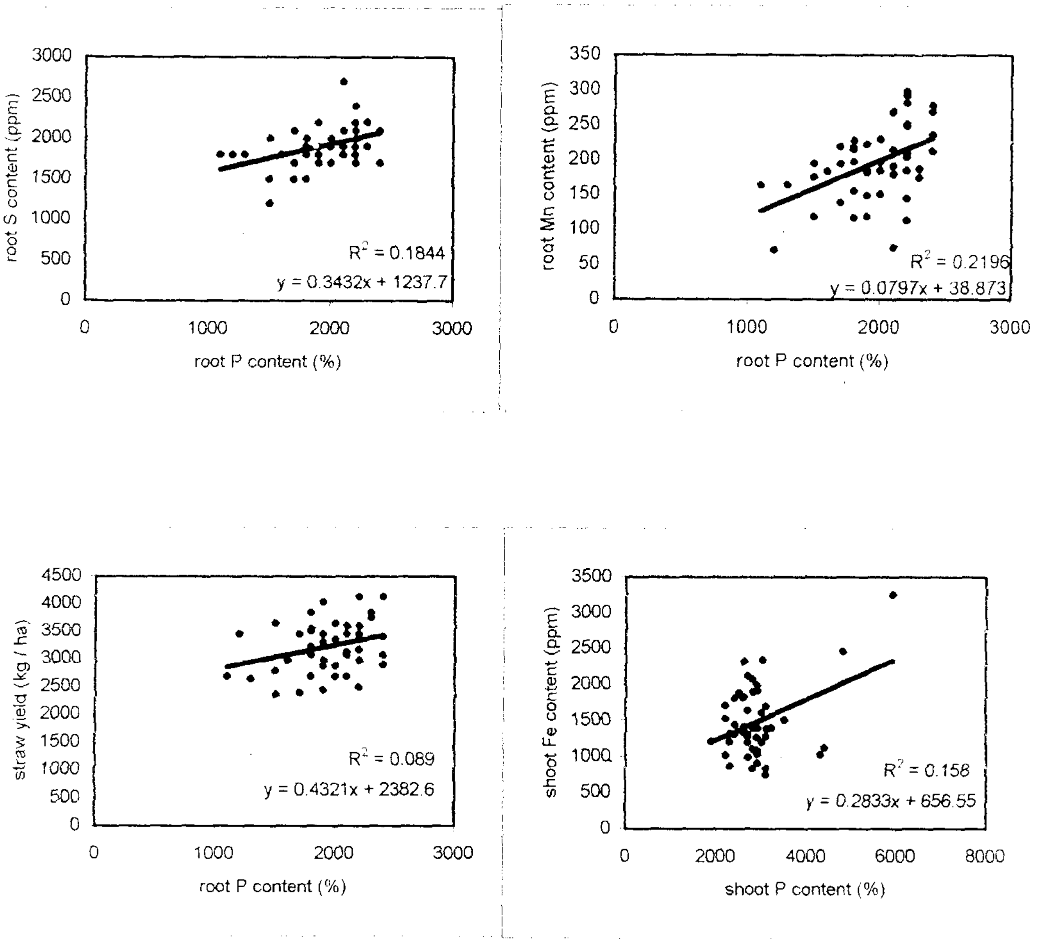
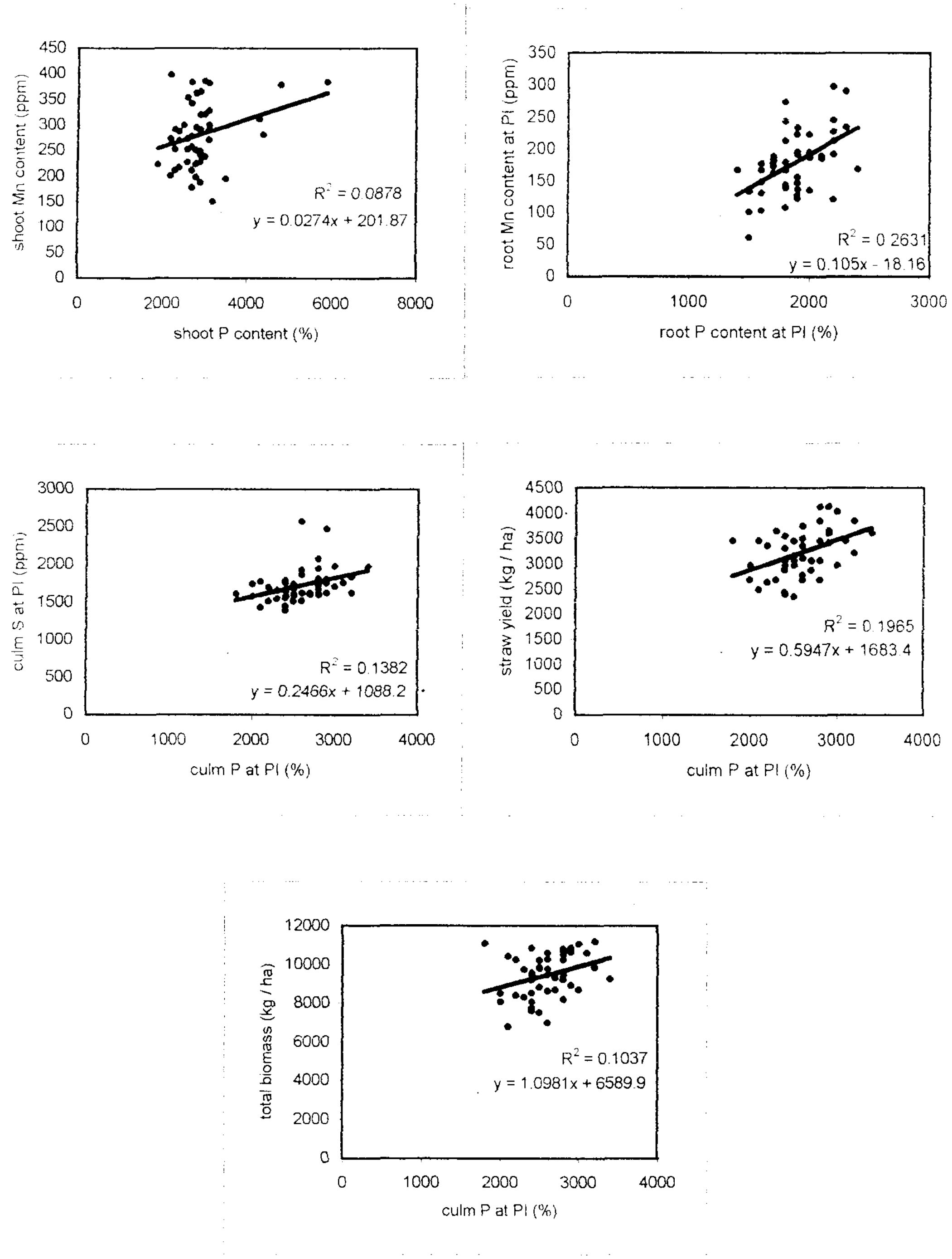


Fig.5.5.1 Influence of P content on S,Fe, Mn and yield of rice

Fig. 5.5.1 contd......



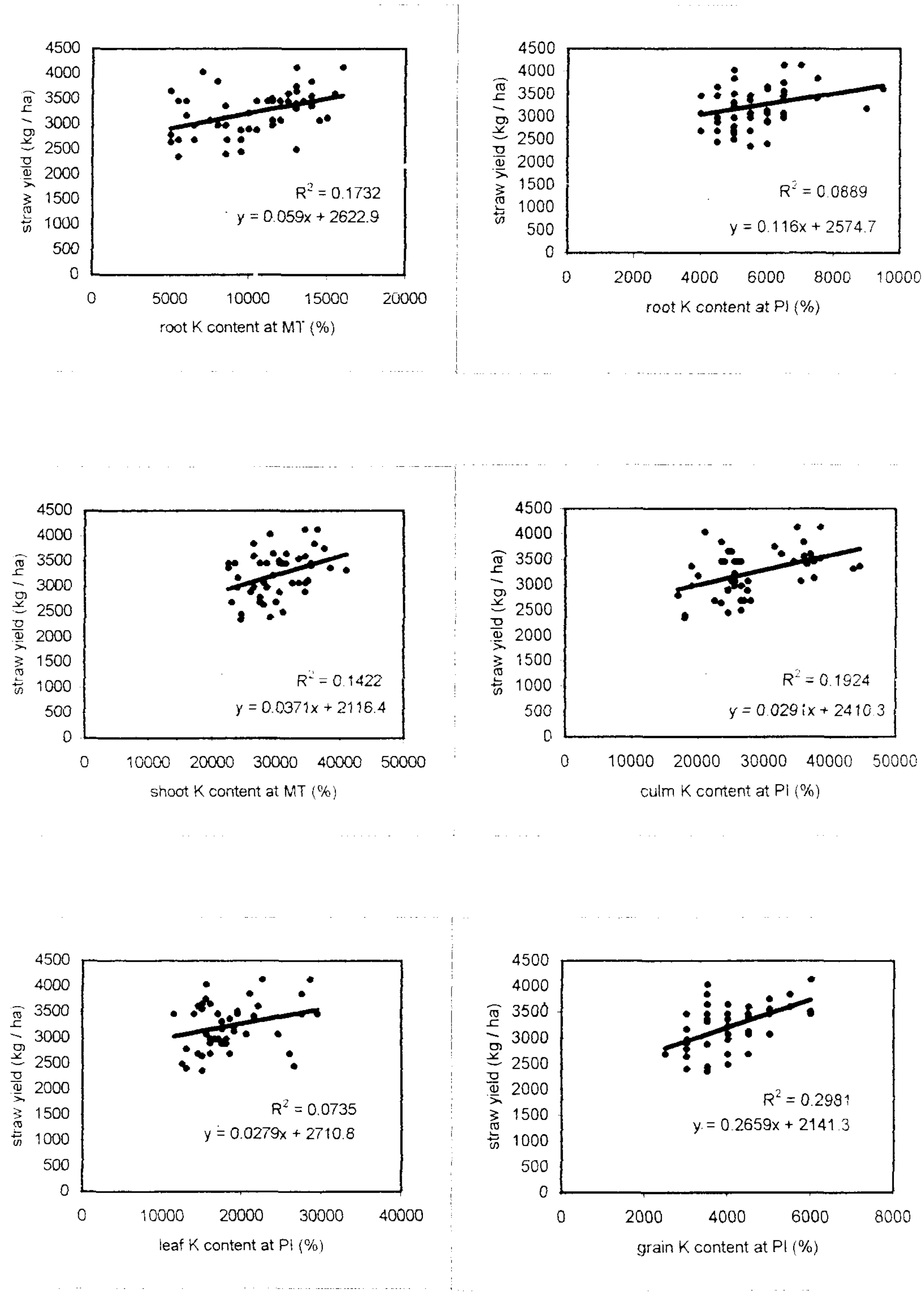


Fig. 5.5.2 Influence of K content on yield of rice

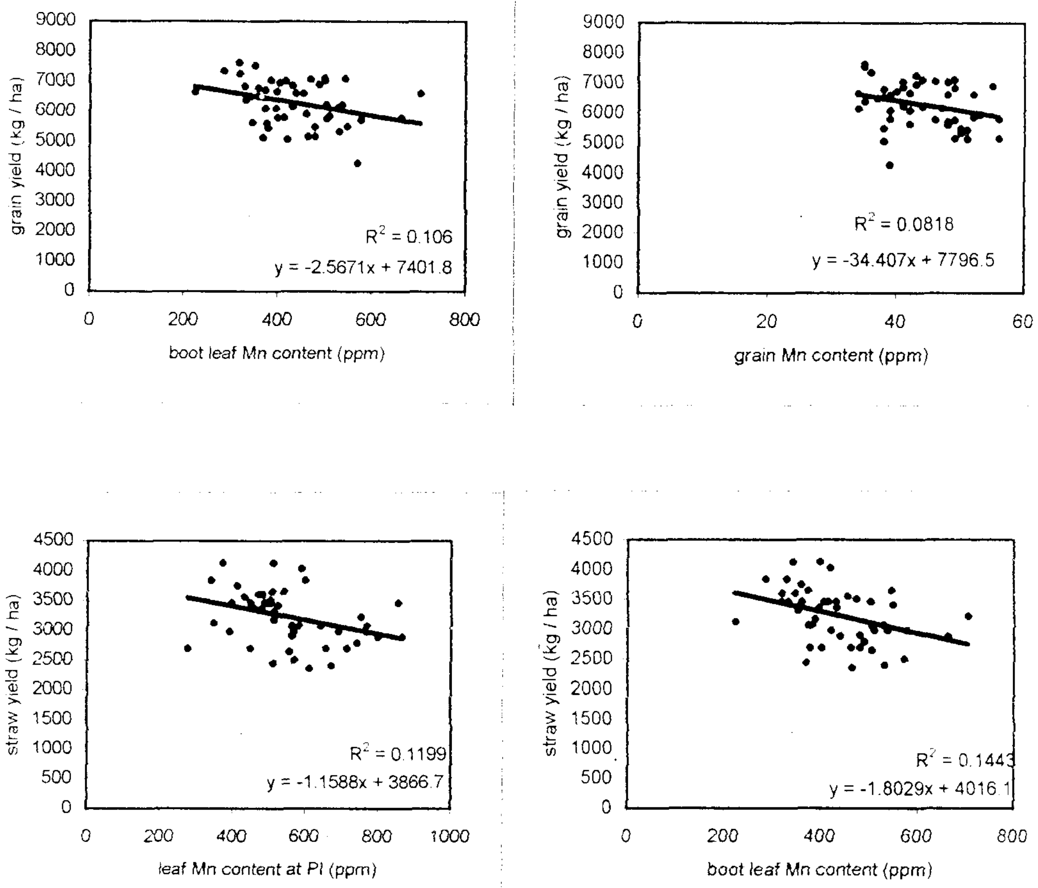
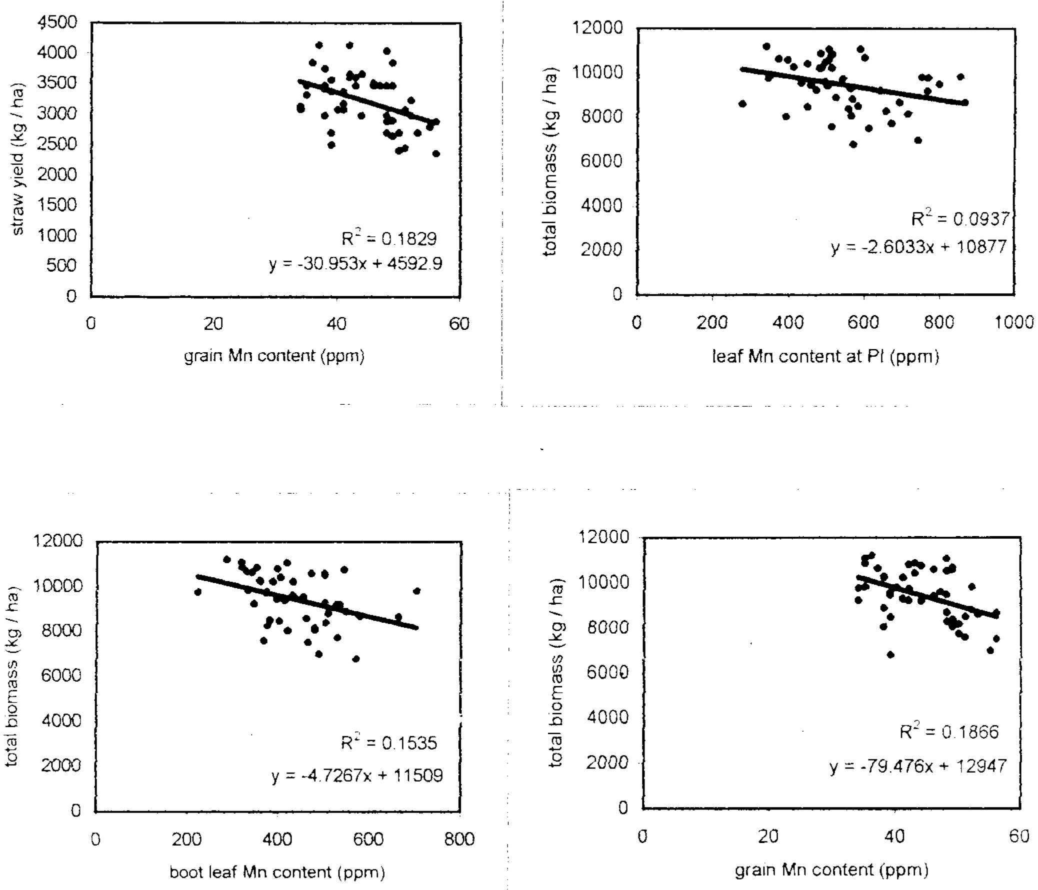


Fig. 5.5.3 Influence of Mn content on yield of rice

Fig. 5.5.3 contd............



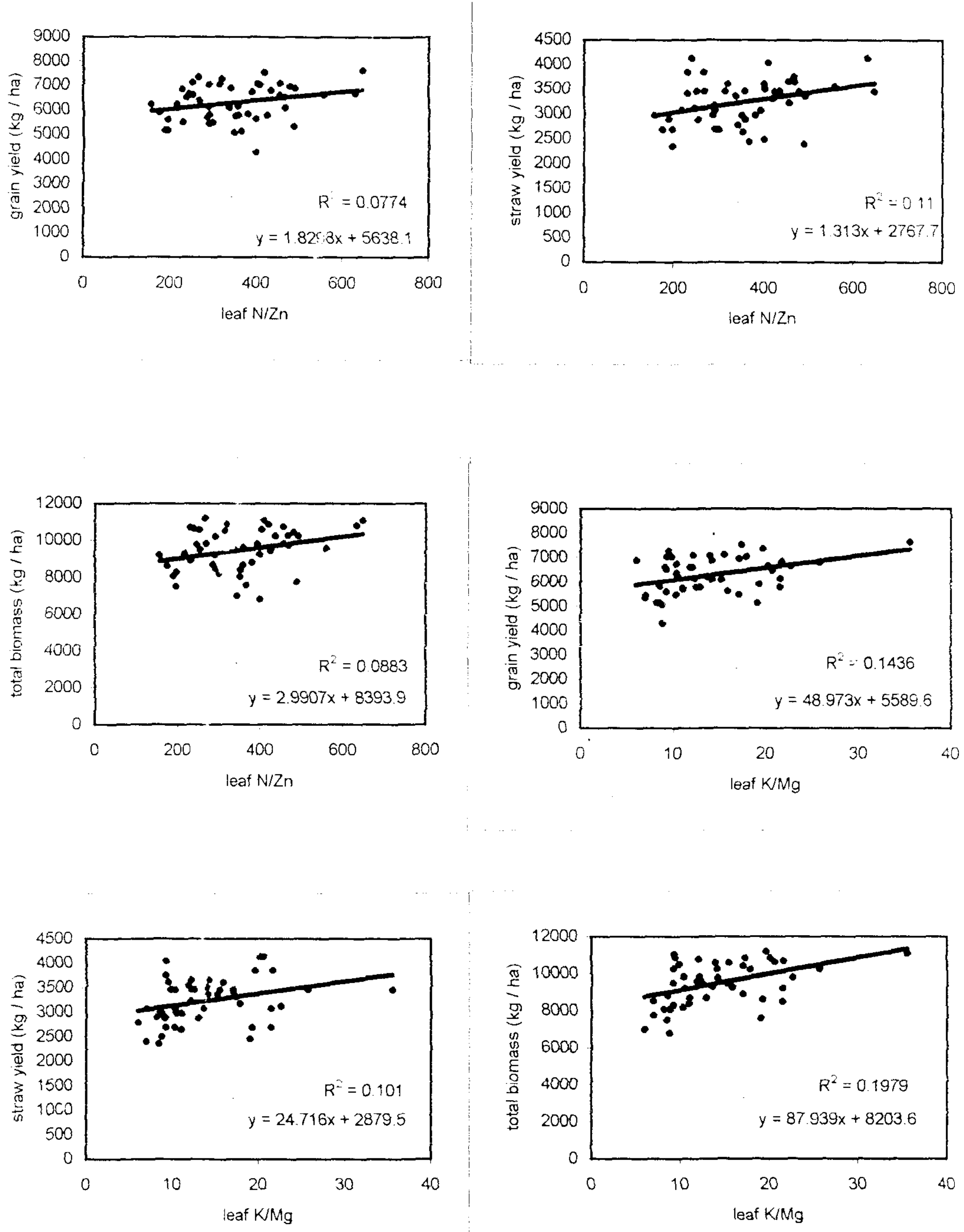
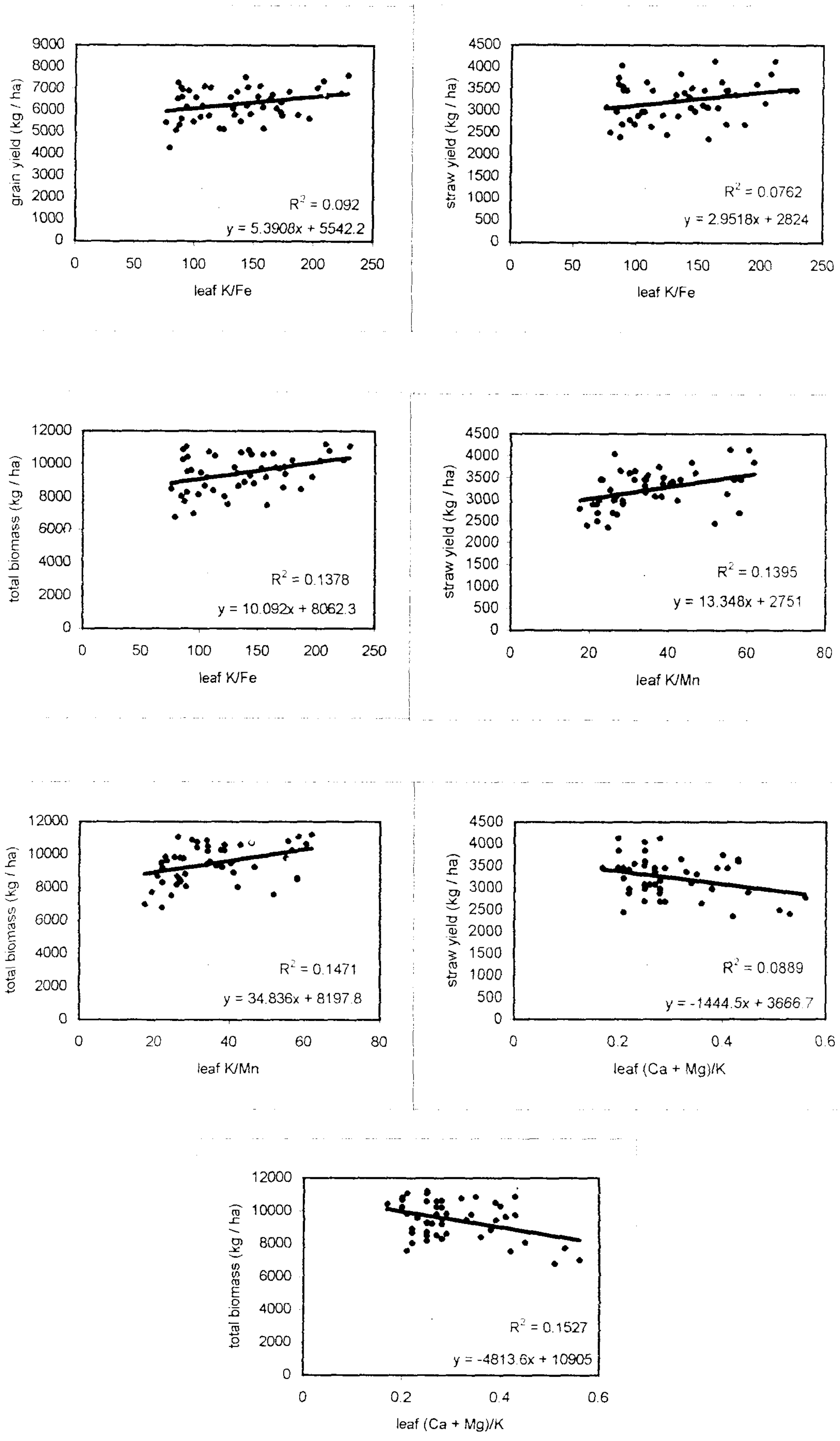


Fig.5.5.4 Influence of leaf nutrient ratios on yield of rice

Fig. 5.5.4 Contd.....



Ca applied as lime @ 150 kg ha^{-1} increased P, Ca, S, Mn and Zn by 52.5, 11.8, 27.3, 10.5 and 17.3 per cent and reduced Fe by 75.3 per cent. But at 120 kg ha^{-1}, K content was reduced by 73.4 and Fe was increased by 5.1 per cent. These results suggested that the nature and extent of interaction changes with the levels of applied elements involved and the elements affected.

The pattern can be seen to undergo a changes when three factor interactions as cation-anion-cation are considered. It can be seen that at lower levels of K, Zn was reduced by 24.5 per cent as against cation-cation interaction and increase in Mn was aggravated (Table 4.5.6e). At higher levels of K, Zn was not affected but Mn was reduced. These observations would not only underline the significance of interaction but also the real situations of involvement of multiple factor as well as the levels of the factors involved and the necessity of multifactor management to get the desired metabolic fractional proportions of the various elements.

Another important observation is the variation in the nature and magnitude of interaction in the boot leaf (Table 4.5.6f) compared to the leaf at PI stage (Table 4.5.6e). This variation probably suggests phasic specificity in interaction pattern on the one hand probably related to functional variations. Boot leaf synthesises carbohydrates and translocates to grain whereas leaf at PI is related to synthesis and utilization of carbohydrates for differentiation. On the otherhand variability may be a function of level and status of various elements involved.

Decline in levels is an expression of selective translocation and selective accumulation which in turn may be another determinant of interactions. Thus K_{60}

combined with Ca_{150} significantly increased K and reduced Ca, S and Mn. All these patterns being contrary to observations in the leaf at PI.

With an increase in the level of K to 120 kg ha^{-1}, K, Mn and Zn content increased by 82.7, 9.5 and 30.2 per cent in the boot leaf but Fe showed a significant decline of the order of 55.9 per cent against a diametrically opposite expression. These diametrically opposite trends is an evidence to the fact that effect of basal dressed treatments may not last long which in turn necessitates a temporal input management. The study also reveals that temporal management as was considered so far need not be confined to nutrient elements as such but for ameliorative and corrective inputs.

When an anion is introduced into the sphere of cation-cation competition at lower level of 60 kg K ha^{-1}, P, K, Ca, Mg, S and Fe were increased and Mn and Zn were reduced. But when the level of K was increased to 120 kg ha^{-1}, P, K, S, Mn and Zn were reduced and Ca, Mg and Fe were increased. These results would suggest that temporal requirement of elements be based on the interaction among elements and their levels.

An interesting observation of the treatment effects on the elemental composition in the culm (Table 4.5.5d) is that the content in the plant is governed by mobility and excess levels of elements. The content of Fe had registered levels upto 2000 ppm in culm. At 60 kg level of K, Ca increases Fe and Zn but decreased Mn, Cu and K. Influence of S anion reduced all the cations. Continuous tiller production associated with high plant Fe content may be the result of this accumulation.

The positive influence of anion effect on mobile cations can be seen to be strong expressed even upto 200 kg S ha^{-1} level and 180 kg K ha^{-1}.

A general indication of these results is that mobility of the element also is involved in defining the interaction effects on it in the plant system.

Higher magnitude of interaction effects evident in mobile cations especially is a favourable sign to neutralise the unfavourable physical presence of immobile elements in the leaf at PI and boot leaf. In the case of cation-cation interaction as in the case of K and Ca at 60 and 150 kg ha^{-1} respectively, the excess reduction in the monovalent K appears to be indicative of the possible influence of activity ratio operating in plants under additional plant influence. However, all these require to be confirmed through further detailed experimentation designed specifically for the purpose.

However as ratios are inclusive both *per se* content and interaction, the same has been used in the present study to explain the yield relations.

The foregoing paragraphs characterises yield expression as a response to net interaction effect of elements in the plant and specifies that yield is not a function of *per se* content of elements. In the context of minimal level of nutrients required for 7000 kg ha^{-1} yield (Table 4.1.2), these results lead to the concept of interaction of minimal use of inputs for maximum yield (MUMY). Such an approach shall be more scientific, more profitable and sustainable as well as environmentally safe. It also bestows a chemically functional role for elements absorbed which may not have a metabolic role. These observations lead to discriminatory role of elements in plant system viz., chemical function and biochemical function.

5.5.3 Correlation results

Interactions and their relations to productivity can be best explained based on interdependent nature of elements and individual relations to productivity.

Data presented in Table 4.5.9 and Fig. 5.5.1, 5.5.2, 5.5.3 and 5.5.4 showed that leaf content of elements either at PI or boot leaf have no relationship to productivity. Straw yield was found linked to P in the root at MT and culm at PI which meant that an increasing content of P in root at MT and culm at PI constitute to higher straw yield. It did not affect the grain yield. Exclusive influence on straw yield itself suggest that there is factor inhibiting differentiation and translocation. Positive and significant relations of P in root with Mn and S at MT and significant relation of P with Fe and Mn in the shoot at MT stage suggest that Fe and Mn may be getting inactivated in root and culm as phosphates and or S compounds. Marykutty *et al.* (1993) have reported similar results. The positive relation of straw yield with P, S, Fe and Mn appears to be due to this anion cation neutralisation.

Potassium is an element retained in the cell sap which does not form an integral part of the structure or growth metabolism. Absence of definite direct relationship of K to grain yield (Table 4.5.10) appears to be primarily due to its non-involvement in metabolism and its inability to counteract the excess effect of Fe and Mn. The fact that K was positively related with straw yield at all the progressive stages and in the various plant parts appears to be due to its role in water relations, differentiation and grain development.

The failure of Ca, S and Fe to show any relationship with productivity of rice (Table 4.5.10, 4.5.11 and 4.5.12) may be because they were in excess in the plant and that in the given situations their role is only to neutralise the excess ions finding entry into the plant (Table 4.5.3a).

Manganese however, showed negative relation with all the components of productivity (Table 4.5.12) from PI stage onwards. These results show that Mn by its high content exert negative influences on productivity of rice. This negative influences starting at PI stage and assuming more seriousness in grain filling stage. These incidentally mean that Mn effect is pronounced more on grain filling either through reduced rate of photosynthesis or reduced translocation or both.

Data on Fe influence (Table 4.3.1a, 4.3.7) had shown that iron limits productivity of rice by causing root damage and drymatter accumulation in the early stages.

Thus low productivity of rice in laterite soils appears to be due to Fe damage in the early stages and Mn excess in the later stages.

As the deleterious effects arise from native factors ameliorative management alone will be a solution. Such ameliorative management shall be based on balance of these factors with ameliorative elements and functional elements having ameliorative ability.

5.5.4 Correlation with nutrient ratios

Correlation coefficients of nutrient ratios with physiological attributes like leaf sap pH and productive components have opened up a way for ameliorative management.

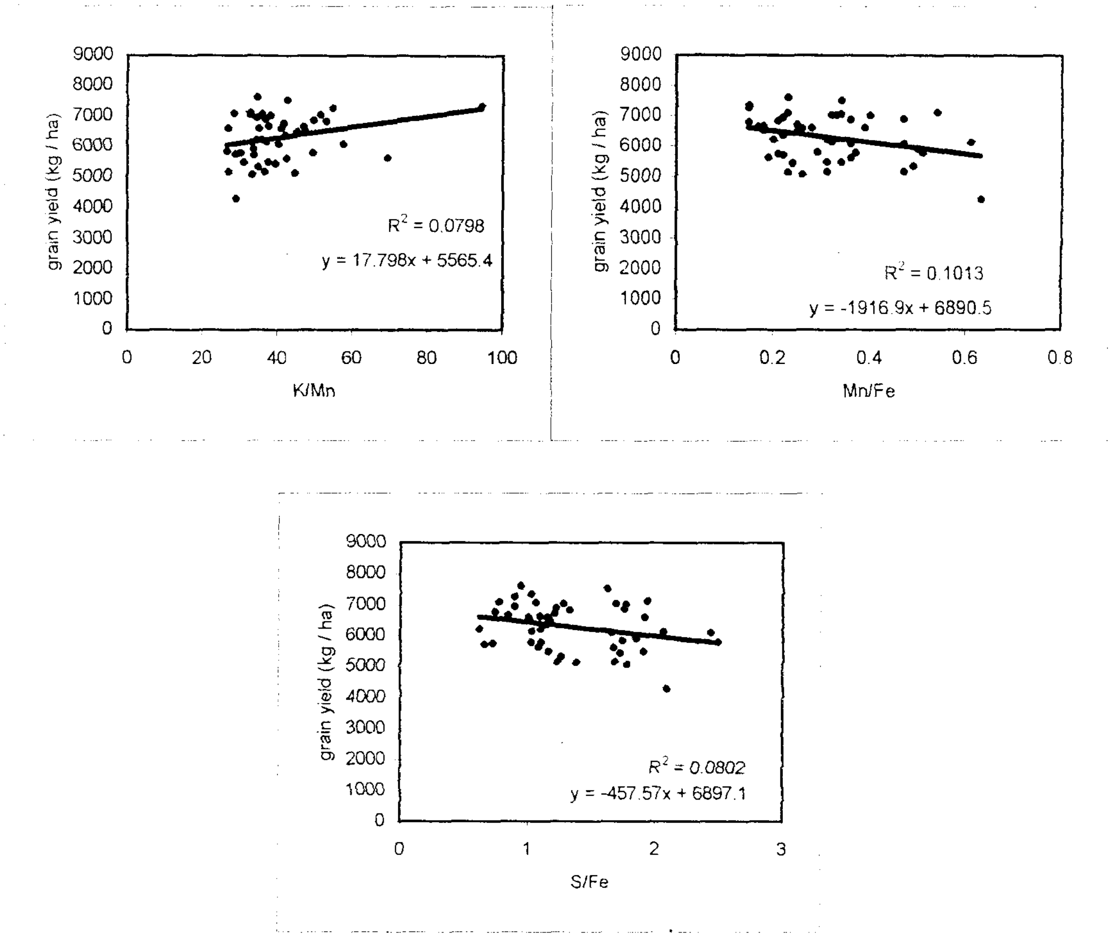
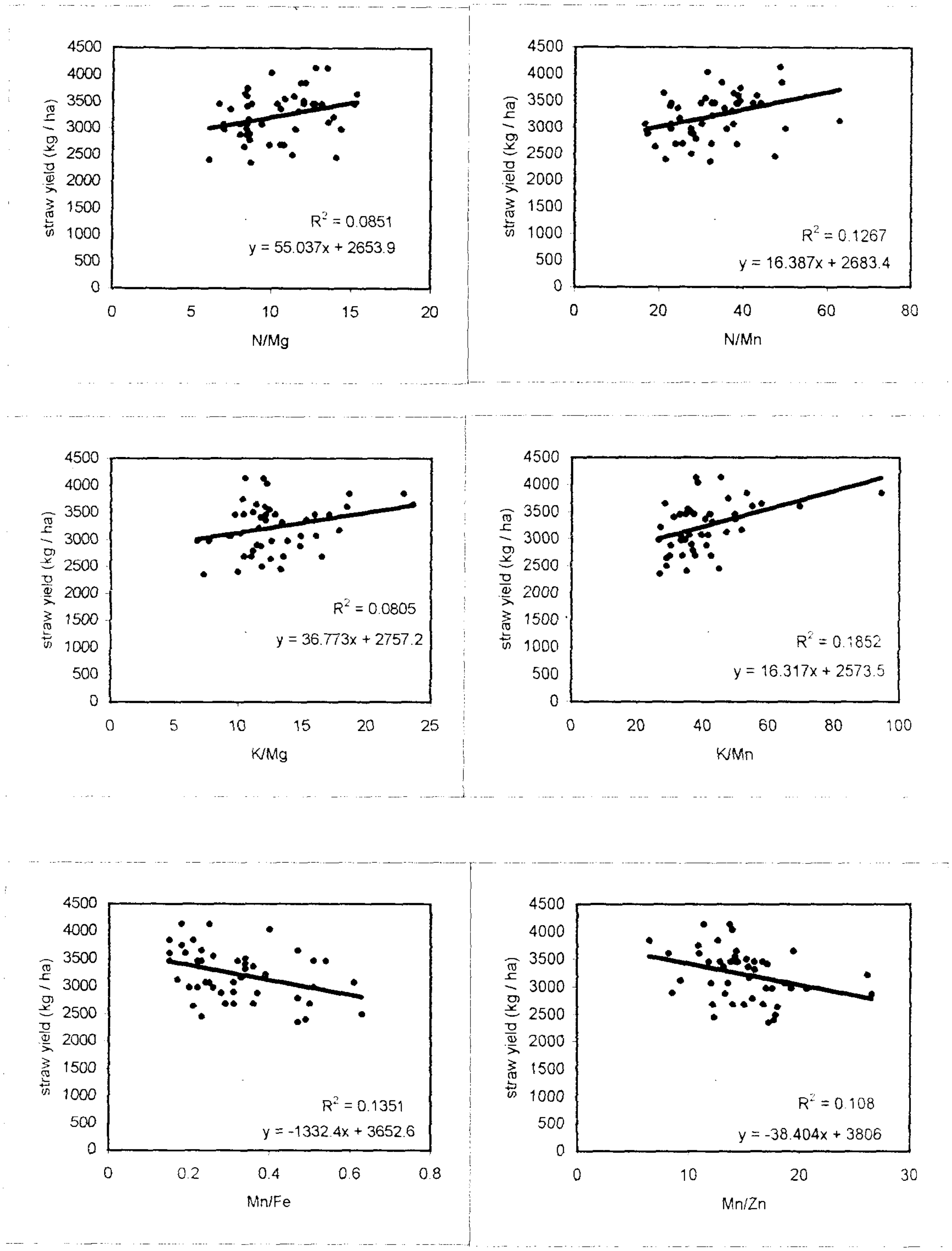


Fig. 5.5.5 Influence of boot leaf nutrient ratios on yield of rice

Fig. 5.5.5 contd......



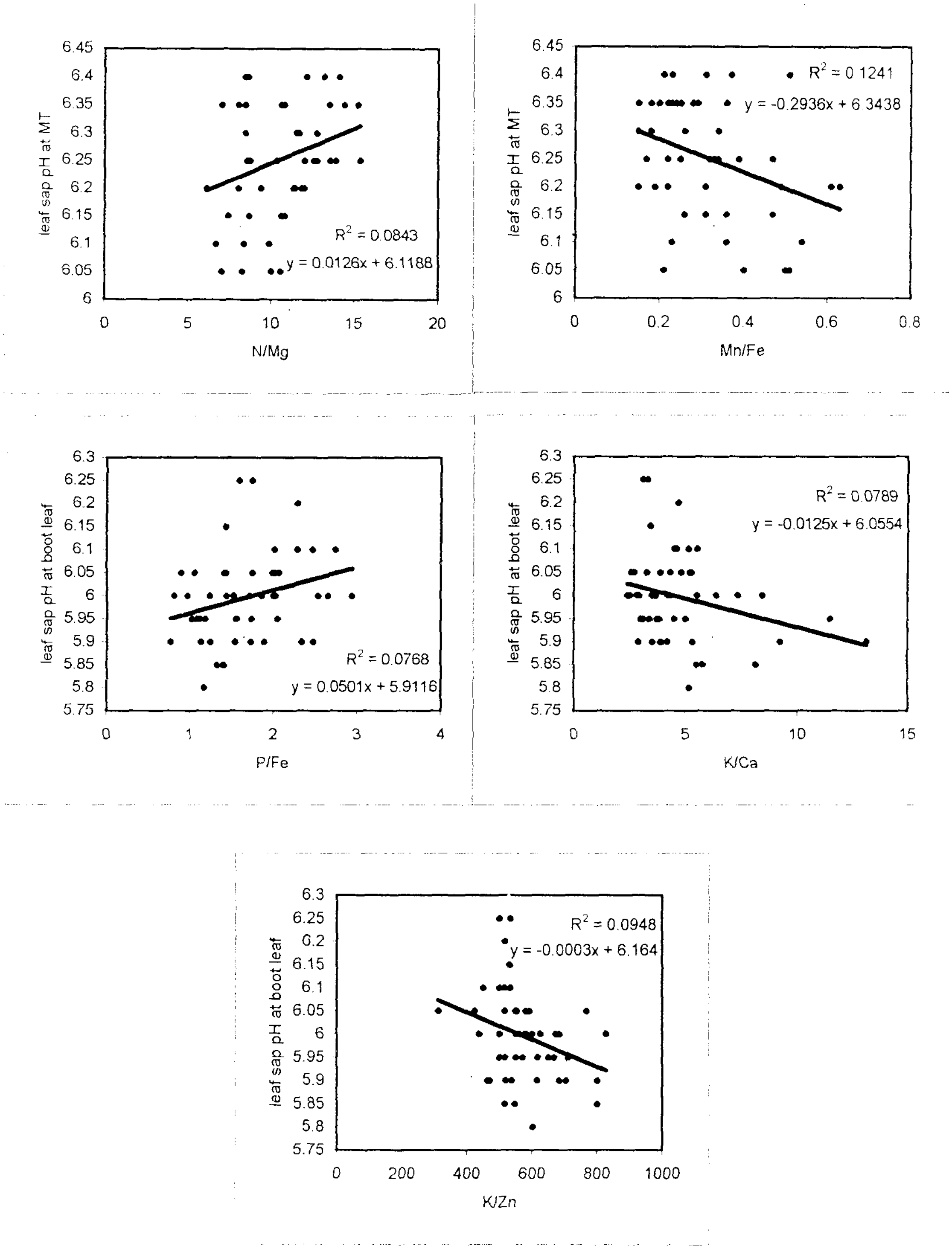


Fig. 5.5.6 Influence of boot leaf nutreint ratios on leaf sap pH

Data presented in Table 4.5.13 and 4.5.14 and Fig. 5.5.5 and 5.5.6 undoubtedly showed that excess of Fe and Zn in relation to N (N/Fe and N/Zn) and Mg, Fe, Mn and Zn in relation to K (K/Mg, K/Fe, K/Mn and K/Zn) are the factors that limit the yield. As Mg, Fe, Mn and Zn are native elements the only alternative will be to increase the level of K and the results show that 120 kg ha^{-1} is necessary. As K cannot reduce Fe, Mn or Zn much increase in level of K has to accompany other ameliorative measures.

Calcium and S can be effectively used for this purpose. This shall be achieved by basal dressing of Ca as lime and top dressing with S containing fertilizers like ammonium sulphate instead of urea. A smaller dose of S instead of 100 kg elemental S applied basally can be expected to keep S/Fe ratio and Mn/Fe ratio within limits to favour higher grain yield by favoured translocation. Level of application of K and Ca shall be adjusted to keep leaf sap pH in favourable range.

5.6 EXPERIMENT VI

Conspicuous aspect of the results have been an apparent lack of response for both silica and zinc in terms of morphophysiologic development and in the main effects. The cause of this, however, is well explained by the interaction effects between zinc and silica in a factorial combination trial. Significant interaction effects were confined to MT stage as well as on dry weight of weeds recorded at MT stage. Though silica upto 500 kg ha^{-1} had no significant influence on P, Zn and Cu content, Zinc had increased these elements significantly. Zinc application had also increased zinc content at PI stage. The experiment on K, Ca and sulphur have shown that one reason for the low yield of rice is narrow K/Zn ratio and the yield improvement due to K application at least in part is due to the widening of k/Zn ratio.

Yoshida (1981) have reported that 15-20 ppm Zn in the shoot is the critical limit of zinc in rice. Thus absence of response to Zn in this trial appeared to be due to narrowing down of K/Zn as well as increasing its level beyond critical limits.

Absence of response in the present study has also been due to the increasing influences of Fe and Mn in the plant due to Zn.

Another important factor for absence of response has been significantly enhanced weed growth due to Zinc application which in turn would have lead to serious deprival of nutrients for the crop. Musthafa (1995) has reported that weeds with their accelerated growth rate remove three fold higher nutrients than rice and that K is the element removed in largest levels. It is possible that induced heavy growth of weeds might have been a factor for absence of response to Zinc.

Silica on the other hand had significantly reduced weed growth (Table 4.6.1) and thereby seriousness of weed competition which should have reflected in yield was circumvented. The fact that it had not happened can only be attributed to the opposite nature of elements as well as their functions. Weed growth under the main effects of Zn and silica itself is evidence to the antagonistic behaviour of these elements.

Significant increase in the yield of grain due to silica at 250 kg ha^{-1} has resulted from low moisture content of grain and higher panicle weight acting cumulatively to increases the yield (Table 4.6.1).

The negative correlation between weed dry weight and yield (Table 4.6.7) suggested that weed effect had also been a factor. Positive correlation between Zinc and dry weight of weeds and negative association of silica with dry weight of weeds requires further investigation.

Nutritionally yield improvement due to silica applied at 250 kg ha^{-1} appeared to be due to a significant increase in silica content of the leaf and boot leaf. Increase in silica content of the shoot at MT stage might have also contributed to the yield increase. Yield increase due to silicate application had been reported by Yoshida (1981).

Positive and significant correlation of content of silica with yield and biomass suggested its deficiency and some specific functions of the element. Deficiency is logical as laterite soils are defined as those with Sio_2/K_2O_3 ratio of less than 1.3. Lower uptake of K, Fe and Zn and constancy in the content of Cu suggest the possibility of discriminatory absorption of elements. An increase in P uptake in the grain without change in uptake in straw suggested selective translocation also.

Nutritionally lack of significant differences in yield due to treatments with control, inspite of numerical increase in Zn content in all the parts will mean a sufficiency of the element which had made it unwanted treatment for productivity improvement. Zinc also failed to significantly modify any nutrient balance in the system implying that it will be able to increase yield only when there is an absolute deficiency of the element.

Moreover Zn application has reduced silica content of both grain and straw. Positive correlation of silica with yield (Yoshida, 1981) and role of Zn in suppressing silica uptake will imply that absence of response is at least in part, due to Zn application and its inhibitory influence on uptake of silica.

Uptake (Table 4.6.5) studies also revealed that increasing levels of application of Zn at least upto 40 kg ha^{-1} had lead to a reduction in the uptake of elements which might have been due to the accumulation of Zn in the straw.

Zinc also had induced an environmental hazard to rice growth and productivity by stimulating weed growth resulting in competition which also might have contributed to absence of response at least in part.

5.7 EXPERIMENT VII

Objectives of the experiment were to confirm the validity of the components already tested, and to test their compatibility as well as to find out the appropriate management programme to get the most efficient technology to circumvent yield limiting influences.

Data presented in Table 4.7.1.2 and 4.7.2.2 showed that irrigation three days after disappearance of ponded water (3 DADPW) was better than continuous submergence. The former treatment had given an increased yield of 786 kg grain per ha. Submergence leads to a reduced environment and facilitates increased availability and uptake of elements like Fe, Mn etc. (De Datta, 1981). Hence higher yields obtained in treatment where irrigation was done only three days after disappearance of ponded water might have been through minimising the uptake of elements like Fe and Mn.

The period of second crop of rice corresponds to September - October to January - February and post withdrawal phase of North East monsoon. As such water scarcity and consequent crop failure are natural and wide spread. The observation that irrigating three days after disappearance of ponded water improves the productivity appears to have double advantage - firstly the reduced use of water will help to save water till the end and avoid crop failure and secondly will improve the yield further. These two advantages together are likely to offset the general complaint of low productivity in the second crop season.

Influence of the water management treatments on the nutrient use efficiency and the mechanics of yield improvement can be noted from Table 4.7.4. It can be seen that physiologic efficiency of N and P has increased due to irrigation at 3 DADPW over continuous submergence which in turn has brought about a better agronomic efficiency.

This increased agronomic and physiologic efficiencies seem to have come about by a reduction in the plant uptake of Mg, Fe, Mn, Zn, Cu and silica. Thus the mechanics of irrigation at 3 DADPW to increase yield appeared to be by reducing the availability of native elements.

These results thus showed that irrigation at 3 DADPW is an economically, scientifically and sustainably advantageous proposition.

Nutritionally, the experiment has shown that from the point of view of yield, application of either K_{120} Si_{250} L_{150} or K_{120} Si_{250} S_{100}, will be sufficient to produce an yield of 6 t ha^{-1} in the second crop season.

A closer scrutiny of the data showed that application of S has increased the grain yield by reducing the straw or through a better translocation efficiency. Application of S had resulted in a lower tiller number, a higher leaf sap pH and a higher boot leaf chlorophyll content. Marykutty *et al.* (1992) reported that leaf sap pH should be around 6.2 only. Application of S is known to reduce leaf sap pH. Failure to get the result in this trial may be because under submerged condition S does not get oxidised. Thus from the morphological point of view Ca appeared to be preferable.

Based on uptake and physiologic efficiency the elements did not differ significantly except in the case of Mn. Application of Ca increased the yield probably by reducing uptake of Fe whereas S increased yield not by preventing uptake but by retaining Mn in the straw. The fact that Mn content in the leaf and boot leaf exceeds critical levels, it appears safe to assume that Ca shall be applied basally and instead of applying elemental S, ammonium sulphate shall be used to top dress rice.

Observations on the necessity of silica will reveal that from the yield point of view, application of silica was found effective when irrigation was done 3 DADPW. Silica also reduced Fe, Mn and Zn uptake by the crop and increased physiologic efficiency of applied nutritional inputs.

A combinations of Ca and silica and S and silica behaved in different ways. Combined application of Ca and silica reduced uptake of Fe, Mn etc. and increased the yields while silica combined with S conserved these elements in the straw. Thus S increased the carrying capacity of excess absorbed Fe, Mn and Zn and increased the yield.

These results are in the light of the fact that increase in Ca in relation to K will reduce the yield. Hence the best possible recommendation shall be application of Ca as lime @ 150 kg ha^{-1} basally and application of S incidentally through ammonium sulphate.

5.8 GENERAL DISCUSSION

A critical overview of the results have validated the conceptual basis of the project, established the morphophysiologic interrelations involved in yield process, brought out the necessity of a phasic analysis for productivity improvement and superimposing influence of season on nutritional efficiency. Based on this study in its totality it was possible to develop prototype models of yield boosting management for the first and second crop seasons which is scientifically tenable, practically viable and economically sustainable.

5.8.1 Conceptual basis of yield expression

Conceptually the study had been based on the assumption that low productivity of rice in the lateritic alluvium has been more due to one or more factors inhibiting the yield expression than real short supply of conventionally applied nutrient inputs.

The observations that dry seeding instead of transplanting has raised the yield by over 1800 kg ha^{-1} to register an yield of 6500 kg ha^{-1} (Table 4.3.1c) validates the hypothesis. This is further confirmed by an yield increase of over 1000 kg ha^{-1} by resorting to irrigation at three days after disappearance of ponded water instead of continuance submergence (Table 4.7.3 and 4.7.4 and Fig. 5.7.1). Absence of significant response to FYM (Table 4.3.1c) and waning out of second order interaction effects beyond maximum tillering stage have added further credence to the validity and applicability of the hypothesis.

Nutritionally, the causes of low yield has been absorption of native and nonapplied elements like Fe, Mn and Zn which were far beyond the critical levels. Data on nutritional requirement of individual elements in leaf for yield above 7000 t ha^{-1} in farmers field (Table 4.1.2) and 120 g pot^{-1} in pot culture studies (Table 4.2.10) have proved beyond doubt that this approach will enjoy superiority over conventional approaches at least in lateritic alluvium.

Morphologically the low productivity has been found to be due to inhibited root development the tendency for longer roots and root damage, low dry matter accumulation during MT to PI and PI to flowering stages (Table 4.3.1.a) and reduced efficiency of boot leaf (Table 4.3.9. and 4.3.11). Another morphological expression has been the tendency for continued tiller production beyond the PI stage observed in wet seeding and transplanting and loss of 25 per cent of the tillers as non-productive (Table 4.3.1.a). Length of panicle and number of branches per panicle are morphological indices of productivity. The fact that grain yield variations between 3400 to 7000 kg ha^{-1} observed in the experiments in the study is an unmistakable proof that the plant has potential but its expression was being limited. As the variety used in the study was Jyothi - a high yielding hybrid derivative, the results also point out that not further varietal improvement but management alternative alone is the means of yield improvement in lateritic alluvium. Thus the results showed that facilitating large number of shoot and root development will instil better vigour and ensure enhanced dry matter accumulation between MT to flowering which will increase the yield.

Nutritionally the low root number and root damage appeared to be due to iron content in the root which had gone beyond 50,000 ppm. Marykutty *et al.* (1993) have reported that this is largely a surface deposition. Reducing this surface deposition will be the first step towards yield improvement. Dry seeded first crop had yielded above 6000 kg grain ha^{-1} and the root content was only 10,600 ppm. This suggested that dry seeding is to be adopted for the first crop season. Submergence leads to increase in the redox potential. As such, whenever dry seeding is not possible as in second crop, surface wet seeding is to be preferred to minimise the excess Fe and Mn influence. Musthafa (1995) have reported that late non productive tillers are a mechanism to shed excess Fe. Dry seeding registered a high yield due to lower iron deposition in the root.

Physiologically significant observations that had a bearing on low productivity was the poor chlorophyll content and its low stability as represented by its declining tendency. Evidently this will get rectified when nutritional maladies are ameliorated.

5.8.2 Crop nutrition

Comparative perusal of the data in Table 4.1.2 for minimal requirement for over 7000 kg grain ha^{-1} and 120 g grain pot^{-1} (Table 4.2.10) and across the results in the control plot experiments will show that lower yields have not been due to an absolute deficiency of any fertilizer element or native micronutrient. As a matter of fact all these elements were higher than the minimum in all the treatments. This observation naturally suggested that any yield improvement registered by addition of any element is due to a balancing effect. This confers a bifunctional role for elements in crop productivity viz., a metabolic function and a chemical function with the latter preceding the former. This is in line with the observations of Dev and Saggar(1974) who classified elemental composition of the plant as protein N, protein P and protein S etc. Such a classification necessarily implies that the entire quantity of an element absorbed will not be metabolised. Dev and Saggar (1974) have further reported that excess accumulation of these non protein elements serve as pre-disposing causes of expression of chlorosis, reduced yields and pest and disease incidence. Such excess accumulation will have to be chemically neutralised. It appears that the balancing act is probably mainly in this respect. The balancing act leading to neutralisation possibly prevents entry into the metabolic streams. Toxicity expressions evidently is the result of entry into metabolic streams. Absence of toxicity systems inspite of abnormally high concentrations in the tissues of elements like Fe, Mn, Zn, Cu etc. may be traced in the neutralisation phenomenon.

The bifunctional role of elements in this context may call for redefining the deficiency, sufficiency, excess and toxic levels of elements in tissues. As the soil environment varies even within a designated type as laterite, black soil etc. leading to varying levels of absorptions, these indices are bound to vary. Seasonal variations will also influence the indices. Thus they appear to be variable indices as they are environment specific.

Deficiency is the low content of an element in plant due to the unavailability in the soil or inability of the plant to absorb, translocate and utilize or chemical inactivation of the same by some other elements or elemental combinations. Thus sufficiency level of any element is the summed up requirement of metabolic/biochemical and chemical needs. Excess level of any element is one a part of which will have to be neutralised or otherwise it may enter the metabolic stream and cause toxic levels.

The bifunctional nature of elements and high absorption of native elements like Fe, Mn and Zn necessitates absorption of elements applied in more than metabolically required levels. Thus nutritional way of yield improvement really is a function of regulation of elemental contents in excess levels in the plants. Excess level of some elements are increased to contain or minimise the excess effect of more harmful ones. The only way to find out this is through ratio or balance analysis of elements in relation to yield. `DRIS' norms have been reported to fail in effecting regulatory management by Sreekumaran (1998).

Necessity of phasic level application of the concept of elemental regulation can be seen from Fig. 5.3.4 and 5.5.2 and data on progressive changes in the elemental composition of the various plant parts. While levels of elements like Ca, Mg and Fe decrease progressively from culm through leaf at PI to boot leaf, Mn and Zn level which were already beyond the upper critical levels tended to increase. Increase in the content of these elements necessitate application of regulatory influences just before the PI stage and, if needed, in the boot leaf stage also.

Another significant aspect of nutritional management is the fact that the same yield level is obtained due to differential plant and foliar contents of the elements. Thus yield of a crop is specific to soil environment. Evidently to raise the yield further from the same level, will require varying treatment combinations in different soil environments. The data (Table 4.1.4 and 4.1.5) show that in laterite soil Fe, Mn and Zn have to be neutralised as against Ca in black soils. Thus while laterite soil require neutralisation of Fe, Mn etc. black soil requires neutralisation of Ca. Season also prevails over soils in deciding the elemental content of the plant. This necessitates substitution of the system of general recommendation at least to soil based recommendations.

Another important revelation in the misconception that organic manuring shall be a panacea to low productivity and for fertilizer responsiveness. Failure of FYM/OM to increase yields in the present trial demonstrate response is governed by combined action of elements and source variations to be to induce response behaviour. Organic manure/FYM failed to increase the yield as had been the residual product of straw having the high level of unfavourable elements.

5.8.3 Phasic analysis of productivity process

Mureta (1969) described the yield as the product of a series of processes in progression and over durational time they were designated as phases viz., tiller production, panicle initiation and grain filling. Significant relationship of root number and dry weight of roots observed at MT stage to yield observed in the present study (Table 4.3.1.a) calls for addition of root production as the first stage of the three phase process. Failure of higher panicle weight and test weight to get transformed in to yield (Table 4.3.1.c) necessitate inclusion of this as the last phase. Thus the results generated in the present project have called for characterising the yield as a five stage process viz. root phase, tillering phase, panicle initiation and flowering, grain filling and survival phase (Fig.5.5.2).

A perusal of the morphophysiological and nutritional factors influencing each progressive phases in the yield process also has been evidenced in the study.

Larger number of roots with average root length and their stability (Plate No.1 and 2) had been the most important morphologic attribute affecting the yield. This had been caused by the usually high iron content (upto 80000 ppm - Table 4.5.4.a) in the root. Dry seeded crop yielded better evidently because the deposition of Fe had been lower which led to a higher root number and their stability. Next to root is the tiller production. A perusal of the data on tiller production proved that the high Fe content of the root caused a lower tiller number at MT, an extended tiller production and accompanied tiller decline till the harvest. This tiller production and decline have been reported to be to exclude Fe though the plant is forced to shed N, P and K in the process (Musthafa, 1995). Probably this shall be designated as a "forced diversionary trend" in the morphological context.

The high Fe content of the root does not appear to affect the physiological processes in this study as the data on the chlorophyll content and cell sap pH will show. A low cell sap pH and chlorophyll `a' dominated chlorophyll formation especially at MT stage pointed out that the rate of photosynthesis is not seriously hampered but diversionary trend is the limiting factor. Progressive decline of Fe in the leaves can be deemed as an evidence of waning out the influence of Fe.

Initiation of panicle involving the fixing up the floret number and container capacity of yield is purely a physiologic transformation not apparent morphologically. The data of the first crop (Table 4.3.1.c) showed that floret number has not changed in the various treatments. Floret number is decided by the carbohydrate content in the plant two weeks before flowering. It followed then that floret number also is decided by root Fe content and dry matter accumulation in between the MT and PI stages.

When once the container capacity has been decided the yield is decided by the quantity of carbohydrates made available to store in the grain.

Morphologically grain filling efficiency is identified with thousand grain weight and grain straw ratio. Progressively declining test weight from dry seeding through transplanting to wet seeding showed that the latter two had lower quantities only of carbohydrates available which may either be due to reduced photosynthesis and/or reduced translocation. A higher grain straw ratio in wet seeding and transplanting coupled with lower test weight would mean reduced photosynthetic efficiency as the cause of low grain weight.

Physiological index of higher pH values in these treatments indicated that reduction of pH of the boot leaf can increase the yield.

Nutritionally the data on boot leaf content will show that the low test weight had been due to a higher Mn and Zn content. It appeared from the data that between Mn and Zn, Mn involved in reducing the photosynthetic rate and Zn in reducing the grain straw ratio.

These results revealed that in the early stages Fe is the limiting factor and in the later stages Mn and Zn are the yield limiting factors. Variation in nature of factors and their mode of action necessitates different sources and probably means of amelioration.

Yield process may virtually appear to be decided among number of panicles, florets per panicle and thousand grain weight. But there can be a gap between produced and realised yields as the apparent low yield of wet seeding (Table 4.4.1.b) inspite of higher panicle and test weight. This had been due to the high desiccating winds on January - February and the only way to escape is earlier crop commencement.

Thus the study showed that along with progressional development of rice plant morphophysiologic inhibitions/and/or limiting influence engineered by native elements operate cumulatively. Minimising these inhibitions and limiting influences in a progressional manner is required which will form a scheme for progressional improvement of productivity, the steps for which identified from the results generated in the third, fourth, fifth and sixth experiments are listed below.

Larger number of roots of medium length to minimise the influence of high redox potential and iron content shall be achieved through wet seeding (Table 4.4.1.a) and Ca application (Table 4.5.3.a) in second crop. In first crop season dry seeding shall be resorted to instead of transplanting or wet seeding.

Enhancing the level of K from 45 to 120 kg ha^{-1} will facilitate a better internal nutritional environment by reducing Fe, Mn and Zn content in the plant and generate favourable N/Fe, N/Mn, K/Fe, K/Mn and K/Zn balance in the plant.

Laterite soils by its very definition are deficient in silica. Uptake studies in the experiments showed that physical unavailability of silica is a factor that limits the yield (Table 4.3.8.a and 4.3.8.b). Application of silica as basal dressing will make up this and contribute to a higher yield. Silica will also reduce the weed menace (Table 4.6.1) and reduce K exhaustion. The observation that plots receiving silica has remained free of pest and disease incidence show that it exercises a protective function and will reduce the gap between realised and realisable yields.

Being a graminaceous crop rice requires only very small quantities of Ca. Calcium however has the capacity to reduce Fe content of the plant in the early stages in addition to its role in neutralising increasing trends in acidity due to chemical fertilization. Calcium also has the disadvantage that it tend to tilt the balance of Ca/K (Table 4.5.10.a, 4.5.10.b and 4.5.10.c). To overcome this Ca at ¼ of the lime requirement (150 kg ha^{-1}) or still less have to be applied basally with a positively higher dose of K.

Calcium has been found incapable to bring about reduction in Mn and Zn content of the plant especially towards PI stage and onwards. Singh (1970) found that S can overcome this disadvantage by restricting uptake and facilitating the dilution. The present study by confirming this suggest inclusion of sulphur in recommendation. This shall be done by partially substituting urea with amophos for basal dressing and with ammonium sulphate for top dressing.

Phosphorus though is essential is now being applied in excess. A six tonne crop does not require more than 20 to 25 kg p ha^{-1}. Increasing P levels in the plant also tilts the Fe, Mn and Zn balances unfavourably. Thus uptake studies through the seven experiments suggested that application of P levels can be halved.

Adoption of this progressional productivity modulation package shall lead to a level of raising the yield levels to well over 6 t ha^{-1} through a progressional increase.

The study has also helped to identify the specific reasons for the comparatively low productivity of rice in the second crop season ie. September - October to January - February. Seasonal variation in productivity calls for differential recommendations. The results of the present study has identified the yield limiting factors as continuous submergence as the most important. The results showed that this malady shall be overcome by widening the temporal spacing of irrigation. Irrigation three days after disappearance of ponded water is the answer.

The second reason for the comparatively low yield in the second crop had been a comparatively high content of Fe, Mn and Zn in the leaves of the plant which could be restricted by basal dressing of Ca and substituting urea with amophos and ammonium sulphate

This shall be made further effective by digging to a depth of 30 cm instead of conventional practice of loosening the soil to a depth of 15 cm. This will help to remove available Fe, Mn and Zn to beyond the root zone.

5.8.4 Sustainability

Sustainability is considered as the pre-requisite for adoption of any production technology. In the case of crop production, it should be scientifically appropriate, practically viable and protective of the component inputs and economically profitable.

Conceptually, the present system considers plant not merely as a medium but one naturally bestowed with high potential for yield. This is based on the observation (Table 4.1.1) that the same variety manifested yield variation of the order of 2860 to 8200 kg ha^{-1}. Adaptive trials of Red Triveni (Rosamma *et al.*, 1991) have also reported similar results. This would mean that low yields are invariably the result of inhibitory influences from the environment. Seasonal effect of productivity (Alexander *et al.* 1991) adds further credence to this. Natural corollary of these indications are that yield shall be improved by ameliorating or correcting the inhibitory influences. In the nutritional front this is akin to the mirror image of law of minimum and vacant barrel concept (Tisdale, *et al.* 1995) which will imply that elements in excess limit the yield.

As the system envisages amelioration of inhibitory influences, progressive amelioration leads to progressional increments in yield which will be in tune with continuing sustainability with increasing needs.

The envisaged system is simple and practically viable as it only demands some addition of new inputs; application of silica, increasing the level of K against reducing the level of P and substituting nitrogen source to one containing S also. This is for the first crop. In the second crop the system recommends deeper preparatory cultivation, wet seeding instead of transplanting and irrigation three days after disappearance of ponded water instead of continuous submergence.

In addition to its ability to increase the yield the system is protective in nature in three ways viz., (1) application of silica keeps the uptake level of K to around 120 kg ha^{-1} - the level of application. (2) Higher levels of K will protect from sheath blight. Silica will virtually avoid pest and disease incidence and reduce weed growth. Basal dressing of Ca will neutralise acidity induced by use of ammonium sulphate. Thus the system simultaneously forecloses temporary or long term deterioration of soil environment proposed by Anilakumar (1993) and Musthafa (1995).

The system is economically profitable as the enhancement in yield even at the minimum will be over 1800 kg even in areas now yielding 3500 to 4500 kg ha^{-1}. Substitution of urea with ammonium sulphate will balance between themselves. Savings by reducing the level of P by 1/3 and liming to 1/4 or less of lime requirement will meet the cost for additional K. Deep digging can be achieved at no extra cost by changing the adjustments in tractor. Irrigation three days after disappearance of ponded water instead of ensuring continuous submergence will reduce the cost of irrigation in the second crop by 1/3. Reduced weed infestation and low incidence of pest and disease and consequential savings on weed removal and pest and disease management will more than compensate the cost involved in application of silica. Thus the system is cost reductive on the one side and additionally profit generative on the other.

Summary

SUMMARY AND CONCLUSIONS

The project entitled "Nutritional balance analysis for productivity improvement of rice in laterite alluvium consisting of five field experiments, a survey on productivity relations in 36 farmers fields and a pot culture trial was conducted during 1995-1997 at Agricultural Research Station, Mannuthy. The salient research results obtained are presented here.

1. Physico-chemical properties of the soil groups varied widely with a pH range of 3.58 to 7.82. Range of clay and sand contents were 10.2-24.2 and 43.9-87.3 per cent respectively. In physico-chemical characteristics soil groups intercrossed each other.
2. Data from farmer's plots showed that the yield ranged between 2800 to 8000 kg ha^{-1} in laterite soils, 4500 to 7500 kg ha^{-1} in `kole' lands and 4500 to 9000 kg ha^{-1} in black soils. Straw yield and partitioning coefficient also showed variation between locations. Grain yield was decided not merely by total dry matter production but also by partitioning coefficient which ranged widely.
3. Comparison of foliar concentration of elements with observed mean levels of elements for an yield above 7000 kg ha^{-1} showed that mean foliar concentrations of individual elements in all the three soil groups were higher.
4. Different soil situations produce the same yield with different elemental combinations.
5. Studies on the interrelationship between available nutrient status of the soil and yield parameters showed that Mn was negatively related with total biomass and yield. Iron, Zn and K were negatively related with straw yield. Calcium alone was positively relating with straw and total biomass yield.

6. Interrelationships between total content of the elements in the soil and yield parameters showed that grain yield remained unaffected. Total content of Ca, Mg, S and Mn showed a positive and significant effect on straw and total biomass yield. Iron and Zn showed negative relations with straw yield.
7. General analysis of crop performance in the farmers fields and their nutritional relations showed that rice crop fails to utilize the available and absorbed N.
8. Total biomass production and straw yields are adversely affected by excess, total and available contents of Fe, Mn and Zn significantly. Of the ten elements studied seven elements showed negative relationships with grain yield, straw yield and total biomass production.
9. Potassium content of the soil was low in 85 per cent of the locations sampled for the study.
10. Split up analysis to get information on specific soil group showed that nutritional relation differed in different soils necessitating soil specific recommendations.
11. The data also suggested that content and relationship wise analysis for individual elements will be inadequate to formulate nutritional management. `Content balance combined analysis' was found more befitting.
12. Excess content in the soil and plant as well as the negative relationship with productivity parameters on the one side and failure of plant to utilize available N showed that ameliorative management alone can bring about significant improvement in yield.
13. Pot culture studies which exclude the subsoil effect showed that negative influences of Fe and Mn are totally sub soil effects. Zinc and Cu effects are total effects in laterite of both surface and sub-surface soils.

14. Studies excluding sub soil influence showed that Mn of boot leaf and root was significantly related to yield. Zinc content of root and leaf and Ca content of boot leaf were related to yield of grain in black soil. Potassium content of the boot leaf and Zn content of the leaf alone showed any relationship with grain yield in `kole' lands.
15. Dry sowing during the first crop season recorded a mean yield of 6400 kg ha^{-1} and was significantly superior to wet seeding and transplanting. Wet seeding and transplanting did not significantly differ between themselves.
16. Morphological indices of root number at MT stage and dry matter accumulation between MT and PI stage, MT and flowering as well as PI and flowering were found to be ideal indices of yield expression.
17. Number of roots per hill appeared to be a function of their iron content. Dry seeding has recorded the lowest iron content of 2.8 per cent iron in the root.
18. Interrelationships of nutrient ratios of leaf and boot leaf showed that N/Zn and N/Ca in the leaf and N/Fe, N/Mn and N/Zn in the boot leaf were related.
19. Increasing contents of Fe in the root tended to reduce root number and average root length at MT stage. It lead to subsequent decay and poor regeneration of the roots.
20. High iron content in the plant lead to lower chlorophyll `a' content, reduced the dry matter accumulation from MT stage to flowering stage and lead to a protracted tillering and tiller decline habit.
21. Dry matter accumulation in rice from MT to PI stage and PI stage to flowering was found significantly correlated with yield.

22. Nutritionally dry seeded crop which completed early span of over 30 days in dry soil environment recorded a lower content of Fe, Mn, Zn and Cu in the plant. Wet seeded and tranplanted crops recorded very high increases in the percentage contents of these elements. Wider N/Fe, N/Mn, N/Zn served as better indices of high yield. The results showed that fertilizer use efficiency and yield expressions were being curtailed by the native elements.
23. Wider ratios of N/Fe, N/Mn and N/Zn were reflected in a higher chlorophyll content, wider chlorophyll `a', `b' ratio and a near steady low leaf sap pH.
24. Shallow and deep digging or increasing organic manure levels failed to improve the yield because they failed to reduce the plant content of Fe, Mn and Zn.
25. Uptake studies showed that increased yield was also related to increased silica uptake.
26. Unlike in the first crop, depth of digging and FYM levels significantly increased the yield of rice during second crop. Deep digging increased the grain yield by 872.0 kg ha^{-1} and 5 t ha^{-1} FYM increased the grains yield by 1145 kg ha^{-1} and at 10 t ha^{-1} FYM straw yield alone was significantly increased by 408 kg ha^{-1}. Grain yield was not affected at 10 t ha^{-1} FYM level and straw yield at 5 t ha^{-1} level. Results showed an improved grain : straw ratio due to increased depth of digging as well as due to the application of 5 t ha^{-1} FYM.
27. Significant interactions were observed in the yield as well as total biomass production due to the combining effect of FYM and method of crop establishment in the second crop season. Significant increase in yield in WSR was obtained only at 5 t ha^{-1} level in transplanting. The mean yields in the two treatments respectively were 4887 and 5647 kg grain. Highest biomass yield was recorded at 10 t ha^{-1} level in both wet seeding and transplanting. The biomass yields were 8938 and 9745 kg ha^{-1} respectively.

28. Combining effect of deep digging and organic manure levels were also significant. Deep digging combined with 5 t ha^{-1} of FYM recorded the highest yield of 5692 kg grain and deep digging combined with 10 t ha^{-1} level produced the highest quantity of 9751 kg ha^{-1} total biomass.

29. The results showed further that combined effect of digging, FYM and crop establishment were manifested only upto MT stage.

30. Increase in yield due to deep digging appeared to be due to a decrease in root iron content by 7055 ppm at MT, a reduction in S content of the shoot at MT and an increased N content of the boot leaf.

31. Increase in yield due to increase in FYM application appeared to be due to a reduction of Cu in the root and an increase in K content of the shoot at MT and a decrease in the S content of the boot leaf.

32. Physiologically a lower leaf sap pH of the boot leaf in deep dug plots and a marginal increase in chlorophyll `a' of the boot leaf appeared to be the cause of increase in yield.

33. The results worked out from the present trials showed that the factors that cause the low yield during the second crop season are Mn, Zn and Cu. The direct effect of fatal concentrations of these elements as well as their indirect influences in restricting K absorption and translocation were responsible for the low productivity of rice in the second crop season. Uptake studies indicated that facilitated silica absorption shall be of help in increasing the yield.

34. Results of the experiment on K, Ca and Mg revealed that there existed a real and relative deficiency of K. Significant yield increments were obtained by application of 120 kg K ha^{-1} and the main effects worked out to 528 kg grain ha^{-1}.

35. Wet seeding appeared to be better than transplanting in the second crop as the latter with deep placement absorb more Mn and Zn.

36. Application of Ca as lime at 150 kg ha^{-1} failed or S at 100 kg ha^{-1} did not significantly increase the yield.

37. Results showed that effect of increasing K content of the culm, leaf and grain was significantly related to the total biomass production. Potassium content in root, shoot and culm and straw yields were significantly related to straw yield and the relation of K in the leaf at PI failed to significantly relate to grain yield. Calcium content of the various plant parts did not show any significant relationship with yield.

38. Results showed that more than the absolute level of K its balances with Fe, Mn and Zn etc. governed the productivity of rice.

39. Application of Ca, though reduced the Fe content, failed to improve the yield because it increased Ca content and increase in Ca alone tilted the Ca + Mg/K balance.

40. Effect of excess Mn was found to interfere in photosynthetic process and Zn in the grain-straw ratio.

41. Results showed that K/Fe, K/Mg ratios of the leaf at PI were significantly correlated with grain yield, straw yield and total biomass, K/Mn ratio was related to yield of straw and total biomass. $\frac{Ca+Mg}{K}$ ratio in the plant showed a negative correlation and the relationship with yield of total biomass.

42. Application of Ca and its increased contents did not increase the yield of rice possibly because of the unfavourable shift in the $\frac{Ca+Mg}{K}$ ratio.

43. Application of S also did not show any positive relationship with yield.

44. Apart from the K based ratios N/Mg ratio had manifested significant positive correlation with straw yield.

45. Studies 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 PI stage and flowering stage. Calcium on the other hand narrowed them. Thus sulphur exerted a beneficial effect though it was not reflected as significant improvement in yield.

46. Progressive variation in the foliar contents of Fe, Mn and Zn showed that iron content steeply reduced progressively when Mn content increased from that in the culm to leaf at PI and boot leaf. Zinc and Cu contents increased from that in the root to culm at PI and reduced progressively to leaf at PI to boot leaf stage. This showed that deleterious influences of these elements are expressed with phasic progression. Iron in the early stages and Mn and Zn in the later stages.

47. Studies on combined effect of K, Ca and S showed 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. For eg: K x Ca or K x S interactions if favoured filled grains per panicle did not affect grain-straw ratio.

48. The results indicated that temporal spacing of Ca and S (S as a soluble source) will yield better results.

49. Application of silica at 250 kg ha^{-1} significantly increased the yield of grain and the mean main effect was 619 kg grain ha^{-1}.

50. Application of zinc did not have any significant effect on grain yield.

51. Inter correlation studies showed that effect of silica and zinc were opposite. Root and shoot content of silica at MT stages was significantly related to straw yield. Relation of culm content of silica at PI stage failed to reach significant level.

52. Zinc on the other hand did not express any relationship with yield.

53. Application of zinc increased the weed dry matter significantly and this was significantly correlated negatively with straw yield.

54. Application of silica at 250 kg ha^{-1} limited K removal by the crop within the level of application. Silicate application was also found to reduce the silica removal.

55. The results of the experiments showed that presently recommended level of P at 45 kg ha^{-1} shall be halved as even a yield level of 6500 kg ha^{-1} removes only 20-25 kg P ha^{-1}.

56. Low yield was also found to be due to unavailability of silica in the submerged condition. Application of silica reduced the K uptake of 6.5 t crop from 180 to 118 kg ha^{-1}.

57. All the experiments in the project showed that even a 6.5 t crop removes only 20-25 kg of P ha^{-1} which suggested that levels of application of P shall be reduced by 50 per cent.

58. Varying positive and negative relationships of individual elements in different plant parts suggested discriminatory translocation of elements and management for metabolic amelioration for the betterment of yield.

59. The coverall results of the study have set the basis of a new approach in fertility management viz. `Mineral Use for Maximum Yield (MUMY) which shall be more sicentific and more sustainable.

60. Results of the study has worked out the scientific relevance of bifunctional role - chemical and biochemical functions-of elements as well as interaction based phasic management.

61. Comprehensive analysis of the data over the experiments carried over first and second crop seasons and integrating the favourable components have lead to the formulation of the following recommendation to get an yield over 6 t ha^{-1}.

i) Virippu season

- Dry seeding
- Basal dressing of FYM 5 t ha^{-1}
- N and P as per existing recommendation. N as usual- source and basal dose
- K-120 kg ha^{-1} - application as per the recommendations
- Silica 250 kg ha^{-1} as basal dressing
- Top dressing N as ammonium sulphate

ii) Mundakan season

- Wet seeding
- FYM 5 t ha^{-1} as basal
- N and P as per existing recommendations; N as usual - source and basal dose
- K 120 kg ha^{-1} - application as per the recommendations
- Silica 250 kg ha^{-1} as basal dressing
- Top dressing N as ammonium sulphate
- Irrigation three days after disappearance of ponded water instead of continuous submergence

62. This production programme has the advantage that it does not involve much additional input and offers the scope of reducing P application by 50 per cent and scientifically sustainable as it keeps nutrient removals within the levels of application of N, P and K.

63. This programme also offers a way to progressional yield improvement above 6.5 t ha^{-1} as the level of Fe, Mn and Zn in the leaves are still far higher than suggested critical levels.

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* Originals not seen

Appendices

Appendix I

Weekly weather at Mannuthy from 07.05.95 to 25.03.96

Standard Week	Temperature (°C)			RH (%)	Rain fall (mm)	Sunshine hours (h/day)	Wind velocity (km/hr)	Evaporn (mm/day)
	Max	Min	Mean					
07/05-13/05	31.3	23.8	27.6	85.0	290.9	1.3	3.8	6.3
14/05-20/05	33.0	24.3	28.7	78.0	23.2	6.8	4.1	4.1
21/05-27/05	33.8	23.8	28.8	74.0	0.6	8.8	3.7	4.6
28/05-03/06	34.5	23.7	29.1	77.0	4.2	8.1	4.0	4.7
04/06-10/06	33.1	23.6	28.35	82.5	68.3	4.4	4.3	3.8
11/06-17/06	30.1	22.5	26.3	90.5	294.4	0.8	3.9	3.0
18/06-24/06	31.1	22.1	26.6	87.0	41.0	4.5	3.4	3.0
25/06-01/07	30.9	23.9	27.4	89.5	167.1	3.1	2.5	3.7
02/07-08/07	30.7	23.4	27.05	86.0	122.6	3.4	2.1	3.2
09/07-15/07	28.9	23.0	25.95	91.0	160.3	1.2	1.0	2.6
16/07-22/07	30.0	23.2	26.6	89.0	227.8	1.8	1.8	2.6
23/07-29/07	29.8	23.1	26.45	87.5	209.0	2.3	1.4	3.1
30/07-05/08	30.2	23.3	26.75	85.0	167.9	3.6	2.3	2.6
06/08-12/08	31.3	24.1	27.7	83.0	40.8	4.6	2.1	3.5
13/08-19/08	31.3	23.6	27.45	85.0	113.7	5.2	1.7	3.3
20/08-26/08	31.0	24.2	27.6	87.0	109.8	3.7	2.0	2.8
27/08-02/09	28.5	23.3	25.9	91.0	194.4	0.2	2.5	2.9
03/09-09/09	30.0	23.9	26.95	86.0	89.6	3.7	2.6	3.1
10/09-16/09	32.0	23.5	27.75	79.0	25.2	8.5	1.4	3.5
17/09-23/09	31.0	23.3	27.15	83.0	121.3	4.7	1.5	2.5

Contd....

Appendix I contd....

24/09-30/09	32.4	23.1	27.75	78.5	1.9	9.4	1.7	3.5
01/10-07/10	33.0	23.2	28.1	82.0	3.8	8.0	1.4	3.0
08/10-14/10	32.0	22.9	27.45	79.5	12.4	7.0	1.9	3.3
15/10-21/10	33.1	23.2	28.15	78.5	7.4	9.1	1.3	4.0
22/10-28/10	34.3	23.5	28.9	71.0	15.0	9.1	2.7	4.4
29/10-04/11	33.5	22.8	28.15	83.5	144.5	6.5	1.1	3.7
05/11-11/11	30.2	22.7	26.45	85.0	15.1	2.2	0.5	2.1
12/11-18/11	30.9	22.3	26.6	81.5	0.6	1.0	1.0	2.8
19/11-25/11	31.6	22.8	27.2	79.0	-	0.8	0.8	3.1
26/11-02/12	32.3	21.9	27.1	65.5	-	1.8	1.8	3.9
03/12-09/12	32.9	20.6	26.75	61.5	-	4.7	4.7	4.9
10/12-16/12	32.6	20.9	26.75	55.0	-	5.4	5.4	5.5
17/12-23/12	31.9	21.7	26.8	55.5	-	8.1	8.1	8.5
24/12-31/12	32.3	22.3	27.3	57.0	-	8.6	8.6	6.7
01/01-07/01	32.4	22.6	27.5	58.5	-	9.4	8.3	6.1
08/01-14/01	32.9	22.4	27.65	53.0	-	9.9	7.9	7.1
15/01-21/01	33.6	22.9	28.25	57.5	-	8.1	3.9	5.3
22/01-28/01	33.3	21.7	27.5	45.0	-	9.9	7.5	7.9
29/01-04/02	33.6	22.0	27.8	49.5	-	10.2	8.5	8.3
05/02-11/02	34.1	33.1	28.6	57.0	-	10.2	7.2	6.8
12/02-18/02	34.8	23.3	29.65	50.5	-	9.6	5.5	6.6
19/02-25/02	35.2	24.2	29.7	57.5	-	9.7	4.5	7.0
26/02-04/03	35.9	23.5	29.7	49.5	-	10.4	5.6	7.5
05/03-11/03	37.1	22.9	30.0	44.5	-	10.4	4.3	8.0
12/03-18/03	37.4	24.8	31.1	63.0	-	7.9	2.9	6.8
19/03-25/03	36.5	25.6	31.05	66.5	-	9.0	3.2	6.7

Appendix II

Weekly weather at Mannuthy from 05.05.95 to 04.03.97

Standard Week	Temperature (°C)			RH (%)	Rain fall (mm)	Sunshine hours (h/day)	Wind velocity (km/hr)	Evaporn (mm/day)
	Max	Min	Mean					
07/05-13/05	32.5	25.3	28.9	75.5	-	7.5	2.2	4.0
14/05-20/05	33.2	26.7	29.05	75.0	16.2	9.6	3.2	4.9
21/05-27/05	33.6	25.6	29.6	70.0	6.0	7.9	2.2	4.6
28/05-03/06	33.5	25.3	29.4	75.5	5.2	6.7	2.3	4.4
04/06-10/06	32.2	24.0	28.1	77.5	42.6	6.2	2.5	3.7
11/06-17/06	28.2	22.9	25.55	80.0	216.1	1.6	3.6	2.4
18/06-24/06	28.4	23.3	25.85	90.0	141.2	2.5	3.5	3.0
25/06-01/07	31.4	24.3	27.85	88.5	0.4	7.5	2.5	4.0
02/07-08/07	30.9	23.7	27.3	80.0	86.8	614	2.3	3.8
09/07-15/07	29.0	22.6	25.8	84.0	133.5	3.1	2.3	2.6
16/07-22/07	27.3	22.8	25.05	90.0	221.4	0.3	2.6	2.2
23/07-29/07	27.7	23.0	25.35	94.0	119.2	1.3	3.3	2.6
30/07-05/08	29.5	23.4	26.45	91.5	65.8	4.8	3.0	3.4
06/08-12/08	28.2	23.4	25.8	87.0	92.6	2.4	2.7	2.7
13/08-19/08	28.6	23.5	26.65	88.0	101.4	1.9	2.5	2.9
20/08-26/08	29.5	23.8	26.65	83.0	62.6	4.1	3.0	3.6
27/08-02/09	29.5	24.0	26.75	84.0	42.6	5.2	3.8	3.6
03/09-09/09	29.7	24.2	26.95	83.5	33.4	5.0	2.6	3.2
10/09-16/09	29.1	23.5	26.3	85.0	88.6	3.5	2.7	3.0
17/09-23/09	29.2	23.8	26.5	83.5	26.8	4.3	2.7	3.3

Contd....

Appendix II contd....

24/09-30/09	28.8	23.3	26.05	85.5	215.6	4.7	2.6	3.1
01/10-07/10	30.0	23.6	26.8	80.0	17.6	7.6	3.4	3.6
08/10-14/10	30.9	23.8	27.35	83.5	69.6	4.5	1.8	3.0
15/10-21/10	29.8	22.6	26.2	86.0	105.3	3.4	1.2	2.3
22/10-28/10	29.7	22.2	25.95	79.0	26.8	7.3	2.1	6.8
29/10-04/11	30.3	22.8	26.55	79.0	2.6	7.3	1.5	3.1
05/11-11/11	31.4	22.3	26.85	76.5	30.6	8.7	1.4	3.4
12/11-18/11	31.8	23.7	27.75	70.5	5.3	7.6	3.7	4.0
19/11-25/11	31.9	24.4	28.15	64.0	0.6	6.9	7.1	5.1
26/11-02/12	32.1	23.7	27.9	64.0	-	6.5	3.6	4.1
03/12-09/12	31.0	20.4	25.7	72.5	46.6	7.5	2.3	3.3
10/12-16/12	29.4	23.0	26.2	75.5	14.2	1.9	7.0	3.2
17/12-23/12	29.7	22.3	26.0	66.5	-	7.4	6.9	4.8
24/12-31/12	30.9	21.6	26.25	61.0	-	9.4	8.7	5.5
01/01-07/01	31.2	21.7	26.45	60.5	-	9.6	7.3	5.4
08/01-14/01	32.0	23.2	27.6	63.5	-	9.1	8.8	6.0
15/01-21/01	32.4	22.4	27.4	60.5	-	9.6	6.0	5.3
22/01-28/01	32.5	21.4	26.95	61.5	-	9.7	5.7	5.3
29/01-04/02	32.5	21.0	26.75	61.5	-	10.1	5.7	6.0
05/02-11/02	33.5	21.7	27.6	67.5	-	9.2	2.7	5.0
12/02-18/02	33.9	21.7	27.8	54.5	-	9.2	4.7	5.8
19/02-25/02	34.4	22.7	28.55	63.5	-	8.5	3.1	5.4
26/02-04/03	35.8	22.5	29.15	48.5	-	10.2	5.9	7.7

NUTRITIONAL BALANCE ANALYSIS FOR PRODUCTIVITY IMPROVEMENT OF RICE IN IRON RICH LATERITIC ALLUVIUM

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Investigation entitled "*Nutritional balance analysis for productivity improvement of rice in iron rich lateritic alluvium*" consisting of seven experiments was conducted during 1995-1997 in the farm attached to the Agricultural Research Station, Mannuthy.

Objective of the study was to identify the factors that limit the productivity of rice in the lateritic alluvium, estimate the nature and extent of their influences, formulate and test the methodology to overcome them and to evolve high-tech management programme to get 6 t or more yield of grain per hectare. The study included evaluation of the influences of all the cultural and nutritional inputs on the content and balances of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and SiO_2 in the root, culm and leaf at MT and PI and boot leaf in addition to uptake in grain and straw.

Results revealed the following

Field evaluation of the crop performance in 36 locations of Thrissur and Palakkad districts of Kerala spread in km^2 and three soil types revealed that yield ranged from 2800 to 9000 kg ha^{-1}. Low productivity was not due to real deficiency of any of the 11 elements in the foliage. Foliar concentrations of individual elements were more than what has required to produce yield levels above 7000 kg ha^{-1} in some locations except for silica.

Low realised yields were found to be due to the excess plant contents of non-applied elements especially Fe, Mn, Zn and Cu as well as their

interactions in plants. As such, soil test or tissue test values of elements were found inadequate, a "content balance combined approach" was found to be better tool in nutritional management.

Iron content of the root of the order of 50,000 ppm under submerged conditions was found to inhibit morphological and physiological development leading to low yield.

Physiologically, lower development of chlorophyll `a' and its poor stability as well as a higher sap pH lead to low dry matter accumulation. Morphologically the effect was expressed through very few long roots at MT, low root weight, root damage and failure of further initiation of roots, protracted production of fewer tillers as well as their decline and low dry matter accumulation in the shoots between MT and flowering periods. Yield variation due to the early suppression alone was of the order of 1800 kg ha^{-1}.

Harmful effects of Fe in the plant was less subsequently as Fe decreased progressively with growth of the plant. Manganese and Zn and to some extent Cu found to take over from Fe in the post panicle initiation phase. Leaf concentrations of these elements at PI and flowering stages rise far higher the critical levels. Manganese was found to reduce photosynthetic efficiency at this stage and Zn was identified with affecting translocation to the grain from vegetative parts in the maturity phase, thereby affecting grain-straw ratio.

Lower productivity of second crop (September-October) compared to first crop (April-May seeded rice) was found to be due to the higher foliar concentrations of Mn and Zn in the PI stage onwards. Cultivation under continuous submergence aggravated these inhibiting influences.

Thus low yield of rice in laterite soils was found to be due to a multi-element multiphase effect.

Nutritionally these effects could be recognised through narrow N/Fe, N/Mn, K/Fe, K/Mn and K/Zn ratios.

Application of Ca @ 150 kg lime ha^{-1} could reduce the Fe content of the plant and S at 100 kg ha^{-1} could reduce Mn and Zn content in the plant at PI. Substituting urea with Ammonium sulphate for top dressing appeared to be better to contain Mn and Zn at PI stage. Application of SiO_2 at 250 kg ha^{-1} and increasing the levels of K from the present level of 45 kg to 120 kg ha^{-1} and resorting to dry seeding in April-May crop and wet seeding in October-crop and irrigation once in three days after disappearance of ponded water were found to be effective means of containing the low yield malady and raise the yield beyond 6 t ha^{-1}.

This production programme has the advantage that it does not involve much additional input, offers the scope of reducing P application by 50 per cent and scientifically sustainable as it keeps nutrient removal within the levels of application of N, P and K.

This programme also offers a way to progressional yield improvement above 6 t ha^{-1} as the levels of Fe, Mn and Zn in the leaves are still far higher than suggested critical levels.

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