INFLUENCE OF IRON TOXICITY ON GROWTH, YIELD AND PLANT COMPOSITION OF MAJOR RICE VARIETIES CULTIVATED IN KERALA

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Influence of iron toxicity on growth, yield and plant composition of major rice varieties cultivated in Kerala" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "Influence of iron toxicity on growth, yield and plant composition of major rice varieties cultivated in Kerala" is a record of research work done independently by Kum. R. Sheela 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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INTRODUCTION

Rice is grown under the submerged conditions in more than 6.5 lakh hectares in Kerala under the various agroclimatic situations. Though the submerged conditions offer several advantages to rice growth, certain undesirable features associated with this situation often create field constraints which influence rice production and its productivity. Imbalance of nutrients and the production of toxic factors under the anaerobic conditions due to lack of activity of aerobic micro organisms coupled with restricted drainage can adversely affect the normal growth and yield of low land rice. Among the major toxic factors, toxicity due to excess soluble iron under the acidic and anaerobic soil conditions has been reported by several farmers growing rice in the acid sulphate soils and in brown hydromorphic soils derived from the midland lateritic regions of the State. All waterlogged rice soils of Kerala in view of their acidic reaction in general, show varying degrees of iron toxicity during different seasons of the year. Though as a micronutrient iron has specific function in chlorophyll production, nucleic acid metabolism, photosynthesis and regulation of the activity of enzymes involved in electron transport chain, its presence in the soil in excessive amounts in the reduced form can lead to indiscriminate absorption by the rice roots resulting in the physiological disorders in the plant which are often manifested through visible symptoms on plant parts during the initial critical stages, on growth and in the reduced yields later.

Several factors influence solubilisation of iron in the soil. These include soil submergence, restricted drainage, soil reaction, salinity status, presence of easily decomposing organic matter and the accompanying low redox potential etc. The redox potential range encountered in water-logged soils extends from -300 mV on the reducing end to nearly +700 mV on the oxidising end. The range is encountered in all biological systems. The rate and magnitude of fall in redox potential values in soils under submergence depend on the amount of decomposible organic matter and the amount of reducible iron and manganese in the soil. The intensity of toxicity symptoms in rice may vary markedly in most soils, with symptoms ranging from clear bronzing to typical yellowing. Varieties differ in their tolerance to iron.

The problem of iron toxicity to rice has received the attention of soil scientists and plant physiologists in India, Sri Lanka, Philippines, Thailand, Malaysia, Indonesia, Liberia, Nigeria, Sierra Leone etc. The problem has been handled by several investigators, viz., Ponnamperuma, 1955; Mandal, 1962; Sahu, 1968; Tanaka and Yoshida,1970; Breemen van, 1978 and many others. Gunawardena, 1975 and Virmani,1976 have done intensive screening of rice varieties and classified them as tolerant, moderately tolerant and susceptible.

Several methods have been suggested by various workers for the amelioration of iron toxicity. These include drainage and aeration of the fields, delayed planting after submergence, liming, substitution of less acid forming nitrogen fertilizers, application of silicate, potash and MnO_2 etc. However, curing or preventing iron toxicity is not a simple procedure since neither the drainage nor the incorporation of lime, MnO_2, potash or silicate can completely eliminate the problem. Very often, the large quantities of lime needed to alleviate iron toxicity is frequently too prohibitive to the marginal farmers to adopt. Considering the economy of the various available methods, the adoption of improved and iron tolerant rice variety is considered as most practical and least expensive solution to the problem.

No attempts have so far been made in Kerala to screen the rice varieties for their iron tolerance. Such screening of the currently popular local as well as high yielding varieties of rice for iron toxicity tolerance under controlled condition will be useful to identify varieties which can be recommended to the farmers in the iron toxicity prone locations. With this in view, the experiment has been taken up with the following objectives.

1. To screen rice genotypes popular in Kerala for tolerance under iron toxicity conditions through solutions culture.

2. To study the effect of toxic levels of applied iron on the uptake by tolerant varieties.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Iron toxicity is a physiological disorder of wetland rice (Oryza sativa L.) in the tropics and subtropics which is ascribed to an excessive uptake of iron. Although iron is regarded as an essential micronutrient for crops, the acidic soil conditions and restricted drainage in many lowland rice fields often creates conditions favourable for the excessive solubilisation of iron and its uptake by rice plant. Available information on the requirement and toxic levels of iron to rice are summarised below.

1. Iron as a toxic factor

Kapp (1936) observed that the green colour and root growth improved in rice grown in culture solutions as the concentration of soluble iron (Fe^{2+}) reached 1-25 ppm. However, on reaching 50 ppm there was decline in growth and number of tillers. Aiyer (1946) reported that the best results were obtained with an iron concentration of 32 ppm.

According to Baba (1958) 45 ppm Fe^{2+} was the critical concentration in soil solution for rice.

Ponnamperuma et al. (1955), Takagi (1958) and Workers at IRRI (1964) found that water soluble iron at about 500 ppm was toxic to rice.

In culture solutions, Okuda and Takahashi (1965) observed 100-500 ppm iron as toxic, while a concentration of 300-400 ppm iron in soil well supplied with nutrients caused iron toxicity (IRRI, 1972).

Patnaik and Bhadrachalam (1965) from nutrient solution studies found that the luxury range of iron for rice was 5-40 ppm and toxic range was above 40 ppm. Iron at 150-200 ppm caused death of the rice plant. Plant height and tiller number were considerably reduced and roots were short, scanty and deep brown in colour. The critical concentration of Fe^{2+} in culture solution for bronzing to occur has been worked out by Tanaka and Navasero (1966) as 100 ppm at pH 3.7. Bronzing symptoms could be observed in rice leaves containing 300 ppm iron.

Investigations by Tanaka and Yoshida (1970) led to the conclusion that the leaf blade from the rice plant containing less than 70 ppm Fe^{2+} at tillering stage would indicate possible deficiency of this element and more than 300 ppm Fe^{2+} at active tillering would indicate suspected iron toxicity. They found that young plants are more susceptible to iron toxicity and further reported that the above figures were tentative and subject to modification. They have also reported that in water culture, it is difficult to determine the critical iron content at which typical bronzing would appear.

The findings of Ota (1968) indicated that apparantly healthy plants might contain more than 1000-1500 ppm iron.

Jayawardena et al. (1977) found that iron content of different rice varieties which are moderately affected by bronzing may vary from 110-1100 ppm.

Van Breemen and Moorman (1978) suggested that rice plants showed bronzing when the dissolved iron in the rooting medium was in the range 300-500 ppm. They even suggested that it is probably impossible to define a generally applicable critical iron content in plant tissue and held the view that a comparison of iron contents in the leaf blades of affected and healthy plants from the same field would be more useful.

2. Visible symptoms of iron toxicity in rice

Ponnamperuma et al. (1955) has characterised iron toxicity symptoms in rice as initial appearance of brown spots on the older leaves which gradually develop a reddish brown colour at the leaf tip spreading towards the base and edges; those parts which turned brown were later dried up and curled inwards. Other accompanying symptoms reported were stunting of severely affected plants with poor tillering, late heading and producing narrow panicles with sterile florets followed by poorly developed, coarse textured and dark brown roots.

According to IRRI (1964), bronzing was a physiological disease of rice occurring on strongly acid, poorly drained latosols and was characterised by purple, marginal discolouration of lower leaves, spreading to the entire leaf, followed by brown spots on the upper leaves with purple discolouration and gradual drying up.

Ota (1968) reported that the symptom first appeared as small spots at the tips of older leaves which later spread downwards to the basal parts of the leaves and finally the surface turned brown leaving the mid-rib green.

Park and Tanaka (1968) showed that the cause for brown spotting in rice was iron toxicity resulting from high uptake of iron.

Sahu (1968) identified iron toxicity in lowland loamy latosols. Bronzing of leaves were noticed after 45 days of transplanting. He noticed brown spots and streaks on all aerial parts including leaf sheath, flag leaf and some grain in the panicle.

Tanaka and Yoshida (1970) characterised bronzing by the appearance of many small brown spots in dark green leaves starting on the tips of lower leaves and spreading to basal parts. In severe cases, the symptom would appear even on top leaves. The tints of affected leaves varied with variety. The roots were coarse, sparse, dark brown and damaged.

In culture solution Tadano (1975) obtained characteristic brown spotting of rice leaves commencing from the tips of older leaves when the iron content was 550 ppm. The spots spread on the leaves, then even on the upper leaves and eventually the lower leaves turned grey and died.

Virmani (1976) characterising the toxicity symptoms reported that a high percentage of spikelet sterility occurred in very susceptible lines. It was also reported that Jaya, Vijaya and IR-589-54-2 exhibited yellow orange foliage symptoms when grown in iron toxic swamps. He found that the rate of development of toxicity symptoms depended upon the level of tolerance of the cultivar.

Gunawardena et al. (1982) noticed that iron toxicity disorder is characterised by a purple or a reddish brown, orange or yellow discolouration of leaves which later dry up giving the rice plant a scorched appearance.

According to Benckiser et al. 1984 a, a large number of small brown spots would appear on purple to dark green coloured leaves about 3 or 4 weeks after the rice plants were transplanted.

From the screening experiments on four varieties and 13 advanced breeding lines conducted in Barapani, Abraham and Pandey

(1989) obtained visual symptoms of iron toxicity (bronzing) of leaves at the boot leaf stage.

Rice genotypes numbering 33 were screened for tolerance for acid sulphate soil in the coastal lowland of the Keralakele area of South Sri Lanka by Chandrasiri and Pathirana (1992). They recorded visual symptoms of iron toxicity (bronzing of leaves and stunted growth) in acid sulfate soil at 4^{th} and 8^{th} week after transplanting and noticed that some of the highly susceptible check and a few selected lines died at the early growth stage.

3. **Growth and yield as affected by excess soluble iron**

Ponnamperuma et al. (1955) noticed that the browning symptom due to iron toxicity in rice was first observed about five weeks after transplanting in submerged soil. The effect on growth, flowering and final yield varied with the severity of the symptom. In mild cases rice growth though retarded, was not seriously affected and rapid recovery was made possible during the heading. The severely affected plants were markedly stunted, tillered poorly, headed late and produced thin and narrow panicle with high proportion of sterile florets. Roots of the diseased plants were poorly developed, coarse textured and dark brown in colour.

Reports from IRRI (1964) indicated that root system of bronzed rice plant seen in strongly acid, poorly drained latosolic soils was coarse, scanty and heavily coated with dark brown deposit of Fe $(OH)_3$. The plant growth was considerably retarded. The severely affected plants flowered late and produced small panicles which resulted in low yield.

Sahu (1968) reported that yield of rice was influenced by the severity of bronzing. Low incidence resulted in reduction of yield from 3-14 per cent, medium from 16-35 per cent and heavy attack as high as 36-38 per cent.

Ota (1968) noticed bronzed rice plants in ill-drained paddy fields of lowland wet zone and reported marked retardation in growth and root formation and development in severely affected plants. The root system became scanty, coarse and dark brown. The yield was also very much reduced.

Serayonakul (1972) noticed that plants grown in solution culture containing 200 ppm iron showed toxicity symptoms. Yield was very much reduced above this level of iron in the medium.

Venkatasubrahmanyam and Mehta (1974) observed that application of iron above 40 ppm significantly reduced the dry matter production and yield of rice.

van Breemen and Mooreman (1978) attributed iron toxicity in rice to a great variety of causes in particular to acidic soils high in active and reduced soluble iron (30-2000 ppm).

Yield data from screening trials on 320 rice varieties conducted in green house at IRRI (1980) and comparison of toxicity symptoms at the 4^{th} and 8^{th} weeks confirmed that in susceptible varieties the plant growth was poor in wet season than in the dry with very much reduced yield than the tolerant varieties due to severe iron toxicity induced by strong acidification during the dry spell preceding the wet season planting.

Ottow et al. (1982) reported that modern as well as traditional varieties suffered losses in yield as a result of bronzing disorder. The development of plants is locally inhibited and in serious cases growth depression occurred.

Gunawardena et al. (1982) found that iron toxicity leads to yield losses which were the lowest among the tolerant set, intermediate in the moderately susceptible set and highest among the susceptible set. They attributed the yield reduction to a decrease in productive tillers and panicle weight.

Patra and Mohanty (1988) during their study on the effect of iron on dry matter production of susceptible and resistant varieties noticed that there was a reduction in growth and dry matter production of susceptible varieties compared with the resistant varieties. Grain to straw ratio decreased with increase in iron concentration in susceptible varieties.

Fageria and Rabelo (1987) reported that root and shoot weight of rice were most sensitive to excess iron in growth media. Based on dry matter yield reduction of shoots, at higher iron concentration compared to the optimum or control, rice cultivars were classified into moderately susceptible, susceptible and tolerant.

Abraham and Pandey (1989) reported that iron toxicity reduced the plant height 20 per cent, panicle length 16 per cent, number of productive tillers 60 per cent and yield 77 per cent.

Bulbule and Deshpande (1989) reported that increasing levels of iron in sand/solution culture media progressively decreased the dry matter production. However, varieties Mashuri and SHM tolerated high iron stress conditions and produced substantial yield.

4. Screening for iron tolerance

Varieties of rice differ in their ability to withstand high iron concentrations. Identification of rice varieties tolerant to iron appears to be the most economical and feasible way of combating iron toxicity conditions in the soil. Rate of development of iron toxicity symptoms depend upon the level of tolerance of the cultivars. Solution culture or sand culture or field screening in acidified reduced soil on a mass scale are the major screening techniques described in literature.

Two week old seedlings of 22 rice varieties were planted on a strongly acid oxisol that built up more than 400 ppm iron in the soil solution, a few weeks after submergence and these plants were scored after four weeks according to the severity of symptoms and rated as resistant, moderately resistant and susceptible (IRRI, 1974).

Varietal screening for tolerance to iron toxicity resulted in identification of Gissi 25 and Gissi 27 as the tolerant rice varieties (Virmani and Tubman, 1974).

Bronzing came into prominence during the period when the Murungakayan 302 was grown extensively in Sri Lanka. This variety is susceptible to iron toxicity. When H_4 replaced Murungakayan 302, bronzing was no longer a problem as H_4 was moderately resistant. However, with the spread of BG-11-11, a new high yielding variety, bronzing became serious again (Gunawardena, 1975).

Field screening for iron toxicity tolerance has been in progress for several years in Sri Lanka (Gunawardena, 1979) and

Liberia (Virmani and Tubman 1974). The problems reported are variability of the severity of iron toxicity within a field with time and between seasons, other nutritional stresses chiefly phosphorus and potassium deficiencies (Yamada, 1959, Tanaka and Yoshida 1970) and climatic and biotic hazards.

Sri Lankan scientists screened more than 750 rices including reputedly resistant varieties, elite lines from the General Breeding programme and material from breeding programme, on an iron toxic soil at Padarkka, Sri Lanka during 1976-77 in cooperation with IRRI using 40 Kg each of N, P and K. The plants were scored at 70 days after planting (IRRI - 1977). However, none of these varieties is popular in Kerala.

Reports from IRRI (1977) contain the result of mass field screening of 1862 rices conducted in farmer's field at Laguna. Three week old seedlings were transplanted in the field during both the dry and wet seasons. Seven weeks after transplanting, the plants were scored on a scale of 0 - 9.

Grain yield of some promising rices mass screene toxicity tolerance at Padukka, Sri Lanka during 1976-77 identified Mahsuri and IR-32 as better performers. (IRRI, 1977).

Green house tests revealed that among the 400 rices mass screened in iron toxic field at Philippines, 31 scored as tolerant, which included Mahsuri, Monkora and four IR-2071 lines (IRRI, 1978). Except Mahsuri, the others are not popular in Kerala.

To ascertain the contribution of varietal tolerance to yield stability under mineral stresses, the performance of tolerant and sensitive genotypes of comparable yield potential was studied in the field in 1978 and 1979 at IRRI. Iron toxicity tolerance was found to vary widely with stress level and genotypes. Sensitive ones suffered severe yield losses even under mild stresses. Grain yield and ratings revealed significant difference in varietal performance (IRRI, 1979).

Gunawardena (1979) has reported that Annapoorna and Cheruvirippu are among others, the lowest yielding entries in screening for iron toxicity tolerance.

Of the 100 lines field screened in Sri Lanka, IR-32, IR-42, Mahsuri, and 7 IR lines showed tolerance for iron toxicity on a strongly acid soils at Padukka wet zone. (IRRI-1979).

Patra and Mohanty (1981) in a solution culture study on Jaya and Mahsuri with graded doses of K, Fe and Mn noticed that the increase in concentration of iron and yield reduction were more pronounced in susceptible variety Jaya whereas not much difference was noticed in the resistant variety Mahsuri.

Of the 609 rices screened in green house, 116 were tolerant which included IR-36 and IR-46 also (IRRI, 1981).

IRRI (1982) reports indicate the results of 340 entries tested on an iron toxic soil from Malinao (P^H 3.5, active Fe 2.5 per cent) in green house, of which 14 were rated tolerant. IR-36 and IR-1974-3 were outstanding entries. IR-42 was also tolerant.

During the screening programme at IITA (1983) using pot and field techniques, it was found that the height of rice plant differed in toxic and non-toxic soils. The widest difference was shown by the susceptible control. Some resistant varieties identified were significantly shorter in toxic than in non-toxic soil. Root number, seedling dry weight and shoot weight of resistant varieties were generally similar under toxic and non-toxic soils.

Reports from IRRI (1986) indicated that iron toxicity was more severe at 4th week and at 8th week after transplanting than during other periods when these plants were scored to iron toxicity.

Mohanty (1986) screened 42 rice cultivars for iron toxicity in solution culture with 80 ppm Fe^{2+} in nutrient solution. The plants were scored on 0-9 scale (IRTP). Certain CRRI varieties showed resistance to iron toxicity at early tillering stage and maximum tillering stage. T-1242 was found to be the best variety for resisting iron toxicity.

Fageria and Rabelo (1987) studied iron toxicity tolerance by growing 40 rice varieties in green house in nutrient solution. The influence of excess iron on plant height, root length, root and shoot dry weight was measured. Root and shoot dry weight were most sensitive to excess iron. Based on dry matter yield the rice cultivars were classified as tolerant, moderately tolerant, moderately susceptible and susceptible.

In a mass screening programme conducted at IRRI (1987), 89 varieties were identified with a score of 4 or better and an average of 14 tillers/hill. Mahsuri consistently performed better.

Mohanty (1986) screened fourteen cultures for their resistance to iron toxicity. The plants were scored on 1-9 scale. He could obtain 4 cultures tolerant to iron toxicity.

Abraham and Pandey (1989) screened four varieties and 13 advanced breeding lines for adaptability to P deficient and Fe toxic rainfed condition. Visual symptoms of toxicity (bronzing) of the leaves were recorded at the boot leaf stage. Yield reduction of 77 per cent was recorded. The primary factor responsible for yield reduction was substantial decrease in the productive tiller count.

5. **Influence of iron toxicity on the uptake of nutrients**

1. Nitrogen

Ota and Yamada (1962) compared the nitrogen and potassium contents of bronzed rice plants with those of healthy plants and observed that the bronzed plants contained higher nitrogen and lower potassium contents than the healthy plants. Inada (1965) and IRRI (1966) also came across similar observations.

Sahu (1968) studied the bronzed rice plant in loamy sand latosol and swampy lowland soils in Orissa. These plants had higher nitrogen and lower potassium contents. The nitrogen content further increased with the severity of bronzing.

Ota (1968) on chemical analysis of severely bronzed plants observed that these plants were high in nitrogen content. The affected plants showed a fairly close positive correlation with the grades of bronzing. The content was higher at higher grades of bronzing.

Takijima and Gunawardena (1969) obtained high N and low K during straw analysis of bronzed rice plants in a variety of soils from Ceylon.

Takijima and Kanaganayagam (1970) from pot and field experiments in iron toxic soil concluded that the bronzed rice plants were very high in nitrogen and iron.

Venkatasubrahmanyam and Mehta (1974) found that iron application to rice plant significantly increased the nitrogen content of plant.

Iron-intoxified rice leaves from many cultivars grown in different iron toxic soils from various Asian countries were analysed at IRRI for mineral content. The nitrogen content was surprisingly higher than that of the normal plant. Iron content was also high. (Benckiser et al. 1982).

2. Phosphorus

Baba and Tajima (1960) observed that leaf discolouration due to excessive uptake of iron, inhibited the absorption of phosphorus to a greater extent than other nutrients.

Sahu (1968) observed that in bronzed plant the P uptake was suppressed and further application of P and K and urea spray at active tillering phase reduced bronzing.

Reports from IRRI (1969) indicated that iron toxicity to rice was frequently observed and associated with phosphorus deficiency in acid sandy lateritic soils and in acid sulfate soils.

Takijima and Kanaganayagam (1970) from pot and field experiment in iron toxic soil noticed that bronzing was associated with low P contents and appeared to be an expression of symptoms due to P deficiency. Enhanced dose of P fertilization was effective in the prevention of bronzing.

From solution culture studies on rice plants, Tanaka and Tadano (1972) concluded that when iron level was higher in culture solution, P uptake was low.

Venkatasubrahmanyam and Mehta (1974) reported that addition of iron decreased the content of phosphorus in the rice plant. Antagonistic relationship between iron and phosphorus has been reported.

Tadano (1975) observed that the rice plant which contained high content of iron in plant parts were deficient in phosphorus and P deficient rice plants were more susceptible to iron toxicity than the normal plant.

Ottow et al. (1981) found that in general, soils where Fe toxicity occurred were P deficient. Low and unbalanced supply of P was one reason for iron toxicity development.

Scherer and Hofner (1981) studied the effect of increasing iron concentration on the dry matter production and nutrient uptake by maize and found that increasing rates of iron application decreased the phosphorus content of plants, showing Fe-P antagonism.

Rice leaves clearly showing bronzing were collected from different sites in South East Asia and were analysed physico-chemically at IRRI. It was found that phosphorus content was relatively low in all the bronzed plants (Benckiser et al. 1982).

Benckiser et al. (1984a) found that plants having high content of iron were low and insufficient in phosphorus content. Phosphorus fertilization could improve iron-excluding mechanism of root efficiently.

While investigating on the nutritional disorder (bronzing) of rice observed in Brunei, Yoshida and Yamamuro (1986) analysed different parts of bronzed plant for phosphorus and iron and found phosphorus as deficient.

3. Potassium

Ota (1968) indicated that bronzing occurred in the ill-drained paddy fields of lowland wet zones and the content of potassium was very low in diseased plants.

Sahu (1968) reported that bronzing disease causes serious damage to rice in waterlogged soils. Plant analysis of bronzed plants indicated low content of potassium and they also showed symptoms due to K-deficiency. Such plants responded to K fertilisation.

Park and Tanaka (1968) concluded that brown spotting was associated with high iron and low potassium content and the plants responded favourably to potassium slag application.

Results of experiments at IRRI (1969) revealed that iron toxicity was frequently observed and associated with potassium deficient acid sandy lateritic soils and plants with bronzing symptoms were often low in potassium content. .

Takijima and Kanagnanyagam (1970) from their studies on nutrient composition of straw of bronzed rice plants reported higher contents of iron and very low contents of potassium. Application of potassium was most effective in increasing the growth and yield.

Tadano and Tanaka (1970) noticed that the K absorbing power of the roots was low when the roots were suffering from high level of iron. Application of K resulted in growth improvement in these soils. The need to maintain favourable K status when iron level was high in growth media has been stressed.

Tanaka and Yoshida (1970) observed that rice plants low in potassium often developed bronzing symptoms.

Yoshida (1971) suggested that roots of K deficient rice plants were unable to oxidise Fe^{2+} and excess Fe^{2+} would enter the plant and produce toxicity symptoms.

Howeler (1973) noticed that iron induced oranging disease of rice was associated with K deficiency. Tadano (1975) noticed that lowland rice frequently suffers from iron toxicity and these plants were low in many of the nutrients especially potassium than normal plants.

Trolldenier (1981) reported that the root oxidising power was highest with complete nutrition and lowest when K was deficient.

Ottow et al. (1982) based on their plant and soil analysis from various sites affected by bronzing noticed that low potassium supplying capacity by the iron-toxic soil was reflected in the plant tissue analysing to lower potassium content.

Mohanty and Panda (1982) analysed plants which exhibited symptoms of iron toxicity and found that potassium concentration decreased in straw with both susceptible and resistant varieties.

When the mineral content of leaves of rice plants grown in high iron toxicity region was estimated, it was observed that potassium content of all the samples was low (IRPS 1982).

Sakal and Sinha (1983) studied the phosphorus and potassium nutrition of rice plant on iron application and observed that potassium content of different plant parts decreased with increasing iron content in the medium.

Benckiser et al. (1984a) concluded that a multiple nutritional stress along with a high iron supply was responsible for iron toxicity in plants. Hence plants that suffered from a low and insufficient supply of potassium were more susceptible to iron toxicity.

Patra and Mohanty (1988) observed that there were significant decreases in potassium content in grain and straw of both susceptible and tolerant rice cultivars of rice with increased levels of iron in the nutrient solution.

4. Calcium

Ota (1968) found that bronzing in rice plant was associated with low yield and plant analysis indicated very low calcium and many of the other essential elements.

Howeler (1973) reported that plants affected by bronzing resulting from excess iron absorption were deficient in calcium.

Venkatasubrahmanyam and Mehta (1974) conducted an experiment to find out the effect of zinc and iron application on yield and chemical composition of rice. They observed that application of iron decreased the calcium uptake but the effect was not significant.

Tadano (1975) on analysing rice plants which were grown in high iron toxic condition reported that the calcium content in those plants were lower than that of a normal plant grown in a normal condition.

Reports from IRRI (1982) on the analysis of rice plants showing bronzing symptoms from different South East Asian countries indicated insufficient calcium.

After an extensive physico-chemical survey of various iron toxic sites in the tropics, Benckiser et al. (1984b) showed that plants grown in these soils were more deficient in calcium content than plants in normal soil conditions and calcium fertilization to plants grown on iron toxic environment alleviated the iron toxicity.

5. Magnesium

During the investigation on the mode of occurrence of bronzing in rice plant, Ota (1968) observed that the magnesium content of bronzed plants was lower than in normal plants.

Howeler (1973) reported that iron induced oranging disease of rice was associated with deficiency of magnesium.

Venkatasubrahmanyam and Mehta (1974) reported that there was significant reduction of magnesium uptake in rice plant with addition of iron.

Tadano (1975) observed that lowland rice usually developed bronzing symptom and those rice plants were deficient in magnesium.

Work conducted at IRRI (1983) on the physico-chemical characterisation of iron-toxic soils in South East Asian countries indicated that those soils were deficient in magnesium and the plant analysis also showed low contents.

Benckiser et al. (1984b) reported that iron toxicity was a physiological disorder caused by multiple nutritional soil stress and the magnesium content of the leaves of the affected plants was lower than that of the unaffected normal plants.

6. Iron

IRRI reports (1964) indicated that plants severely affected by bronzing contained high content of iron in the straw (670 ppm compared to that of the healthiest plants (120 ppm).

Ota (1968) reported that bronzed rice plants seen in lowland fields contained high content of iron which was positively correlated with the grade of bronzing.

Serayonakul (1968) conducted solution culture experiments containing 20, 50, 200, 300, 400, 500 and 600 ppm Fe^{2+}. He observed that plants grown in 200 ppm iron and above showed toxicity symptoms followed by excessive uptake of iron. Plants grown in solutions less than 200 ppm showed no toxicity symptoms but the yields were low.

Park and Tanaka (1968) concluded that the cause for brown spotting in rice was iron toxicity which was due to high uptake of iron. Drainage of the soil improved the growth of plants and alleviated the brown spotting symptoms.

Sahu (1968) observed that bronzing disease caused serious damage in waterlogged area and found a close relationship between iron content and bronzing in rice in loamy sand latosol. The more the concentration of iron, the higher was the incidence.

Under solution culture and soil culture experiments, Tanaka et al. (1968) observed that iron at 100 ppm induced bronzing. The content of iron in the shoot was found to be high.

Venkatasubrahmanyam and Mehta (1974) found that iron application significantly reduced the dry matter yield of rice and the addition of iron increased the iron content by 61 per cent over the control.

Tadano (1975) observed that lowland rice frequently suffered from iron toxicity. Iron concentration in the soil solution increased significantly when soil was kept under submergence. Plant analysis of these rice plants showed a very high content of iron in the plant tissue.

Benckiser et al. (1982) collected rice leaves showing symptoms of Fe toxicity from different Asian countries. The affected leaves were much higher in iron content than the accepted critical level of 300 ppm.

Yamanonchi and Yoshida (1982) reported that the older leaves suffered from iron toxicity more severely because they accumulated more iron than young leaves and they had less tolerance for excess iron.

From the experiments with seven rice cultivars grown in different levels of iron, Camargo (1984) concluded that the iron concentrations in the leaves increased when the levels of iron increased in the nutrient solution. The tolerant ones were associated with lower iron content compared with susceptible ones.

Agarwal and Srivastava (1985) conducted field experiments during two wet seasons and reported that the uptake of iron increased with increasing iron supply.

Ho and Houng (1986) reported that high iron concentration retarded the growth of rice varieties. Indica varieties seemed to be more susceptible to iron toxicity than Japonica varieties. The severity of reddish brown discolouration in the leaves due to high iron concentration correlated with iron content in the leaves of a given variety.

Yoshida and Yamamuro (1986) studied the nutritional disorder of rice plants which occurred in Brunei and found high content of iron in rice plants and there was a relationship between the grade of symptoms and iron content in the rice plant. Varietal differences in iron contents were also reported.

Mohanty (1987) found that increasing iron concentration in the nutrient solution resulted in increase of iron in rice plant significantly. Relatively higher content of iron was found in the aerial plant parts of susceptible variety whereas the roots of the resistant variety contained more iron.

Patra and Mohanty (1988) studied the effect of iron on dry matter production and nutrient content of rice and reported that iron content in grain, straw and roots increased significantly with increasing levels of iron in the nutrient solution in both susceptible and tolerant varieties. At a given level of iron in the nutrient solution, the iron content in straw and roots of tolerant varieties was comparatively more than that of susceptible varieties.

Verma and Tripathi (1989) studied the nutritional status of soil and occurrence of physiological disorders in rice. They found that the soils supporting bronzed plants contained the highest and the soil supporting yellow and mottled plants contained the lowest amounts of iron. Plant analysis revealed that the bronzed plants contained a very high amount of iron than normal and yellow mottled plants.

Mohanty and Panda (1982) conducted solution culture experiments with different levels of iron. The rice plant parts were analysed. With increase in iron concentration in the nutrient solution, concentration of iron in grain, straw, and root increased in resistant (Mahsuri) and susceptible (Jaya) varieties. The plants exhibited symptoms of iron toxicity at 500 ppm in straw in the case of susceptible variety and beyond 700 ppm in resistant variety.

Patnaik and Bhadrachalam (1965) reported that in solution culture experiments, increased concentration of iron increased the iron content of straw and reduced the grain yield.

Bulbule and Deshpande (1989) observed that increasing levels of iron in sand/solution culture media progressively decreased the dry matter production and the iron content in fresh tissue progressively increased with increasing levels of iron in culture media.

MATERIALS AND METHODS

MATERIALS AND METHODS

The effect of higher concentrations of ferrous iron on growth of rice was studied under the conditions of solution culture. The investigations were carried out under two experiments. Experiment I on the screening of selected rice genotypes popular in Kerala for tolerance under iron toxicity conditions and experiment II on finding out the influence of toxic levels of applied soluble iron on the content and uptake by varieties observed in Experiment I as tolerant to iron.

Experiment - I

Thirty rice varieties popular in Kerala consisting of 27 high yielding and 3 traditional were included in the study. The seeds procured from the Regional Rice Research Station, Pattambi, Rice Research Stations, Moncombu and Kayamkulam, were subjected to screening trials under solution culture (Hoagland No. II) supplied with 500 ppm soluble iron and the growth was monitored upto active tillering (AT) stage. The procedure followed by Bulbule and Deshpande (1989) for the preparation of solution culture to contain toxic levels of iron, was followed in the present study.

Composition of basal nutrient solution

Concentration of chemicals	ml per lit. of nutrient solution
M. $NH_4H_2PO_4$	1
M. KNO_3	6
M. $Ca(NO_3)_2$	4
M. $MgSO_4 . 7H_2O$	2

Supplimentary nutrient solution was prepared as follows:

Compound	g/litre
1. Boric acid (H_3BO_3)	2.86
2. Manganese chloride ($MnCl_2.4H_2O$)	1.81
3. Zinc sulphate ($ZnSO_4.7H_2O$)	0.22
4. Copper sulphate ($CuSO_4.5H_2O$)	0.08
5. Molybdic acid ($H_2Mo_0O_4.H_2O$)	0.02

One ml each of these solutions was added to each litre of basal nutrient solution before use.

The pH of the solution was adjusted to 5.0. Concentration of soluble Fe^{+2} in the solution was maintained at 500 ppm. The source of iron was $FeSO_4.7H_2O$. Sucrose 50 ppm was used as an antioxidant.

The following rice genotypes were used for the study:

Name of variety		Duration	Parentage
1.	Annapoorna	90-100	TN-1 x Ptb 10
2.	Aruna	100-105	Jaya x Ptb 33
3.	Asha	115-120	IR-11-66-1 x Kochuvithu
4.	Aswathi	120-125	Ptb 10 x Dgwg
5.	Bhadra	125-130	IR-8 x TBB-20
6.	Bhagya	100	Thadukkan x Jaya
7.	Bharathi	115-125	Ptb 10 x IR-8
8.	Cherady	120-135	Traditional local variety
9.	H4	125-145	Muringakayam x Mahsuri
10.	IR-36	118-120	Introduction from IRRI
11.	Jaya	120-125	TN-1 x T-141
12.	Jyothi	110-125	Ptb 10 x IR-8
13.	Kanakam	120-125	IR-1561 x Ptb 33
14.	Karthika	115-120	Triveni x IR-1539
15.	Keerthy	110-120	IR-2061 x Triveni
16.	Kochuvithu	90-100	Local cultivar
17.	Makam	100-105	ARC-6650 x Jaya
18.	Mahsuri	125-145	Introduction from Malaysia. (Taichung-65 x Maying Ebos)
19.	Neeraja	130-140	IR-20 x IR-5
20.	Onam	95	Culture 16 x Triveni

21. Ptb-2	135	selection from Ponnaryan
22. Ptb-10	100	selection from Thekkancheera
23. Ptb-20	130	selection from Vadakkan-Chitteni
24. Pavizham	115-118	IR-8 x Karivennu
25. Red Triveni	95	Selection from Triveni
26. Remya	110-120	Jaya x Ptb-33
27. Rasi	120-125	TN-1 x Co-29
28. Sabari	100-135	IR 8/2 x Annapoorna
29. Santhosh	110-120	Local variety
30. White Triveni	95-105	Annapoorna x Ptb-15

White cylindrical porcelain glazed pots of 2.5 litre capacity were used. The pots were cleaned with dilute hydrochloric acid to remove soluble impurities and then with distilled water.

Preparation of seedlings

Seeds were surface sterilized for one minute with a 0.1 percent mercuric chloride solution to free them from seed borne diseases and subsequently with several lots of demineralized water. The nursery was prepared in sand culture using sand, acid washed and subsequently cleaned with several lots of distilled water. Sprouted paddy seeds were sown in sand culture and nutrients were given at weekly intervals through Hoagland solution at a concentration which was one fifth of the normal dose used later in solution culture.

Layout of the experiments

The pots were arranged in CRD with three replications. They were filled with Hoagland solution No.II.

Three week old seedlings were transferred to the pots filled with culture solution and supported by perforated plastic bowls. Glass balls were also used to support the seedlings. Two seedlings per pot were transplanted.

The culture solution was replaced once in every five days. The level of the solution in the pots was maintained steady by periodical additions as and when needed in order to compensate any loss due to evapotranspiration. Plant protection measures including control of rodents were taken during the growth period. Toxicity symptoms in the plant due to excess iron were recorded and scored as per the Standard Evaluation System for Rice recommended under the International Rice Testing Programme (IRTP) of IRRI (1980) with scale 1 to 9 as follows.

Toxicity scores for Iron

Scores	Symptoms (Seedling - Booting)
1	Growth and tillering normal
2	Growth and tillering normal, reddish-brown spots or orange discolouration on older leaves

3 Growth and tillering nearly normal, older leaves reddish brown, purple or orange yellow

5 Growth and tillering retarded, many leaves discoloured

7 Growth and tillering cease, most leaves discoloured or dead

9 Almost all plants dead or dying

Visible symptoms and their scoring were the only criteria followed for identifying the tolerance of the varieties to toxic levels of iron. Weekly scoring was attempted upto AT stage. At AT stage, the plants were removed, washed thoroughly in running tap water, rinsed with distilled water, dried in hot air oven at 60-65°C till constant weight was obtained. It was powdered and stored for analysis.

Experiment - II

Five rice varieties which registered low score numbers and hence identified as tolerant in Experiment I were further tested for their growth, yield and plant composition under the influence of graded toxic levels of iron supplied to solution culture. The different levels of Fe^{2+} maintained in the solution culture were:

T_1	50 ppm (control)*
T_2	400 ppm
T_3	500 ppm
T_4	600 ppm

Varieties identified as iron tolerant based on low scores recorded

V_1	Mahsuri
V_2	H_4
V_3	Kochuvithu
V_4	Cherady
V_5	Keerthy

* Control with no Fe^{2+} treatment was not maintained in the present study in view of the essentiality of iron to rice as a micronutrient. Critical content of iron in the rice at AT has been reported in literature as 50ppm, below which the display of deficiency symptom of foliar yellowing would make comparison with other treatments difficult. Hence the treatment with minimum needed 50 ppm to Fe^{+2} with normal growth expected, was considered as the control.

Layout

The glazed pots after the Experiment-I were arranged in CRD with five rice varieties grown under four different iron concentrations. The experiment was replicated thrice. The seedlings were raised as in experiment I and transplanted at the rate of two seedlings per pot. The iron toxicity symptoms were scored as described under Experiment-I. Growth characters like plant height and tiller count were recorded. The plants were harvested at their respective stages of maturity. Yield parameters and yield of grain and straw were recorded. Samples of grain, straw and roots were analysed for various constituents as follows:

Preparation of plant samples

The grain, straw and roots of the entire plants in each were separately dried at 60-65°C, chopped to small pieces and preserved in labelled containers and used for further chemical analysis.

a) Total nitrogen

Nitrogen content in the plant sample was estimated by microkjeldahl method as outlined by Jackson (1973).

b) Digestion of plant samples with tri acid mixture

To 0.5g of plant sample in a conical flask, added 20 ml of tri acid mixture of sulphuric acid, perchloric acid and nitric acid and digested on sand bath till the solution became clear. The volume was made upto 50ml.

Phosphorus

A suitable aliquot of tri acid extract was diluted and phosphorus was estimated following Vanadomolybdic yellow colour method using Klett - Summerson Photoelectric Colorimeter as described by Jackson (1973).

Potassium, Calcium and Magnesium

Potassium, calcium and magnesium were estimated in aliquots of the tri acid mixture using Atomic Absorption Spectrophotometer (PERKIN-ELMER model) with appropriate Hollow Cathode Lamps.

Iron

An aliquot of the digested plant extract was diluted with distilled water to about 35 ml. A drop of 30 per cent H_2O_2, 5ml of 6N HCl and 5ml of 20 per cent potassium thiocyanate were added. The volume was made upto 50 ml and the red colour was immediately measured with a 490nm light maximum, using Klett-Summerson Photoelectric Colorimeter.

Statistical analysis

The data were processed statistically for the analysis of variance to give statistical backing for the observed variations due to the treatments.

The methods as described by Panse and Sukhatme (1961) were followed for the parameters such as grain yield, straw yield and uptake of nutrients. Correlations were also worked out for toxicity score and iron content with nutrient content, uptake of nutrients and yield.

RESULTS

RESULT

The result on the investigations relating to the influence of iron toxicity on growth, yield and chemical composition of rice are presented in this chapter under the following headings:

Experiment I

Toxicity symptoms and plant iron content in rice varieties as influenced by high iron concentration (500 ppm).

Experiment II

(a) Influence of toxic levels of iron (400, 500 and 600ppm) on growth and yield of rice varieties earlier observed as iron tolerant.

(b) Influence of graded toxic levels of iron on the chemical composition of tolerant rice varieties.

The figures provided in the accompanying Tables are the mean values of three replications. The data on analysis of variance and critical differences are also given to make precise comparison of the treatment effects.

Experiment I

Toxicity symptoms and plant iron content in rice varieties as influenced by high iron concentration

Toxicity symptoms

Concentration of iron at 500 ppm given in the culture solution was toxic enough for the rice plant to produce physiological disorders which were manifested by visual symptoms on leaf during plant growth. In the sand culture nursery, all the 30 varieties got established more or less satisfactorily but started developing toxic symptoms when subsequently transplanted to solution culture. The toxicity symptoms developed by the different varieties varied between mild leaf yellowing to complete death of the plant with intermediate symptoms in between.

However, the intensity and pattern of the symptoms displayed in the present study showed variations from the many related symptoms described by Ponnamperuma (1965) and Tanaka and Yoshida (1970). The bluish colouration of the leaves as described in literature was absent. Instead, the leaves showed mildly yellowish symptoms. The tip burning of older leaves later developed, was followed by stunting of the plant and complete wilting thereafter. In the present examination the symptoms started with a few reddish brown spots appearing on older leaves which later coalased and elongated. This was subsequently followed by yellowing of the older leaves. The leaf tip showed a mild purplish colouration which later exhibited a burnt appearance. The tip-burning gradually became dominant throughout the leaf with other few leaves also affected in the same manner. The plant growth in some treatments was stunted and gradual drying up of the plant could be seen even before reaching the AT stage. In some varieties, some of these intermediate symptoms were found bypassed, while a few other varieties failed to exhibit any of these symptoms and survived as healthy plants.

The IRTP recommendation was adopted for the screening of rice varieties, using scores 1 to 9 as explained under Materials and Methods. However, the scoring for toxicity symptoms was restricted to the period between transplanting in the solution culture and active tillering. The mean scores of symptoms in the different rice varieties due to iron toxicity during the period of 8 weeks after transplantation are furnished in Table.1 and the trend in variation in the toxicity symptoms with period are illustrated in fig. 1.

In Asha, even while removing from the nursery the seedlings were found affected by yellowish discolouration of the older leaves with mean score 3.3. However, scoring seedlings while in the nursery was not attempted and the extent of damage to plant prior to transplantation was not quantified.

During the second week after transplanting, Sabari and Santhosh displayed brown discolouration on the leaves and the leaf tip showed gradual drying symptom. Annapoorna, Bhagya, Bhadra, IR-36, Bharathy, Cherady, H_4, Keerthy, Kochuvithu, Mahsuri, Ptb-2,

Table 1. Mean score of symptoms (1-9) due to iron toxicity in rice

Variety	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week
1. Annapoorna	1.0	1.3	2.6	4.0	4.3	5.3	6.0	6.3
2. Aruna	1.0	2.0	2.3	3.6	3.6	5.6	6.0	6.3
3. Asha	3.3	4.0	6.3	7.3	7.6	8.0	8.3	8.3
4. Aswathi	1.6	2.0	3.0	4.6	5.3	6.0	6.3	6.6
5. Bhadra	1.0	1.6	2.0	2.3	2.3	3.3	5.0	5.0
6. Bhagya	1.0	1.0	2.0	2.0	2.3	2.6	3.3	3.6
7. Bharathy	1.0	1.6	1.6	2.3	2.3	2.6	3.0	4.0
8. Cherady	1.0	1.0	2.0	2.0	2.0	2.0	2.3	2.6
9. H_4	1.0	1.0	1.0	1.3	1.3	1.6	1.6	2.0
10. IR-36	1.0	1.6	2.0	2.3	2.6	3.0	3.3	3.6
11. Jaya	1.0	2.0	3.0	4.6	6.0	6.6	8.3	8.6
12. Jyothi	1.0	2.0	2,6	4.3	4.6	6.3	8.0	8.3
13. Kanakam	1.0	2.0	2.3	2.6	2.6	3.3	4.6	5.0
14. Karthika	1.0	2.0	2.3	2.6	4.3	4.3	5.6	6.3
15. Keerthy	1.0	1.0	1.5	1.6	2.3	2.6	2.6	3.0
16. Kochuvithu	1.0	1.0	1.3	1.6	2.3	2.3	2.6	2.6
17. Makam	1.0	2.0	2.3	2.3	2.6	3.0	3.6	4.3
18. Mahsuri	1.0	1.0	1.0	1.3	1.3	1.6	2.0	2.3
19. Neeraja	1.0	2.6	3.3	3.6	5.3	6.6	7.3	8.0
20. Onam	1.0	2.0	2.6	3.3	4.6	5.3	6.0	6.3
21. Ptb-2	1.0	1.3	2.0	2.6	3.6	5.6	5.9	6.0
22. Ptb-10	1.0	1.6	2.6	4.3	6.3	7.3	7.6	8.0
23. Ptb-20	1.0	2.0	2.6	4.3	4.3	5.6	6.0	6.6
24. Pavizham	1.0	2.3	2.6	3.6	5.3	7.3	7.6	7.6
25. Rasi	1.0	1.3	2.0	2.3	2.6	2.6	3.6	3.6
26. Red Triveni	1.0	2.0	2.0	2.3	3.3	4.0	4.3	5.0
27. Remya	1.0	2.0	2.0	2.3	2.6	3.3	3.6	4.3
28. Sabari	1.0	3.3	3.6	3.6	5.0	7.3	7.3	7.6
29. Santhosh	1.3	3.6	4.3	6.3	6.3	6.6	7.0	7.3
30. White Triveni	1.3	1.6	2.3	3.6	4.0	4.3	4.3	4.3

Ptb-10 and White Triveni failed to produce any noticeable symptom. Other varieties viz., Aruna, Aswathi, Jaya, Jyothi, Kanakam, Karthika, Makam, Neeraja, Onam, Ptb-20, Pavizham, Remya and Red Triveni started showing bronzing symptoms on the lower leaves from the second week after transplantation onwards.

In Asha, during the 3rd week, many leaves showed yellowish discolouration, lower leaves dried and growth got retarded. Brown streaks were seen on Aswathi and Neeraja. Sabari and Santhosh started displaying brown spots on upper leaves with drying up of the older leaves. Bhadra, Bhagya, Bharathy, Cherady, H_4, Keerthy, Kochuvithu, Mahsuri, Rasi and Remya had normal growth.

During the fourth and fifth weeks after transplanting, more varieties were affected by iron toxicity with dominant symptoms. The oranging disolouration of older leaves was observed in Bhadra, Bharathy, Kanakam, Makam and Remya. In Rasi, no severe symptom could be noticed but the growth was stunted compared to other varieties viz., H_4, Mahsuri, Cherady, Kochuvithu and Keerthy, all of which had low scores of 2 or less than 2. Upto the fourth week after transplanting, White Triveni and Red Triveni failed to show any serious symptom of bronzing. During the fifth week, however, symptoms of brown spots could be seen on the older leaves and these spots gradually got coalased and brown streaks were seen in

Red Triveni. Though discolouration occurred, the growth was not seen much affected in White Triveni.

Rasi and Annapoorna were affected by BPH. The adults were seen at the bottom of plant. However, control was possible by spraying Ekalux 0.05per cent and the pest attack was reduced during the following periods.

During the fourth week, the variety *Aruna* showed silver shoots due to the attack of gall fly. Ekalux 0.05 *per cent* was sprayed to control the insect. Mahsuri showed symptoms of blast. A combination of Dithane M-45 and Ekalux was sprayed at weekly intervals. No other serious pest attack or disease infestation could be noticed.

During the sixth and seventh , the plants which earlier displayed symptoms of iron toxicity showed more *intensified* symptoms, which were manifested by the spreading of the brown spots or streaks or oranging discolouration to younger leaves also. The symptoms were seen aggravated in Jaya and *Jyothi* which were affected on the sheath also. In Ar, *Aruna*, Aswathi, Bhadra, Kanakam, Karthika, Onam, Ptb-20, Red Triveni, Remya and White Triveni, these symptoms extended to more leaves but growth reduction was not conspicuous as that for

Asha, Jaya, Jyothi, Neeraja, Ptb-10, Pavizham, Sabari and Santhosh, where most of the leaves were discoloured and dead. The varieties H_4, Mahsuri and Cherady did not produce any symptom and had normal growth. In Keerthy and Kochuvithu, tiny brown spots were observed during this period.

Eighth week of transplantation is the critical period for exhibition of iron toxicity symptoms (IRRI, 1980). During this period the severe symptoms shown by rice enabled more reliable scoring and interpretations. The intensity of bronzing increased in most of the varieties. Varieties Jaya, Jyothi and Asha were almost dead and score was very high followed by Neeraja. Ptb-10, Pavizham, Sabari and Santhosh. The variety Cherady also produced some brown spots on lower leaves during this period as in the case of Kochuvithu. However, this score was lower than ? the growth of H_4 and Mahsuri was nearly normal throughout the period and these varieties did not produce any visual syms. Varieties Keerthy, Bhagya, IR-36 and Rasi had lower mean § ranging between 3.0 and 3.6 and survivd even under high concentration in the solution culture.

Plant iron content

The iron contents of different ties at the 8th week after transplantation in solution cul ven in Table-?

Table 2. Plant iron content of the rice varieties in solution culture

Sl. No.	Variety	Fe Content (ppm)
1	Annapoorna	2018
2	Aruna	2057
3	Asha	2297
4	Aswathi	2084
5	Bhadra	1944
6	Bhagya	1695
7	Bharathy	1801
8	Cherady	1583
9	H_4	1471
10	IR-36	1721
11	Jaya	2223
12	Jyothi	2158
13	Kanakam	1976
14	Karthika	2013
15	Keerthy	1674
16	Kochuvithu	1627
17	Makam	1823
18	Mahsuri	1507
19	Neeraja	2114
20	Onam	2028
21	Ptb-2	2038
22	Ptb-10	2074
23	Ptb-20	2041
24	Pavizham	2061
25	Rasi	1823
26	Red Triveni	1982
27	Remya	1865
28	Sabari	2067
29	Santhosh	2099
30	White Triveni	1886

and illustrated in fig. 2. The iron content of the varieties which showed least iron toxicity symptoms with scores less than three was comparatively lower than the varieties which showed more severe symptoms.

The varieties Asha and Jaya which showed extreme symptoms of iron toxicity registered plant iron content of 2297 and 2223 ppm respectively, while the iron-tolerant varieties H_4, Mahsuri, Keerthy, Kochuvithu and Cherady recorded iron contents ranging between 1471 to 1674 ppm.

Experiment II

(a) Influence of toxic levels of iron on growth and yield of rice varieties earlier observed as iron tolerant

Five varieties namely H_4, Mahsuri, Cherady, Kochuvithu and Keerthy which had low scoring for iron toxicity symptoms and hence identified as tolerant in the previous experiment, were grown in solution culture. The effect of higher (toxic) levels of Fe^{2+}, viz., 400 ppm, 500 ppm and 600 ppm in the growth medium, on growth, yield and yield attributes and nutrient uptake of the above varieties was investigated. Scoring of iron toxicity symptoms displayed by these varieties was also attempted during the growth period and compared with those in the control treatment.

Toxicity Symptom

Symptoms of iron toxicity developed by the rice varieties were monitored at active tillering as well as at the flowering stages. The scores registered by the varieties are presented in Table 3. The scores revealed that no appreciable toxicity symptoms were displayed by any of the varieties upto 400 ppm level at AT stage. At 500 ppm, symptoms could be noticed in lower leaves of Cherady, Kochuvithu and Keerthy. However, the mean score remained low (2.5). At 600 ppm, the symptom was seen exended in all varieties. The varietal effect was not significant. H_4 recorded the minimum toxicity score of 1.8 and it was followed by Mahsuri (1.9). Among the varieties examined, Keerthy scored the highest (2.6). At flowering stage, at 400 ppm Fe^{2+} level and beyond that, symptoms emerged. The varieties H_4 and Mahsuri had mean scores 2.1 and 2.2 respectively while the variety Keerthy scord 2.9 which was the highest with significant difference fro othe. The varieties viz., Cherady and Kochuvithu had intermediate mean scores of 2.5 and 2.6 respectively and they were on par. The interaction effect was, however, not significant.

Plant height

Date on the mean plant height of five varieties given in Table 4 (A) indicated that when the irotent was increased in

Table 3. Scoring for toxicity symptoms exhibited by rice varieties at AT and flowering stages under the influence of different iron levels.

	AT stage					Flowering stage				
	Fe^{2+} level (ppm) in solution culture					Fe^{2+} level (ppm) in solution culture				
Varieties	Control	400	500	600	Mean (var.)	Control	400	500	600	Mean (var.)
Mahsuri(V_1)	1.0	1.3	2.3	3.0	1.9	1.0	1.6	2.3	3.6	2.2
H_4(V_2)	1.0	1.3	2.0	3.0	1.8	1.0	1.6	2.0	3.6	2.1
Kochuvithu(V_3	1.0	1.6	2.6	4.0	2.3	1.0	2.3	2.6	4.3	2.6
Cherady(V_4)	1.0	1.3	2.6	3.6	2.2	1.0	2.3	2.6	4.0	2.5
Keerthy(V_5)	1.0	2.0	3.0	4.3	2.6	1.0	2.6	3.3	4.6	2.9
Mean (Fe)	1.0	1.5	2.5	3.6		1.0	2.1	2.6	4.1	

ANOVA

	AT stage		Flowering	
	F test	CD	F test	CD
Variety (var.)	NS		S*	0.6
Treatment (Fe.)	S**	0.6	S**	0.5
Var x Fe	NS		NS	

culture solution, the height of the plant significantly got reduced in all the varieties. Among the varieties, H_4 recorded maximum plant height of 124.3 cm at 50 ppm Fe^{2+} (control). However, as the iron concentration was increased to 400 ppm and further to 500 ppm, a decrease in plant height could be noticed. The height further reduced to still lower values and reached 103.00 cm at 600 ppm Fe^{2+} level. The percentage reduction in the plant height recorded at 600 ppm Fe^{2+} level as compared to the control was 17.1. Mahsuri recorded a plant height of 120.7 cm which gradually decreased with increase in Fe^{2+} level. At 600 ppm Fe^{2+} level the height was 97.3 cm. The percentage of reduction in plant height in Mahsuri recorded at 600 ppm Fe^{2+} level over the control was 19.4. Kochuvithu with a plant height of 113.7 cm in the control treatment reduced to 89.00 cm at 600 ppm Fe^{2+} level, registering a decrease of 21.2 per cent over the control, while Cherady with a plant height of 121.00 cm in the control recorded 95.0 cm at 600 ppm Fe^{2+} level with a decrease of 20.9 per cent over the control. The variety Keerthy with a plant height of 98 cm in the control was reduced to 76.6 cm in the treatment of the highest Fe^{2+} level registering a height reduction of 22.4 per cent. It could be seen that the variety H_4 recorded the least reduction in plant height which was followed by Mahsuri. Keerthy recorded the highest reduction percentage. The varietal effect was significant. The highest mean plant height was registered by H_4 followed by Mahsuri and the lowest mean plant height by Keerthy. The interaction effect was however, not significant.

Tiller count

Table 4 (B) provides data on the mean tiller count of the rice varieties. The treatment effect on the tiller count was significant. In all the varieties the tiller number had decreased progressively as the level of added iron was increased. The extent of reduction in tiller count as compared to control, was maximum in the variety Keerthy while the reduction was minimum in H_4. In terms of percentage of reduction in the number of tillers over the control, Keerthy registered maximum of 50 followed by Cherady while Kochuvithu registered 40 per cent which was minimum among the varieties studied. This was followed by H_4 (42 per cent) and Mahsuri (43 per cent). The effect of varieties was significant. The highest mean tiller count could be noticed in Kochuvithu followed by Mahsuri and the lowest in Keerthy.

Productive tillers

Table 5 (A) contains data on the productive tillers as influenced by different levels of Fe^{2+} supplied to the growth medium. As in the cases of plant height and tiller count, the treatment had significant influence on productive tiller count. The mean productive tiller count of 18.0 registered by Keerthy in the control treatment reduced to 8.6 at 600 ppm Fe^{2+} level and this reduction was 52 per cent over the control, while in H_4 which had the least influence by iron, the reducion in the productive tiller

Table 5. Productive tillers and Grains per panicle in rice varieties as affected by different iron levels

A. Productive tillers

Variety	Fe^{2+} levels (ppm) in culture solution					Reduction at 600 ppm	
	Control	400	500	600	Mean (var.)	Quantity	Per-cent
Mahsuri(V_1)	19.0	14.3	12.6	10.6	14.1	8.4	44.2
H4(V_2)	20.3	16.0	13.0	11.6	15.3	8.7	42.8
KochuvithuV_3	21.0	18.0	14.0	11.0	16.0	10.0	47.6
Cherady(V_4)	19.0	15.0	12.6	10.3	14.2	8.7	45.7
Keerthy(V_5)	18.0	14.6	10.3	8.6	12.8	9.4	52.0
Mean (Fe)	19.5	15.6	12.5	10.4			

B. Grains per panicle

V_1	91.0	87.0	85.0	80.0	85.7	11	12.1
V_2	95.0	91.0	87.0	83.0	89.0	12	12.6
V_3	83.0	77.0	74.0	70.0	76.0	13	15.6
V_4	89.0	84.0	80.0	76.0	82.3	13	14.6
V_5	88.0	83.0	76.0	73.0	80.0	15	17.0
Mean (Fe)	89.2	84.4	80.4	76.4			

ANOVA

	Productive tillers		Grains per panicle	
	F test	CD	F test	CD
Variety (var.)	S*	1.8	S**	3.7
Treatment (Fe.)	S**	1.6	S**	3.3
Var x Fe	NS		NS	

count over the control was 42.8 per cent. The other varieties viz., Kochuvithu, Cherady and Mahsuri recorded similar reduction in productive tiller count which varied between 44 and 48 per cent over the control. Varietal effect and interaction effect on productive tiller count were significant. The highest mean count (16.0) was recorded in Kochuvithu followed by H_4 and the lowest in Keerthy (12.8).

Grains per panicle

Table 5 (B) provides data on the grains per panicle under the influence of different iron levels. While the control recorded grain numbers ranging from 83 to 95 in the five rice varieties, the treatment 600 ppm iron level, brought about decrease in all the varieties, ranging from 70 to 83. However, in terms of percentage loss of the grains per panicle, Mahsuri recorded 12.1 which was the lowest among the varieties. This was followed by H_4, Cherady and Kochuvithu. Keerthy suffered the maximum loss of 17 percent over the control. The varietal effect was also significant. When the varietal means were compared, all the varieties significantly differed from each other. The highest mean grain number per panicle was observed in H_4 and the lowest in Kochuvithu. The interaction effect was however not significant.

Yield data

The data on the per pot yields of grain, straw and root recorded at harvest are furnished in Table 6 (A) (B) and (C) respectively.

A. Grain yield

Data on Table 6(A) indicated that the treatment had a significant effect on grain yield. In all the varieties the grain yield followed a significantly decreasing trend with rise in the concentration of Fe^{2+} in the culture medium. Among the varieties grown in the control pot, H_4 recorded maximum grain yield of 50.0g but reduced to 24.6g in the highest iron level (600 ppm Fe^{2+}) treatment, recording an yield reduction of 25.7g over the control. Under similer situations the variety Keerthy recorded maximum yield reduction of 61 per cent. The lowest yield reduction of 52 per cent over the control was registered by H_4 followed by Mahsuri (53 per cent) and Cherady (55 per cent). The varietal effect was also significant. The mean grain yield was maximum in H_4 followed by Mahsuri. Under highest iron toxicity condition, the maximum grain yield was recorded by H_4, followed my Mahsuri and Cherady and the least grain weight in Keerthy.

B. Straw Yield

Table 6 (B) provides data on mean straw yield. In the control treatment, the maximum straw yield (84.0 g/per pot) could be noticed in H_4 followed by Cherady which gave 80.6g per pot. The

Table 6. Yield in rice varieties as affected by toxic iron levels

A. Grain Yield g/pot

Variety	Fe^{2+} levels (ppm) in culture solution					Reduction at 600 ppm	
	Control	400	500	600	Mean (var.)	Quantity	Per-cent
Mahsuri(V_1)	48.0	36.6	30.7	22.6	34.3	25.4	53
H4(V_2)	50.0	37.2	32.0	24.6	35.0	25.7	52
KochuvithuV_3	45.6	34.3	29.0	19.6	32.12	24.6	57
Cherady(V_4)	47.0	35.9	31.0	21.8	33.9	23.6	55
Keerthy(V_5)	48.8	33.0	27.2	19.0	32.0	27.0	69
Mean (Fe)	47.8	35.3	29.9	21.5			

B. Straw weight g/pot

V_1	80.3	65.5	54.3	38.0	59.5	41.6	53
V_2	84.0	67.9	56.0	41.0	62.2	43.0	51
V_3	72.2	59.3	50.3	36.0	53.9	34.9	50
V_4	80.6	65.0	53.0	36.6	58.6	34.4	55
V_5	71.2	55.7	46.6	30.9	51.1	40.3	57
Mean (Fe)	77.6	62.7	52.0	36.9			

C. Root weight - g/plot

V_1	6.38	5.10	4.36	2.87	4.77	3.51	51.6
V_2	6.50	5.50	4.62	2.98	4.90	3.52	54.2
V_3	5.98	4.59	3.77	2.55	4.22	3.43	57.4
V_4	6.16	4.75	3.92	2.70	4.38	3.46	56.2
V_5	5.75	4.40	3.40	2.30	3.96	3.45	60.0
Mean (Fe)	6.15	4.86	4.01	3.80			

ANOVA

	Grain weight		Straw weight		Root weight	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S**	0.9	S**	1.3	S**	0.21
Treatment(Fe)	S**	0.8	S**	1.1	S**	0.19
Var. x Fe	NS		S	2.5	NS	

least content of straw was noticed in Keerthy (71.2g/pot). The treatment effect was found to be significant. In all the varieties, the straw yield significantly reduced with increasing levels of iron. The extent of yield reduction in straw at 600 ppm iron level was minimum for Kochuvithu (50 per cent) while it was maximum for Keerthy (57 per cent), followed by Cherady (55 per cent), Mahsuri (53 per cent) and H_4 (51 per cent). The varietal effect on straw yield was also significant. Among the varieties H_4 consistantly yielded maximum straw at all iron levels and at the highest iron level of 600 ppm H_4 recorded maximum yield of 41.0 g per pot, while Keerthy recorded the least straw yield of 30.9g followed by Kochuvithu. When the varietal means were compared, H_4 had the maximum mean value of straw yield, followed by Mahsuri and Cherady, while Keerthy recorded the lowest.

C. Root weight

Table 6 (C) provides data on the mean root weight of rice varieties as affected by iron toxicity. In control the root weight was highest in H_4 (6.50 g per pot) which was closely followed by Mahsuri (6.38g). Least root weight was recorded by Keerthy (5.75g), the next higher being Kochuvithu (5.98g). Treatment effect was significant. With progressive increase in iron concentration the root weights in all the varieties were found to be significantly suppressed to very low levels. At 600 ppm Fe^{2+} level which was the highest iron level tried, Keerthy had the lowest root weight of 2.30g per pot closely followed by Kochuvithu (2.55g). The variety Mahsuri registered the lowest percentage reduction while Keerthy recorded the highest. The varietal effect was significant. When the varietal means were compared, H_4 recorded the highest, closely followed by Mahsuri. The lowest mean was registered by Keerthy.

(b). Influence of graded levels of iron on the nutrient composition of tolerant rice varieties

The plants were analysed after harvest for the different nutrients. The nutrient contents were multiplied by the respective dry matter yield and the uptake values were computed.

Nitrogen

The mean nitrogen content in rice genotypes as influenced by toxic levels of iron in culture solution are presented in Table 7 and illustrated in Fig. No. 3. Despite the wide varietal variation the nitrogen content registered higher values at higher levels of iron.

The nitrogen content of grain varied from 1.14 per cent 1.48 per cent in the rice varieties under the influence of different iron levels. The treatment effect was highly significant. The nitrogen content registered an increasing trend with graded increase of iron supplied in the solution culture. The varietal effect was also

Table 7. Nitrogen content (per cent) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture Control	400	500	600	Mean (var).
Mahsuri(V_1)	1.14	1.22	1.28	1.35	1.25
H_4(V_2)	1.15	1.22	1.27	1.33	1.24
Kochuvithu(V_3)	1.21	1.32	1.37	1.46	1.34
Cherady(V_4)	1.17	1.28	1.32	1.39	1.29
Keerthy(V_5)	1.20	1.34	1.38	1.48	1.35
Mean (Fe)	1.17	1.28	1.32	1.40	

2. Straw

V_1	0.93	1.05	1.19	1.23	1.11
V_2	0.91	0.98	1.15	1.20	1.06
V_3	0.96	1.08	1.25	1.33	1.15
V_4	0.92	1.02	1.21	1.26	1.12
V_5	0.97	1.17	1.27	1.41	1.21
Mean (Fe)	0.94	1.08	1.21	1,29	

3. Root

V_1	1.30	1.39	1.44	1.49	1.41
V_2	1.33	1.43	1.47	1.53	1.44
V_3	1.36	1.38	1.41	1.46	1.40
V_4	1.31	1.37	1.46	1.48	1.41
V_5	1.35	1.39	1.41	1.44	1.39
Mean (Fe)	1.33	1.37	1.44	1.48	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S*	0.04	S**	0.10	NS	
Treatment(Fe)	S**	0.03	S**	0.09	S**	0.06
Var. x Fe	NS		NS		S**	

significant. Significantly higher mean values were noticed in Keerthy and Kochuvithu and these were on par. The varieties H_4 and Mahsuri registered lower nitrogen content at all the iron levels. The effect of interaction (var. x Fe.) was not significant.

The nitrogen content in straw varied from 0.91 per cent to 1.41 per cent. The treatment had a highly significant increasing effect on straw nitrogen content. The highest nitrogen content was recorded at the highest ppm iron level, 600 ppm in all the varieties. The varietal effect was also significant. The highest nitrogen content was noticed in Keerthy. The variety H_4 recorded the lowest mean nitrogen content followed by Mahsuri. However, the interaction effect was not significant.

The root nitrogen content varied from 1.30 to 1.53 per cent among the rice varieties at the different iron levels. The root nitrogen content in all the rice varieties increased significantly with increasing levels of iron in culture solution. The highest value was estimated at 600 ppm iron level in all the varieties. The vartietal effect and the interaction effect were not significant.

Nitrogen uptake

The mean uptake of nitrogen as influenced by toxic levels of iron are presented in Table 8 and illustrated in Fig.4.

Table 8. Nitrogen uptake (mg/pot) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture Control	400	500	600	Mean (var).
Mahsuri(V_1)	547.2	439.2	392.9	305.1	421.1
H_4(V_2)	575.0	453.8	406.4	327.2	440.6
Kochuvithu(V_3)	551.8	452.8	397.3	286.2	422.0
Cherady(V_4)	549.9	459.5	427.8	303.0	435.1
Keerthy(V_5)	585.6	442.2	375.4	281.2	421.0
Mean (Fe)	561.8	449.5	399.9	300.5	

2. Straw

V_1	746.8	687.8	646.2	467.4	637.1
V_2	764.4	665.4	644.0	492.0	641.5
V_3	693.1	640.4	578.5	478.8	597.7
V_4	741.5	663.0	641.3	461.9	626.8
V_5	690.6	651.7	591.8	435.7	592.5
Mean (Fe)	727.3	661.7	620.4	467.0	

3. Root

V_1	82.9	70.9	62.8	42.8	64.9
V_2	92.9	78.7	67.9	45.6	71.3
V_3	81.3	63.3	53.2	37.2	58.8
V_4	80.7	65.1	57.2	39.9	60.7
V_5	77.6	61.2	47.9	33.1	54.9
Mean (Fe)	83.1	67.8	57.8	39.7	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	NS		S**	37.1	S**	3.5
Treatment(Fe)	S**	43.0	S**	33.2	S**	3.2
Var. x Fe	NS		S**	74.1	NS	

The nitrogen uptake of grain decreased with increasing levels of iron in culture medium. The treatment effect was highly significant. The highest uptake was noticed in the control treatment and the lowest in the highest iron level treatment. Among the varieties, H_4 and Cherady recorded higher uptake. However, the varietal effect and interaction effect were not significant.

With regard to uptake of nitrogen by straw variation with iron levels could be noticed. The uptake decreased significantly with increasing iron level in all the varieties. The varietal effect and interaction effect were highly significant. The uptake of nitrogen was maximum in H_4 which was on par with Mahsuri and Cherady. Minimum uptake of nitrogen was noticed in Keerthy.

In the root portion of the rice plant the uptake of nitrogen showed a decreasing tendency with increasing levels of iron in culture solution. The treatment and varietal effect were highly significant. The highest nitrogen uptake was recorded in H_4 followed by Mahsuri. The variety Keerthy recorded lowest uptake of nitrogen which was significantly lower than all other varieties. The interaction effect was not significant.

Phosphorus

Data on the phosphorus content of the grain, straw and root in the different rice varieties as influenced by toxic levels of iron

Table 9. Phosphorus content (per cent) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture Control	400	500	600	Mean (var).
Mahsuri(V_1)	0.33	0.24	0.23	0.20	0.25
H_4(V_2)	0.34	0.27	0.25	0.22	0.27
Kochuvithu(V_3)	0.32	0.23	0.22	0.19	0.24
Cherady(V_4)	0.34	0.24	0.23	0.21	0.25
Keerthy(V_5)	0.31	0.25	0.22	0.19	0.24
Mean (Fe)	0.33	0.25	0.23	0.21	

2. Straw

V_1	0.29	0.25	0.23	0.22	0.25
V_2	0.30	0.26	0.25	0.23	0.26
V_3	0.28	0.24	0.23	0.21	0.24
V_4	0.28	0.25	0.24	0.22	0.25
V_5	0.27	0.23	0.22	0.21	0.23
Mean (Fe)	0.28	0.25	0.24	0.22	

3. Root

V_1	0.20	0.18	0.15	0.13	0.17
V_2	0.22	0.16	0.15	0.11	0.16
V_3	0.21	0.18	0.14	0.13	0.17
V_4	0.23	0.17	0.13	0.12	0.16
V_5	0.22	0.17	0.14	0.11	0.16
Mean (Fe)	0.22	0.17	0.14	0.12	

ANOVA

	Grain F test	Grain CD	Straw F test	Straw CD	Root F test	Root CD
Variety (Var.)	S**	0.01	S**	0.01	NS	
Treatment(Fe)	S**	0.01	S**	0.01	S**	0.01
Var. x Fe	NS		NS		NS	

supplied to the culture solution are furnished in Table 9 and illustrated in Fig. 5.

The phosphorus content of the grain varied from 0.34 per cent to 0.19 per cent. The treatment effect and varietal effect were highly significant. The value decreased significantly with increasing additions of Fe^{++} to the culture solution. The variety H_4 recorded significantly higher phosphorus content than others. The lowest P content was recorded in Keerthy and it was on par with Kochuvithu. However, the interaction effect (treatment vs. varieties) was not significant.

Phosphorus content in straw varied from 0.29 per cent to 0.21 per cent in straw. The treatment effect and the varietal effect were highly significant whereas the interaction effect was not significant. The P content of straw decreased with increase in iron level in growth medium. The variety H_4 recorded significantly higher phosphorus content and it was on par with that of Mahsuri. The variety Keerthy recorded significantly lower phosphorus content compared to others.

In roots the phosphorus content varied from 0.22 per cent to 0.13 per cent. The treatment had a highly significant decreasing effect on phosphorus content. The highest value was noticed in the control and the lowest in 600 ppm iron level. The varietal effect and interaction effect were not significant.

Phosphorus uptake

The data relating to phosphorus uptake by rice varieties under the influence of toxic levels of iron in culture solution are presented in Table 10 and illustrated in Fig. 6.

The varietal effect as well as the treatment effect on the uptake of phosphorus in grain was significant. The phosphorus uptake by rice varieties at all iron levels differed and it showed a decreasing trend with increasing levels of iron in culture solution. The phosphorus uptake in Keerthy was the lowest and it was significantly lower than all other varieties except Kochuvithu. The variety H_4 recorded the highest phosphorus uptake. The interaction effect was however not significant.

The phosphorus uptake in straw was found to decrease significantly with increasing levels of iron in culture medium. Varietal effect was significant. The variety H_4 registered maximum uptake followed by the variety Mahsuri. The phosphorus uptake in Keerthy was significantly lower than all other varieties. The interaction effect was not significant.

Table 10. Phosphorus uptake (mg/pot) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture				Mean
	Control	400	500	600	(var).
Mahsuri(V_1)	159.4	87.5	69.7	46.8	90.9
H_4(V_2)	168.5	101.6	80.9	54.9	101.5
Kochuvithu(V_3)	159.3	78.9	64.7	37.8	85.2
Cherady(V_4)	167.2	84.4	69.8	46.4	91.9
Keerthy(V_5)	162.5	81.5	59.8	36.1	84.9
Mean (Fe)	163.4	86.8	68.9	44.4	

2. Straw

V_1	232.9	168.9	129.8	84.3	153.9
V_2	244.4	175.9	135.5	92.3	162.1
V_3	206.5	147.7	118.7	77.4	137.6
V_4	228.1	163.8	126.1	90.8	152.2
V_5	205.1	132.0	106.2	65.2	127.1
Mean (Fe)	223.4	157.7	154.1	82.0	

3. Root

V_1	14.1	8.6	6.3	3.6	8.2
V_2	14.5	9.3	6.6	3.7	8.5
V_3	13.2	7.8	5.5	3.3	7.5
V_4	13.7	8.1	5.7	3.4	7.7
V_5	12.7	7.5	4.9	2.9	7.0
Mean (Fe)	13.6	8.3	5.8	4.2	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S**	5.9	S**	7.0	NS	
Treatment(Fe)	S**	5.3	S**	6.2	S**	0.4
Var. x Fe	NS		NS		NS	

In all the varieties, the increased levels of iron had significantly decreased the uptake of phosphorus in root. The lowest uptake was noticed at 600 ppm iron level. However varietal effect and interaction effect were not significant.

Potassium

The data relating to the potassium content of rice varieties as influenced by different levels of iron are presented in Table 11. and illustrated in Fig. 7.

The potassium content in grain in different varieties varied from 0.18 per cent to 0.34 per cent. The effect of treatment on the potassium content was highly significant. The data indicated that the increasing levels of iron in the culture solution had a suppressing effect on the content of potassium in all rice varieties. The varietal effect was also highly significant. H_4 recorded the highest content of potassium in the grain followed by Mahsuri. Keerthy recorded the lowest Potassium content. The interaction effect was however, not significant.

The potassium content of straw of different rices ranged from 1.31 per cent to 1.87 per cent. Increasing levels of iron significantly decreased the potassium content. The varietal effect was also highly significant. H_4 recorded significantly higher content of

Table 11. Potassium content (per cent) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture				Mean
	Control	400	500	600	(var).
Mahsuri(V_1)	0.33	0.26	0.22	0.21	0.26
H_4(V_2)	0.34	0.27	0.24	0.23	0.27
Kochuvithu(V_3)	0.31	0.26	0.21	0.19	0.24
Cherady(V_4)	0.32	0.25	0.22	0.20	0.24
Keerthy(V_5)	0.31	0.27	0.20	0.18	0.23
Mean (Fe)	0.32	0.26	0.22	0.20	

2. Straw

V_1	1.83	1.60	1.50	1.41	1.59
V_2	1.87	1.66	1.51	1.44	1.63
V_3	1.86	1.57	1.41	1.34	1.55
V_4	1.84	1.57	1.44	1.38	1.56
V_5	1.85	1.52	1.42	1.31	1.53
Mean (Fe)	1.85	1.58	1.46	1.36	

3. Root

V_1	0.30	0.20	0.15	0.14	0.20
V_2	0.31	0.19	0.15	0.13	0.19
V_3	0.30	0.21	0.16	0.15	0.20
V_4	0.31	0.20	0.16	0.13	0.20
V_5	0.30	0.21	0.17	0.15	0.21
Mean (Fe)	0.304	0.202	0.158	0.140	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S**	0.04	S**	0.06	NS	
Treatment(Fe)	S**	0.03	S**	0.04	S**	0.04
Var. x Fe	NS		NS		NS	

potassium and this was followed by Mahsuri. The variety Keerthy had recorded the lowest potassium content. However, the interaction effect was not significant.

Potassium content in roots in rice varieties varied from 0.13 per cent at the highest iron level to 0.31 per cent in the control. The treatment effect was highly significant. At higher levels of added iron the potassium content decreased significantly. Keerthy recorded the highest content of potassium. However, the varietal effect and interaction effect were not significant.

Potassium uptake

The data on the potassium uptake of rice varieties under the different treatment levels of iron are presented in Table 12 and illustrated in Fig. 8.

Potassium uptake was decreased significantly by the effect of different levels of iron in the growth medium. The varietal effect was highly significant. The variety H_4 recorded the highest content of potassium in the grain and Keerthy the lowest. The interaction effect of variety x treatment was however not significant.

The uptake of potassium by straw under varying iron levels varied from 405 mg/pot to 1571 mg/pot in the different rice

Table 12. Potassium uptake (mg/pot) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture				Mean
	Control	400	500	600	(var).
Mahsuri(V_1)	158.4	93.6	67.5	47.5	91.8
H_4(V_2)	170.0	100.4	76.8	56.6	100.8
Kochuvithu(V_3)	141.4	89.2	60.9	37.2	82.2
Cherady(V_4)	150.4	89.8	68.2	43.6	88.0
Keerthy(V_5)	151.3	87.9	54.4	34.2	82.0
Mean (Fe)	154.3	92.2	65.6	43.8	

2. Straw

V_1	1469.5	1048.0	815.0	535.8	967.1
V_2	1570.8	1127.1	845.8	590.4	1033.3
V_3	1342.9	931.0	709.2	482.4	866.4
V_4	1483.0	1020.5	763.2	505.0	942.9
V_5	1317.2	846.6	661.7	404.8	807.6
Mean (Fe)	1436.7	994.6	758.9	503.7	

3. Root

V_1	19.1	9.6	6.5	3.7	9.7
V_2	20.2	9.9	6.9	3.6	10.2
V_3	17.9	9.6	6.0	3.6	9.3
V_4	19.7	9.0	6.3	3.5	9.6
V_5	16.1	9.2	5.8	3.2	8.6
Mean (Fe)	18.6	9.5	6.3	3.5	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S**	8.4	S**	25.7	NS	
Treatment(Fe)	S**	7.5	S**	22.9	S**	1.3
Var. x Fe	NS		S**	51.4	NS	

varieties. The treatment effect was highly significant. Increasing levels of iron, in general decreased the uptake of potassium. The varietal effect and interaction effect were also highly significant. The lowest uptake was observed in Keerthy and it differed significantly from the uptake by all other varieties. The variety H_4 recorded the highest uptake.

The potassium uptake varied from 3.2 mg/pot to 20.2mg/pot in the different rice varieties under the influence of different iron levels. The treatment effect was highly significant. Increasing levels of iron, in general, decreased the uptake of potassium. The variety H_4 recorded the highest mean uptake of potassium whereas the variety Keerthy registered the lowest. However, the varietal effect and the interaction effect were not significant.

Calcium

The data on the calcium content of different rice varieties as affected by graded toxic levels of iron supplied to the culture solution are given in Table 13 and illustrated in Fig.9.

The grain calcium content of the rice varieties varied from 0.14 per cent to 0.29 per cent due to the influence of toxic levels

Table 13. Calcium content (per cent) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture Control	400	500	600	Mean (var).
Mahsuri(V_1)	0.28	0.20	0.18	0.17	0.21
H_4(V_2)	0.29	0.21	0.19	0.16	0.21
Kochuvithu(V_3)	0.27	0.20	0.17	0.15	0.20
Cherady(V_4)	0.25	0.21	0.18	0.15	0.20
Keerthy(V_5)	0.27	0.18	0.16	0.14	0.19
Mean (Fe)	0.27	0.20	0.18	0.15	

2. Straw

V_1	0.67	0.44	0.39	0.36	0.47
V_2	0.69	0.44	0.42	0.39	0.49
V_3	0.66	0.41	0.36	0.34	0.45
V_4	0.68	0.42	0.38	0.37	0.47
V_5	0.69	0.42	0.35	0.33	0.45
Mean (Fe)	0.68	0.44	0.38	0.36	

3. Root

V_1	0.22	0.16	0.14	0.12	0.16
V_2	0.21	0.16	0.13	0.11	0.15
V_3	0.22	0.17	0.15	0.14	0.17
V_4	0.23	0.17	0.14	0.13	0.17
V_5	0.24	0.18	0.16	0.13	0.18
Mean (Fe)	0.22	0.16	0.14	0.13	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S**	0.01	S**	0.02	NS	
Treatment(Fe)	S**	0.01	S**	0.01	S**	0.02
Var. x Fe	NS		NS		NS	

of iron. The different levels of iron influenced the calcium content of the grain significantly. The content got reduced with the increase in iron content in the culture solution. The effect of varieties on the calcium content of grain was also significant. Among the varieties H_4 and Mahsuri recorded the highest calcium content which maintained the trend at all iron concentrations. Keerthy had the least calcium content. The interaction effect was, however, not significant.

The calcium content of the rice straw was also influenced by iron toxicity. The content ranged from 0.33 per cent in Keerthy to 0.70 per cent in H_4 under the different iron levels. The treatment effect was highly significant. All levels of iron significantly decreased the calcium content of straw. The varietal effect was also significant. The highest calcium content was recorded in H_4. The lowest calcium content was noticed in Kochuvithu and Keerthy. The interaction effect was, however, not significant.

The root calcium varied from 0.24 per cent to 0.11 per cent. The graded toxic levels of iron supplied to the culture solution could influence the calcium content of the roots to a significant level. As the iron level increased the calcium content got reduced. The lowest calcium content was recorded in H_4. However, the varietal effect and interaction effect were not significant.

Calcium uptake

The data on the uptake of calcium by the different rice varieties as affected by graded toxic levels of iron in culture solution are given in Table 13 and illustrated in Fig. 10.

The calcium uptake in grain varied from 27.9 mg/pot to 143.0 mg/pot. All the iron levels decreased the uptake significantly. The varietal effect was also highly significant. The mean calcium uptake by Keerthy was significantly lower than that of all the varieties except that of Kochuvithu. The highest uptake was recorded in H_4. The interaction effect was however not significant.

The calcium uptake by straw varied from 101.9 mg/pot 585.5 mg/pot. The varietal effect was highly significant. Highest value of calcium uptake could be recorded in H_4. The uptake by Keerthy was significantly lower than all others but on par with that of Kochuvithu. The effect of treatments was highly significant. The calcium uptake by rice straw at all levels of iron differed significantly from each other. The lowest uptake was obtained at 600 ppm level. The interaction effect was not significant.

The mean uptake of calcium by roots varied from 3.0 mg/pot to 15.6 mg/pot. The different levels of iron influenced the calcium uptake significantly. The uptake decreased with

Table 14. Calcium uptake (mg/pot) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture				Mean
	Control	400	500	600	(var).
Mahsuri(V_1)	132.9	73.8	55.3	31.7	71.9
H_4(V_2)	143.0	77.0	59.5	38.6	78.4
Kochuvithu(V_3)	124.5	66.2	48.4	30.8	66.9
Cherady(V_4)	125.5	72.9	52.7	32.7	75.9
Keerthy(V_5)	121.6	66.9	45.4	27.9	66.0
Mean (Fe)	129.5	71.4	52.3	33.5	

2. Straw

V_1	540.4	289.5	213.4	137.9	295.3
V_2	585.5	303.5	36.9	159.9	321.5
V_3	478.7	244.9	183.1	124.9	257.9
V_4	553.7	276.9	203.5	136.5	292.7
V_5	491.3	235.6	166.4	101.9	248.8
Mean (Fe)	529.9	270.1	200.7	132.2	

3. Root

V_1	15.4	8.6	6.2	3.6	8.5
V_2	15.6	9.3	6.6	3.8	8.8
V_3	14.4	7.8	5.4	3.3	7.7
V_4	14.9	8.1	5.6	3.5	8.0
V_5	13.8	7.5	4.9	3.0	7.3
Mean (Fe)	14.8	8.3	5.7	3.4	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S**	5.2	S**	12.7	S**	0.62
Treatment(Fe)	S**	4.6	S**	11.4	S**	0.5
Var. x Fe	NS		NS		NS	

increasing levels of iron. Varietal effect was also significant. Variety H_4 recorded significantly higher root calcium uptake while the variety Keerthy recorded the lowest.

Magnesium

The data on the magnesium content of rice varieties grown under the influence of toxic levels of iron are presented in the Table 15 and illustrated in Fig. 11.

The magnesium content of rice grain under the different iron levels varied from 0.11 per cent to 0.25 per cent. The influence of varieties on the mean magnesium content was not significant. Highest magnesium content was observed in H_4 followed by Mahsuri and the lowest in Keerthy. The treatment effect was highly significant. With increasing toxic levels of iron the grain magnesium decreased significantly, with the lowest magnesium at the highest iron level of 600 ppm. The interaction effect was, however, not significant.

The magnesium content of rice straw varied from 0.18 per cent to 0.41 per cent with maximum content recorded by H_4. Significant difference in magnesium content among the varieties could not be noticed. The different iron levels had highly significant influence on the magnesium content. In all the rice varieties there was a decrease in magnesium content with increasing iron levels. Variety H_4 had the highest magnesium content. The most adverse effect of iron toxicity was reflected in the varieties Kochuvithu and

Table 15. Magnesium content (per cent) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture				Mean
	Control	400	500	600	(var).
Mahsuri(V_1)	0.25	0.17	0.14	0.12	0.17
H_4(V_2)	0.25	0.18	0.16	0.13	0.18
Kochuvithu(V_3)	0.24	0.17	0.14	0.12	0.16
Cherady(V_4)	0.23	0.17	0.15	0.13	0.17
Keerthy(V_5)	0.25	0.16	0.13	0.11	0.16
Mean (Fe)	0.24	0.17	0.14	0.12	

2. Straw

V_1	0.40	0.25	0.23	0.20	0.27
V_2	0.41	0.27	0.24	0.21	0.28
V_3	0.39	0.24	0.22	0.18	0.26
V_4	0.40	0.25	0.23	0.19	0.27
V_5	0.41	0.25	0.21	0.18	0.26
Mean (Fe)	0.40	0.25	0.23	0.19	

3. Root

V_1	0.24	0.11	0.10	0.09	0.14
V_2	0.21	0.12	0.10	0.08	0.13
V_3	0.24	0.12	0.11	0.09	0.14
V_4	0.22	0.12	0.11	0.08	0.13
V_5	0.23	0.13	0.12	0.10	0.15
Mean (Fe)	0.23	0.12	0.11	0.09	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	NS		NS		NS	
Treatment(Fe)	S**	0.02	S**	0.02	S**	0.01
Var. x Fe	NS		NS		NS	

Keerthy as evidenced by the least content of Magnesium in the varieties. The magnesium was the lowest in the treatment which received the highest level of iron. The interaction effect of varieties x treatment was not significant.

In the rice roots, the magnesium content varied from 0.08 per cent to 0.24 per cent. The effect of different levels of iron on the magnesium content of roots was highly significant. Magnesium was lowest in the treatment which received the highest level of iron. However, the varietal effect and interaction effect were not significant.

Magnesium uptake

The data on the uptake of magnesium by the rice varieties under the influence of toxic levels of iron are presented in Table 16 and illustrated in Fig. 12.

In the rice grain, the uptake of magnesium varied from 22.2 mg/pot to 123.9mg/pot. The varieties influenced the grain uptake of magnesium significantly. The lowest mean uptake was observed in Keerthy and the highest in H_4 under the iron toxicity condition. The influence of different levels of iron on the magnesium uptake was highly significant. Increased concentrations of iron suppressed the magnesium uptake. The interaction effect was, however, not significant.

Table 16. Magnesium uptake (mg/pot) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture				Mean
	Control	400	500	600	(var).
Mahsuri(V_1)	120.5	64.1	42.9	27.8	63.8
H4(V_2)	123.5	68.1	48.9	31.2	67.9
KochuvithuV_3	113.1	58.7	40.6	23.5	58.9
Cherady(V_4)	118.4	62.1	46.5	25.7	63.2
Keerthy(V_5)	118.7	53.8	37.3	22.2	58.0
Mean (Fe)	118.6	61.4	43.2	26.1	

2. Straw

V_1	317.9	165.7	126.5	74.9	171.3
V_2	346.9	181.3	136.1	84.8	187.3
V_3	283.7	164.3	112.2	65.9	156.5
V_4	324.0	164.5	123.5	69.5	170.4
V_5	291.9	140.9	105.3	55.6	148.4
Mean (Fe)	312.9	163.3	120.1	70.1	

3. Root

V_1	15.5	5.8	4.5	2.6	7.1
V_2	15.3	6.5	4.5	2.5	7.2
V_3	13.0	5.6	4.1	2.5	6.4
V_4	14.2	5.7	4.4	2.6	6.7
V_5	12.7	5.5	3.8	3.2	6.3
Mean (Fe)	14.1	5.8	4.3	2.6	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S*	5.1	S**	7.0	NS	
Treatment(Fe)	S**	4.5	S**	14.1	S**	0.4
Var. x Fe	NS		NS		NS	

The uptake of magnesium by rice straw was found to vary from 55.6 mg/pot to 346.9 mg/pot due to iron treatments. The varietal effect on the magnesium uptake was highly significant. The highest magnesium uptake was observed in H_4 and the lowest in Keerthy. The different levels of iron influenced the uptake of magnesium significantly. The uptake decreased with increased levels of iron in the culture solution. The interaction effect was also highly significant. At 600 ppm iron level, H_4 showed maximum uptake by straw while Keerthy had the lowest uptake. At lower iron levels also, the trend was maintained.

The uptake of magnesium by rice root varied from 2.5 mg/pot to 15.5 mg/pot. The treatment effect was highly significant. Lowest iron level resulted in significantly higher magnesium uptake by rice roots, whereas the highest level of 600 ppm iron could bring about minimum uptake. The varietal effect and interaction effect were, however, not significant.

Iron

The data relating to the changes in the iron content of the rice varieties under the influence of graded levels of iron toxicity induced in the culture solution are presented in Table 17 and illustrated in Fig. 13.

Table 17. Iron content (ppm) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture Control	400	500	600	Mean (var).
Mahsuri(V_1)	183	481	711	802	544
H4(V_2)	175	444	644	729	498
KochuvithuV_3	181	530	774	838	581
Cherady(V_4)	185	512	732	833	566
Keerthy(V_5)	180	557	805	875	604
Mean (Fe)	181	505	733	816	

2. Straw

V_1	485	1229	1540	1978	1308
V_2	478	1169	1472	1930	1262
V_3	480	1427	1741	2184	1458
V_4	496	1329	1661	2106	1398
V_5	502	1478	1849	2302	1533
Mean (Fe)	488	1326	1653	2100	

3. Root

V_1	1496	3644	4666	5592	3849
V_2	1511	3690	4748	5628	3894
V_3	1483	3453	4518	5388	3711
V_4	1491	3526	4603	5523	3786
V_5	1446	3420	4491	5363	3681
Mean (Fe)	1485	3547	4605	5499	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	S*	47	S**	43	NS	
Treatment(Fe)	S**	25	S**	39	S**	167
Var. x Fe	S**	55	S**	86	NS	

The iron content of rice grain varied from 175 ppm to 875 ppm. The varietal effect was highly significant. The mean iron content was found lowest in H_4. This variety maintained low iron status in grain at all the iron levels tried. A significantly higher content of iron was observed in Keerthy and it was on par with Kochuvithu. With regard to the treatment effect, in general, the iron content of the grain increased significantly with rise in the concentration of iron. The grain iron content was highest at 600 ppm iron level. The interaction effect was also highly significant. The variety H_4 had the minimum grain content of iron at all iron levels including the control, while the variety Keerthy registered highest iron content in grain at the toxic levels of iron supplied.

The iron content in straw under the influence of iron toxicity showed variations from 478 ppm to 2302 ppm. Varietal effect was highly significant. The variety Keerthy recorded highest iron in straw. All varieties differed significantly from each other. The iron content in straw increased significantly with increase in the levels of iron in the culture solution. The interaction effect was also highly significant. The variety H_4 at all the levels of applied iron recorded the lowest contents of iron in straw while the highest content of iron was found in Keerthy at the toxic levels of iron supplied.

Iron content in root varied from 1446 ppm to 5628 ppm at the different iron levels. The treatment effect was highly significant in all the varieties. Root iron increased with increase in the level of iron supplied to the culture solution. The varietal effect and interaction effect were not significant. The variety Keerthy recorded the lowest content of root iron and H_4 the highest, under the influence of all the levels of iron treatments.

Iron uptake

Different levels of applied iron have influenced the iron uptake by different rice varieties as explained in Table 18 and illustrated in fig. 14.

The uptake of iron by grain under the different iron treatments varied from 8.2 mg/pot to 22.7 mg/pot. The varietal effect was not significant. Cherady recorded the highest uptake of iron and H_4 the lowest. The treatment effect was highly significant. The uptake of iron increased with increasing levels of iron upto 500 ppm and thereafter declined to lower values in all the rice varieties. Mean values indicated that the interaction effect of variety x treatment was not significant.

Table 18. Iron uptake (mg/pot) of the rice varieties as influenced by toxic levels of iron

1. Grain

Variety	Fe^{2+} levels (ppm) in solution culture Control	400	500	600	Mean (var).
Mahsuri(V_1)	8.8	17.3	21.8	18.1	16.5
H4(V_2)	8.7	16.5	20.6	17.9	16.0
KochuvithuV_3	8.2	18.2	22.5	16.4	16.3
Cherady(V_4)	8.7	18.4	22.7	18.2	17.0
Keerthy(V_5)	8.8	18.3	21.9	16.6	16.4
Mean (Fe)	8.7	17.7	21.9	17.4	

2. Straw

V_1	38.9	80.5	83.6	75.2	69.6
V_2	40.2	79.3	86.0	79.1	71.1
V_3	34.8	84.6	87.6	78.6	71.4
V_4	39.9	86.4	88.0	77.1	72.6
V_5	35.7	82.3	86.1	71.1	68.8
Mean (Fe)	37.9	82.7	85.6	76.2	

3. Root

V_1	9.5	18.6	20.3	16.0	16.1
V_2	9.8	20.3	21.9	16.8	17.2
V_3	8.7	15.8	17.0	13.7	13.8
V_4	9.2	16.7	18.1	14.9	14.7
V_5	8.3	15.0	15.3	12.3	12.7
Mean (Fe)	9.1	17.3	18.5	14.7	

ANOVA

	Grain		Straw		Root	
	F test	CD	F test	CD	F test	CD
Variety (Var.)	NS		NS		S**	0.6
Treatment(Fe)	S**	0.9	S**	2.7	S**	0.5
Var. x Fe	NS		NS		S**	1.2

Iron uptake by straw ranged at different iron levels in the culture solution from 34.6 mg/pot to 88 mg/pot. The lowest mean iron uptake was recorded in Keerthy and the highest in Cherady. However, the effect of variety was not significant. The treatments had a highly significant effect on the uptake of iron. The lowest iron uptake was observed at 50 ppm level and highest uptake was recorded at 500 ppm. As in the case of iron uptake by grain, the straw iron also increased upto the treatment levels of 500 ppm iron beyond which the uptake declined to lower values. The effect of variety x treatment interaction was not significant.

The uptake of iron by roots grown under the influence of iron, varied from 8.3 mg per pot to 21.9 mg per pot among different varieties. The varietal effect was highly significant. H_4 recorded the highest mean uptake of iron in roots followed by Mahsuri and the lowest value was recorded in Keerthy. The iron levels also significantly influenced the iron uptake. The mean uptake of iron by root increased with increasing levels of added iron upto 500 ppm and further toxic levels of iron had a suppressing effect on its uptake. The variety x treatment interaction was highly significant. H_4 recorded the highest uptake of iron at 500 ppm iron concentration while Keerthy gave estimates of lowest iron uptake at 50 ppm iron supplied.

CORRELATION STUDY

The correlation of score and iron content with yield and nutrient content and uptake were studied. The yield was negatively and significantly correlated with score and iron content at 1% level of significance. The nitrogen content was significantly and positively correlated with score and iron content whereas the nitrogen uptake was negatively and significantly correlated with the score at 1% level of significance. A negative and significant correlation was obtained for nitrogen uptake and iron uptake at 5% level of significance. The content and uptake of phosphorus, potassium, calcium and magnesium was correlated significantly and negatively with score and iron content and uptake. A significant and positive correlation was obtained between iron content and score at 1% level of significance.

Table 19. Correlation coefficient of score and iron content and uptake with yield and nutrient content and uptake

		Score			Fe content/uptake		
		Grain	Straw	Root	Grain	Straw	Root
	Yield	-0.5149**	-0.6280**	-0.7349**	-0.6896**	-0.7654**	-0.8213**
N	Content	0.5118**	0.5826**	0.3263*	0.5340**	0.6085**	0.5480**
	Uptake	-0.5413**	-0.4732**	-0.3061*	-0.3299*	-0.3030*	-0.2733*
P	Content	-0.7900**	-0.7030**	-0.7263**	-0.8402**	-0.8524**	-0.8675**
	Uptake	-0.7413**	-0.7963**	-0.7820**	-0.8020**	-.0.6303**	-0.5061**
K	Content	-0.5449**	-0.6595**	-0.5798**	-0.6961**	-0.8198**	-0.6884**
	Uptake	-0.7053**	-0.7655**	-6074**	-0.7972**	-0.7399**	-0.6407**
Ca	Content	-0.5477**	-0.4882**	-0.5148**	-0.6466**	-0.6332**	-0.6659**
	Uptake	-0.5881**	-0.5327**	-0.5661**	-6048**	-0.6470**	-0.4129**
Mg	Content	-0.5030**	-0.5139**	-0.4721**	-0.5946**	-0.6458**	-0.6231**
	Uptake	-0.4277**	-0.6040**	-0.5522**	-0.5240**	-0.5285**	-0.5141**
Fe	Content	0.7885**	0.8054**	0.7572**			
	Uptake	0.4959**	0.4549**	0.2273*			

S* Significant at 5%

S** Significant at 1%

DISCUSSION

DISCUSSION

Iron toxicity is a field constraint in rice production in poorly managed acidic wetland soils wherein the solubilisation of iron under anaerobic soil conditions, often leads to indiscriminate absorption by the rice roots which results in visible physiological disorders in the plant and later reflected in the crop yield. The disorder has been variously characterised by different workers and arises when the Fe^{2+} concentration in the soil exceeds 300 ppm (Ponnamperuma *et al.*, 1958; Tanaka and Yoshida, 1970). Under unsatisfactory soil management situations iron toxicity to rice may develop at as low as even 100 ppm, while in well managed situations even 400 or 500 ppm will be inadequate for the development of iron toxicity (Nhung and Ponnamperuma, 1966).

Toxicity symptoms and plant iron content in rice varieties influenced by high iron concentration

Toxicity Symptoms

The experimental data on scoring iron toxicity symptoms of rice grown in solution culture furnished in Table 1 clearly indicated that the presence of high levels of soluble iron in the growth medium produced visual symptoms in several of the rice cultivars and affected plant growth at varying intensity. The visual symptoms developed varied with the genotype, ranging from mild leaf yellowing to severe bronzing followed by ultimate death of the plant. Tillering of the rice plant would normally start during the third week after transplantation and the stage at which the most adverse effect of iron toxicity exhibited by plant through visual symptoms would be, during tillering to booting (IRRI, 1980).

In the present study most of the varieties subjected to high levels of iron, displayed bronzing. The varieties with lower scores performed better in their growth compared to other varieties with higher scores. Based on scores 1 to 9 the varieties could be classified as tolerant, fairly tolerant, susceptible and highly susceptible. Based on guidelines provided in the IRTP Hand Book, (1980), the varieties with scores 3 and below 3 were considered as tolerant and scores more than 5 as susceptible. In the present study, however, an additional categorisation as 'highly susceptible' had also to be considered based on the high scores of 8 to 9 and unsatisfactory performance by a few varieties.

In the variety Asha, yellowing symptom existed even while removing from the nursery, indicating the susceptible nature of the variety. After, transplantation to solution culture, the symptoms slowly aggravated and Asha was almost dead when the growth reached booting stage. The score registered at this stage was 8.3.

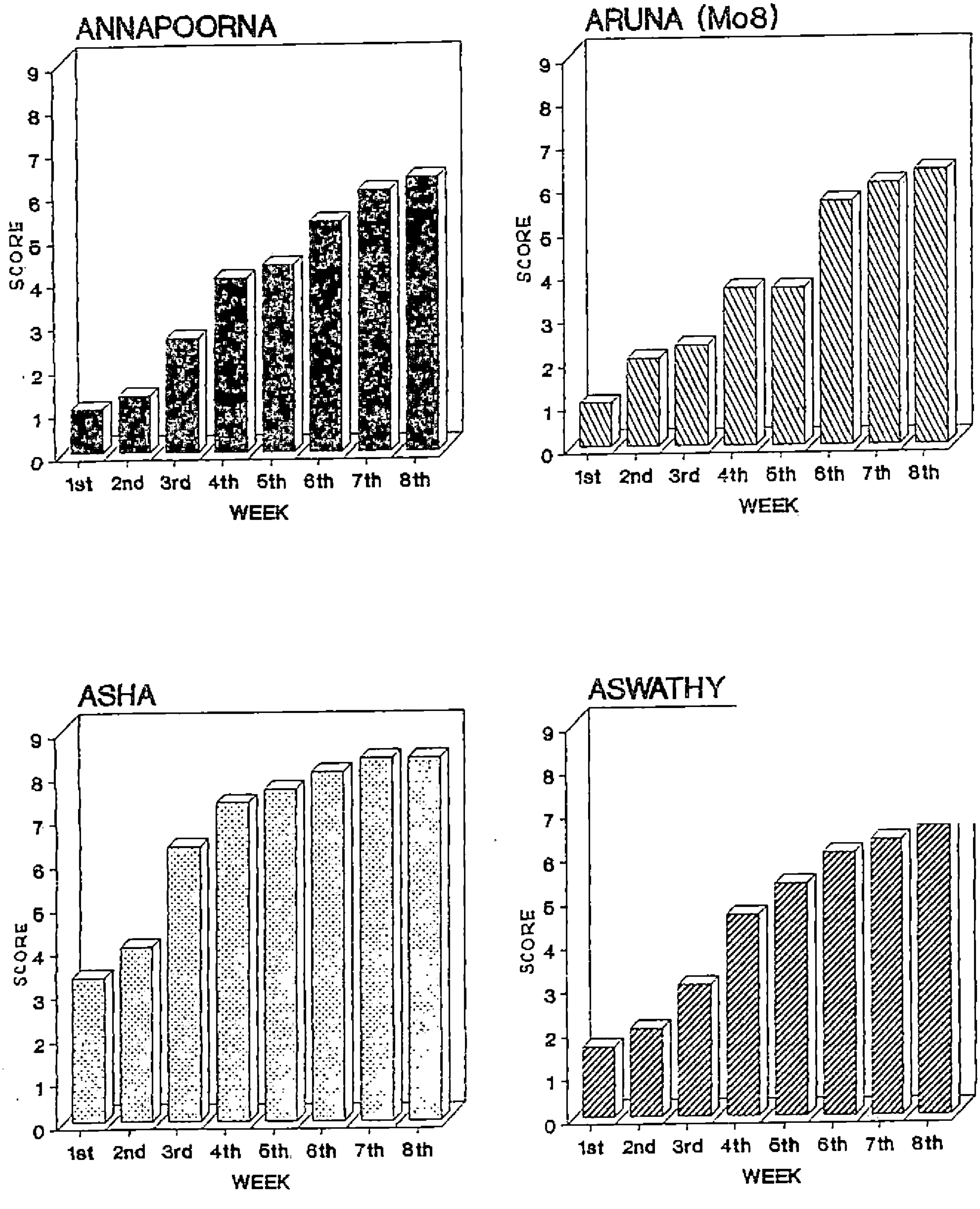
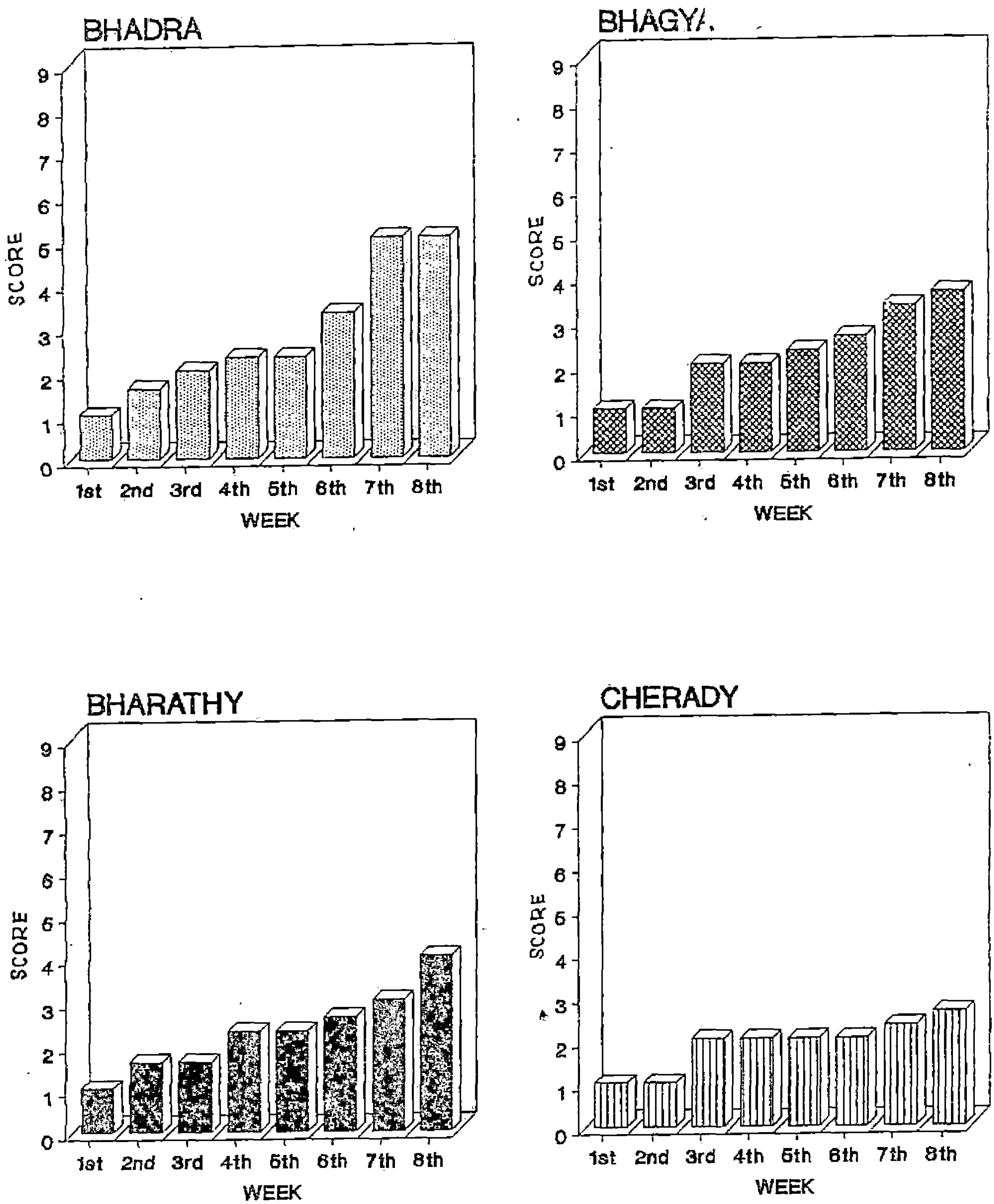


Fig. 1. Score of symptoms due to iron toxicity in rice

Fig 1.(contd)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SCORE
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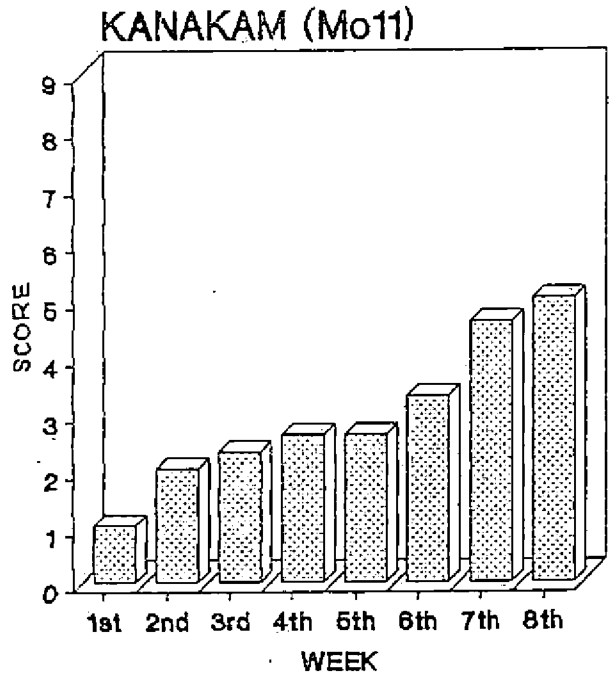
Fig.1.(contd)


KANAKAM (Mo11)
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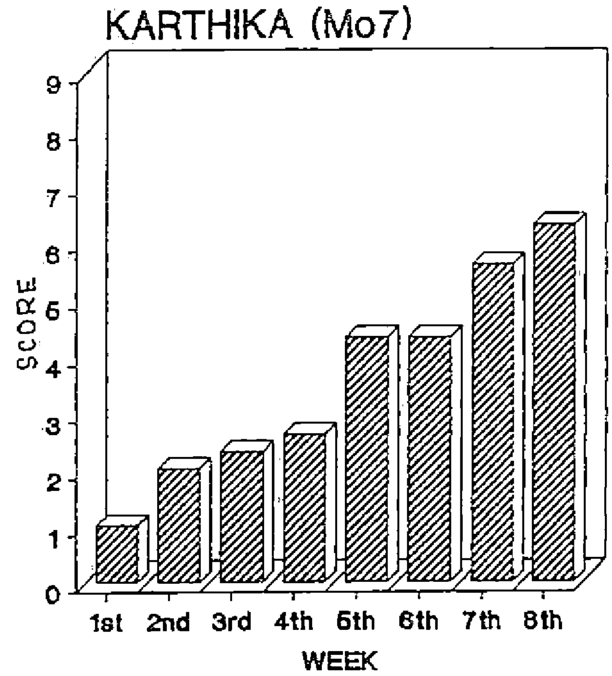
KARTHIKA (Mo7)
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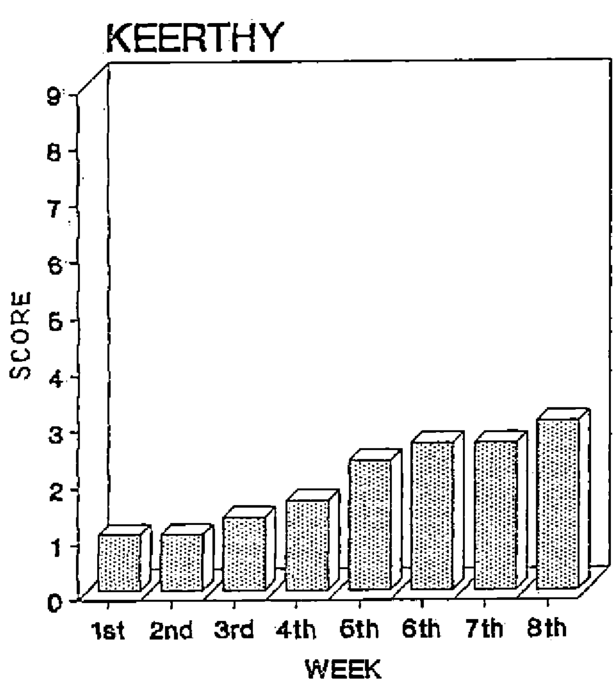
KEERTHY
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8th
WEEK

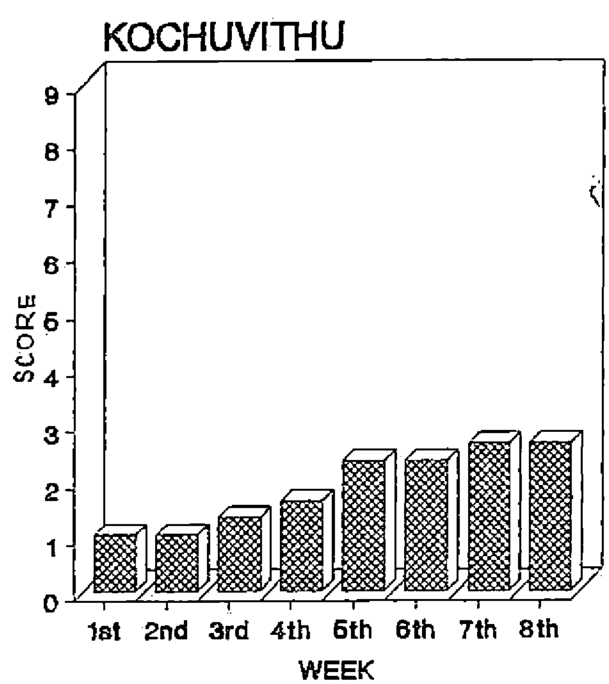
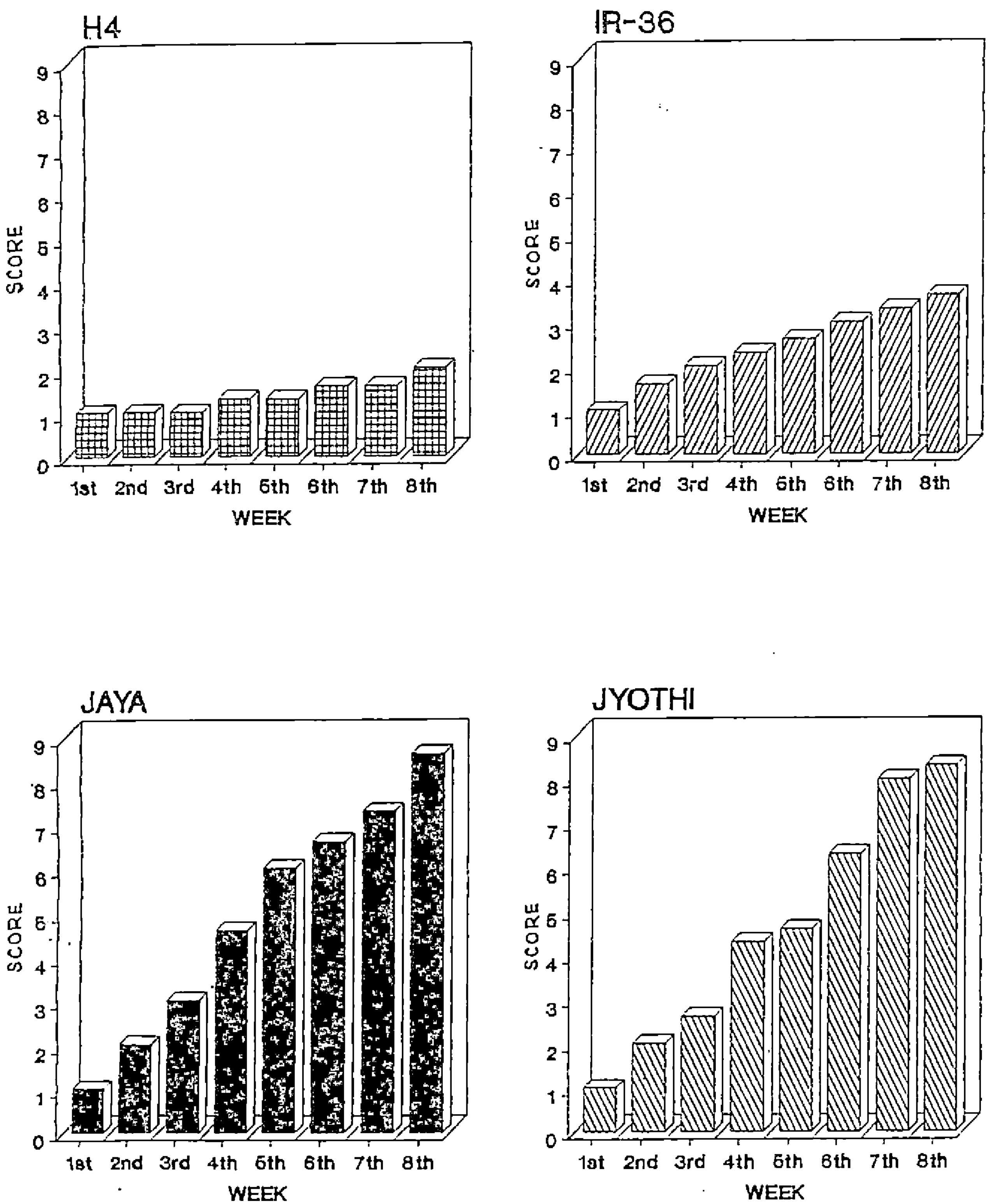

KOCHUVITHU
SCORE
0
1
2
3
4
5
6
7
8
9
1st
2nd
3rd
4th
5th
6th
7th
8th
WEEK

Fig 1. (contd)


H4
IR-36
JAYA
JYOTHI
SCORE
0
1
2
3
4
5
6
7
8
9
1st
2nd
3rd
4th
5th
6th
7th
8th
WEEK

The highly susceptible nature of the variety Asha towards iron toxicity was thus evident even prior to transplantation.

Jaya and Jyothi which were healthy when uprooted from nursery, continued to perform satisfactorily upto the first week after transplantation. However, bronzing symptoms started in the lower leaves during the second week and subsequently became more intense till the 6^{th} and 7^{th} weeks with the appearance of discoloured and dead leaves with scores 8.3 and 8.6 respectively, beyond which both these varieties failed to survive. Thus the varieties Jaya and Jyothi though appeared more resistant in the early stages after transplantation, failed to resist iron toxicity later and therefore these two were also considered as highly susceptible. Virmani (1976) reported that varieties such as Jaya, Vijaya and IR-589-54-2 exhibit yellow orange foliage symptoms when grown in the iron toxic soil.

More or less similar performances could be seen in varieties Neeraja, Ptb-10, Pavizham, Sabari and Santhosh with scores ranging between 7 and 8 at the booting stage.

Varieties Annapoorna, Aruna, Aswathi, Karthika, Onam, Ptb-20 failed to show bronzing symptoms upto the second week after transplanting. The foliar yellowing developed during the subsequent

Fig.1. (contd)

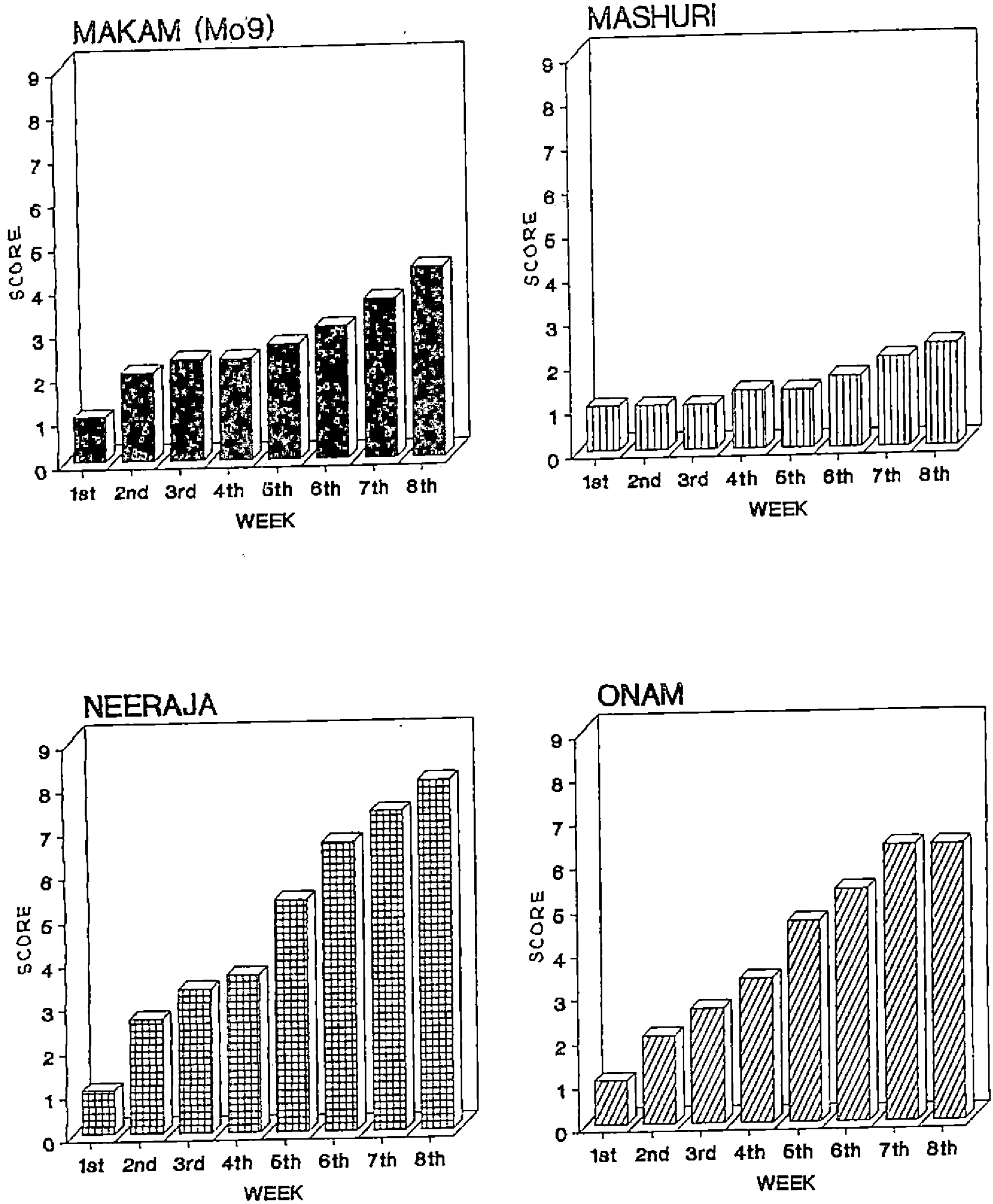
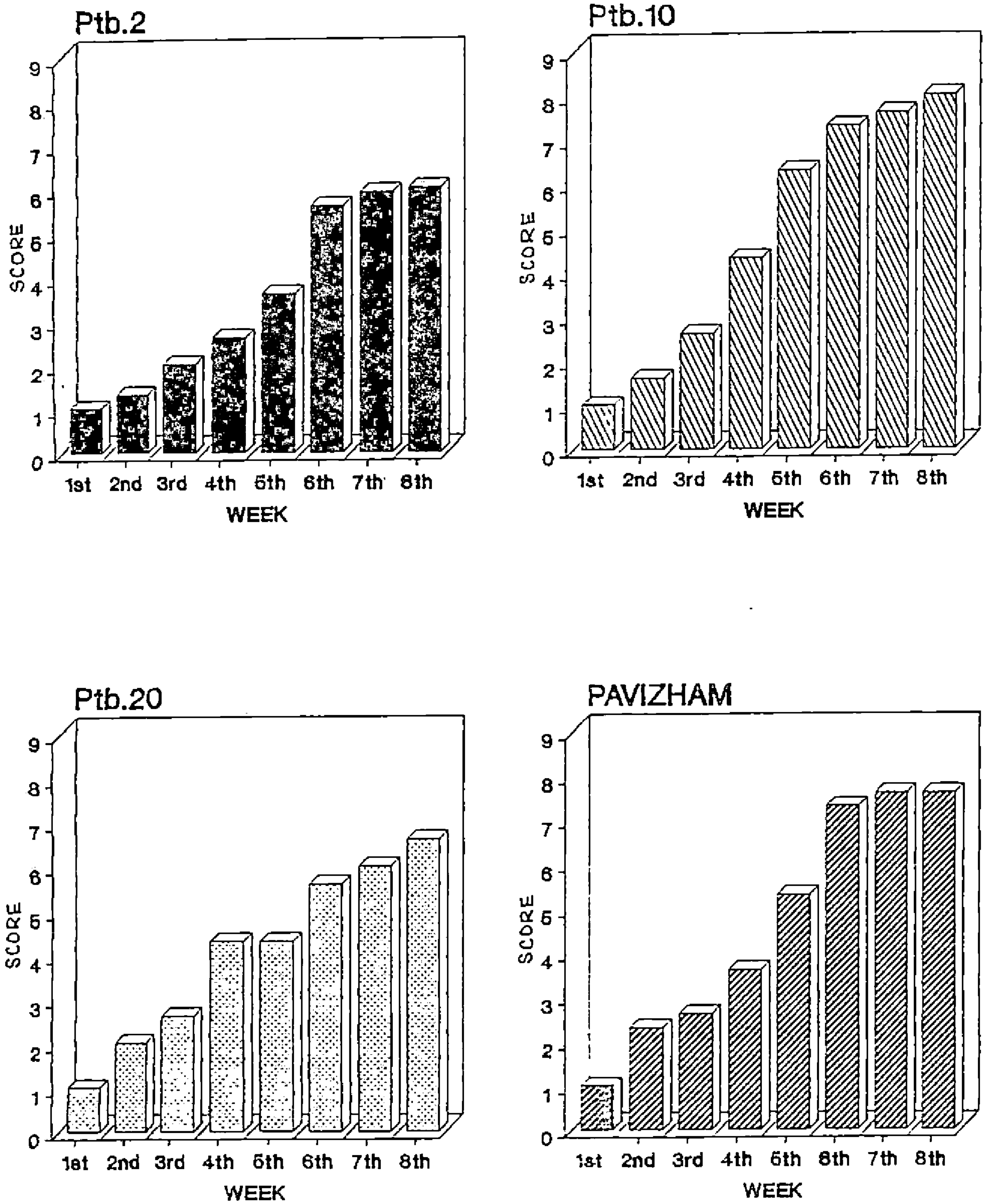

MAKAM (Mo9)
SCORE
0
1
2
3
4
5
6
7
8
9
1st
2nd
3rd
4th
5th
6th
7th
8th
WEEK
MASHURI
SCORE
0
1
2
3
4
5
6
7
8
9
1st
2nd
3rd
4th
5th
6th
7th
8th
WEEK
NEERAJA
SCORE
0
1
2
3
4
5
6
7
8
9
1st
2nd
3rd
4th
5th
6th
7th
8th
WEEK
ONAM
SCORE
0
1
2
3
4
5
6
7
8
9
1st
2nd
3rd
4th
5th
6th
7th
8th
WEEK

Fig.1.(contd)



Ptb.2
SCORE
0 1 2 3 4 5 6 7 8 9
1st 2nd 3rd 4th 5th 6th 7th 8th
WEEK
Ptb.10
SCORE
0 1 2 3 4 5 6 7 8 9
1st 2nd 3rd 4th 5th 6th 7th 8th
WEEK
Ptb.20
SCORE
0 1 2 3 4 5 6 7 8 9
1st 2nd 3rd 4th 5th 6th 7th 8th
WEEK
PAVIZHAM
SCORE
0 1 2 3 4 5 6 7 8 9
1st 2nd 3rd 4th 5th 6th 7th 8th
WEEK

Fig.1. (contd)

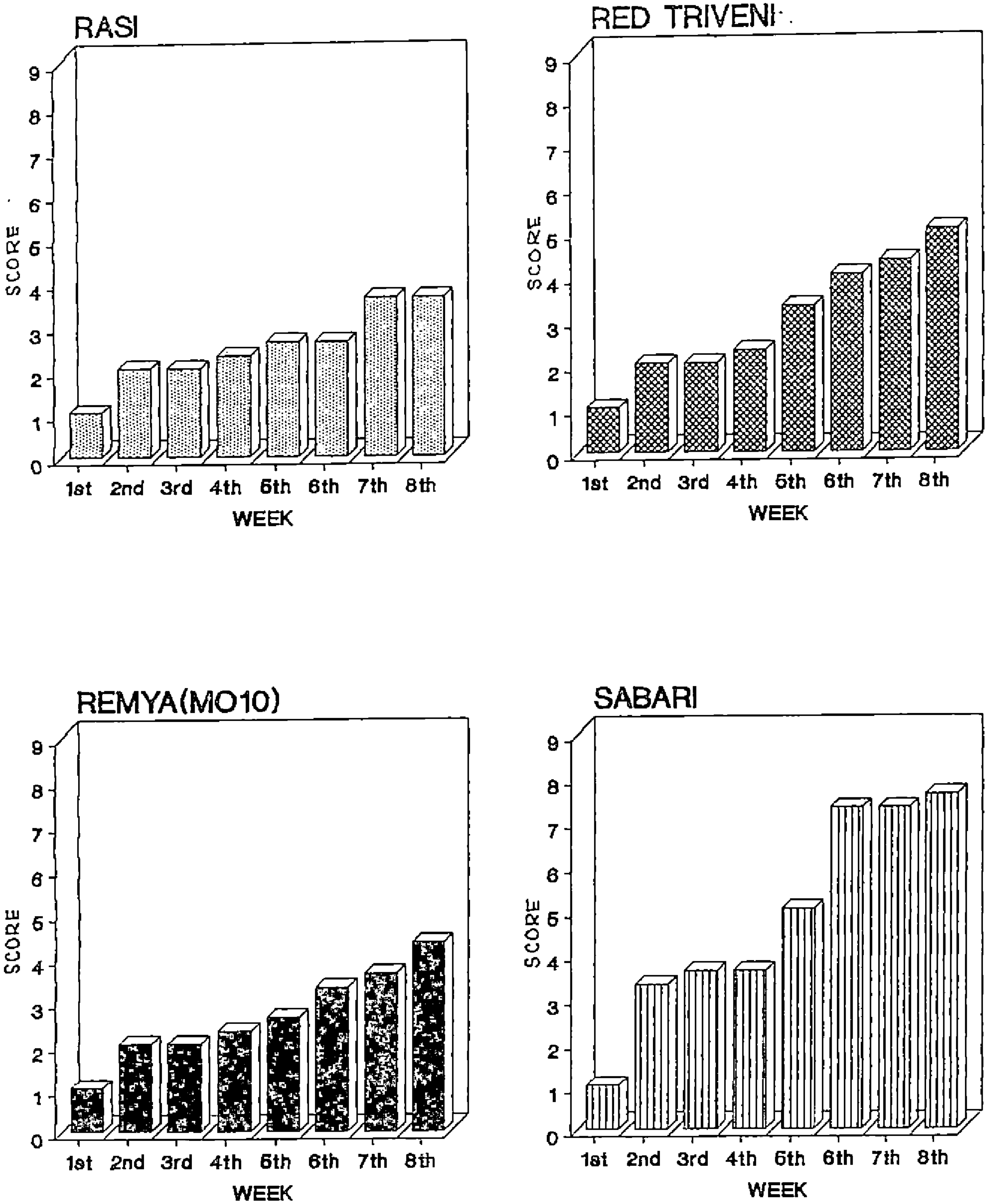
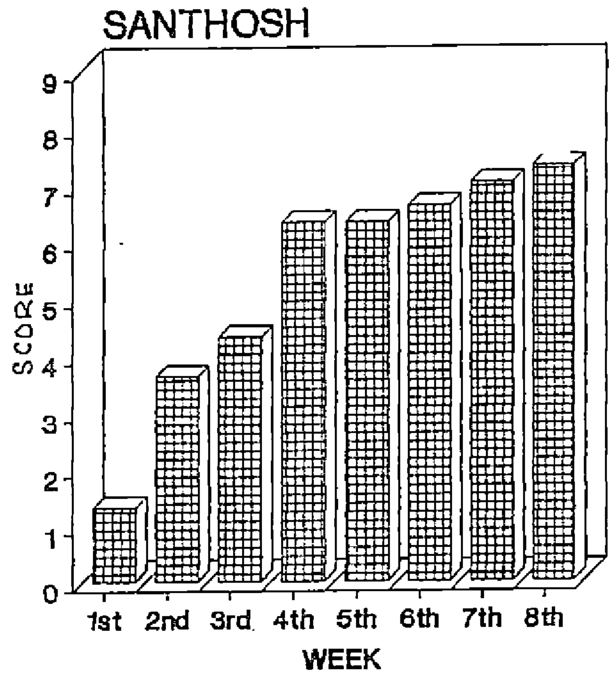
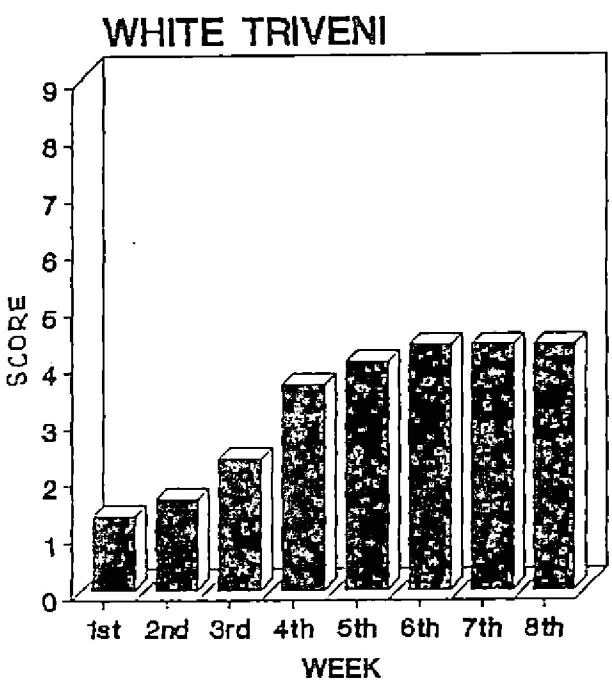

RASI
RED TRIVENI
REMYA(MO10)
SABARI
SCORE
0 1 2 3 4 5 6 7 8 9
1st 2nd 3rd 4th 5th 6th 7th 8th
WEEK

Fig.1.(contd)

170463





periods extended to more leaves registering a score between 6 and 7. However, growth reduction was not as serious as in the varieties discussed earlier.

Eventhough the varieties Kanakam, Makam and Remya developed slight symptoms of iron toxicity in early stages, these got revived at later stages with lesser scores of 5-6. Varieties Red Triveni and White Triveni also performed more or less in the same manner.

The scores for Bhadra and Bharathy at booting stage ranged between 4 and 5 even though those varieties resisted iron toxicity in the early stages of transplantation as evidenced by lack of symptoms.

Varieties Bhagya, IR-36 and Rasi registered more or less identical scores ranging from 3 to 4 at the booting stage and no severe symptom could be noticed upto fourth week after transplantation. However, the growth was retarded in later periods, but still maintaining lower scores.

Varieties Kochuvithu and Keerthy performed satisfactorily without any toxicity symptom upto the 6th week after transplantation. However, at latest stages, tiny brown spots could be noticed on the lower leaves of Kochuvithu and Keerthy registering reasonably lower scores of 2.6 and 3.0 respectively.

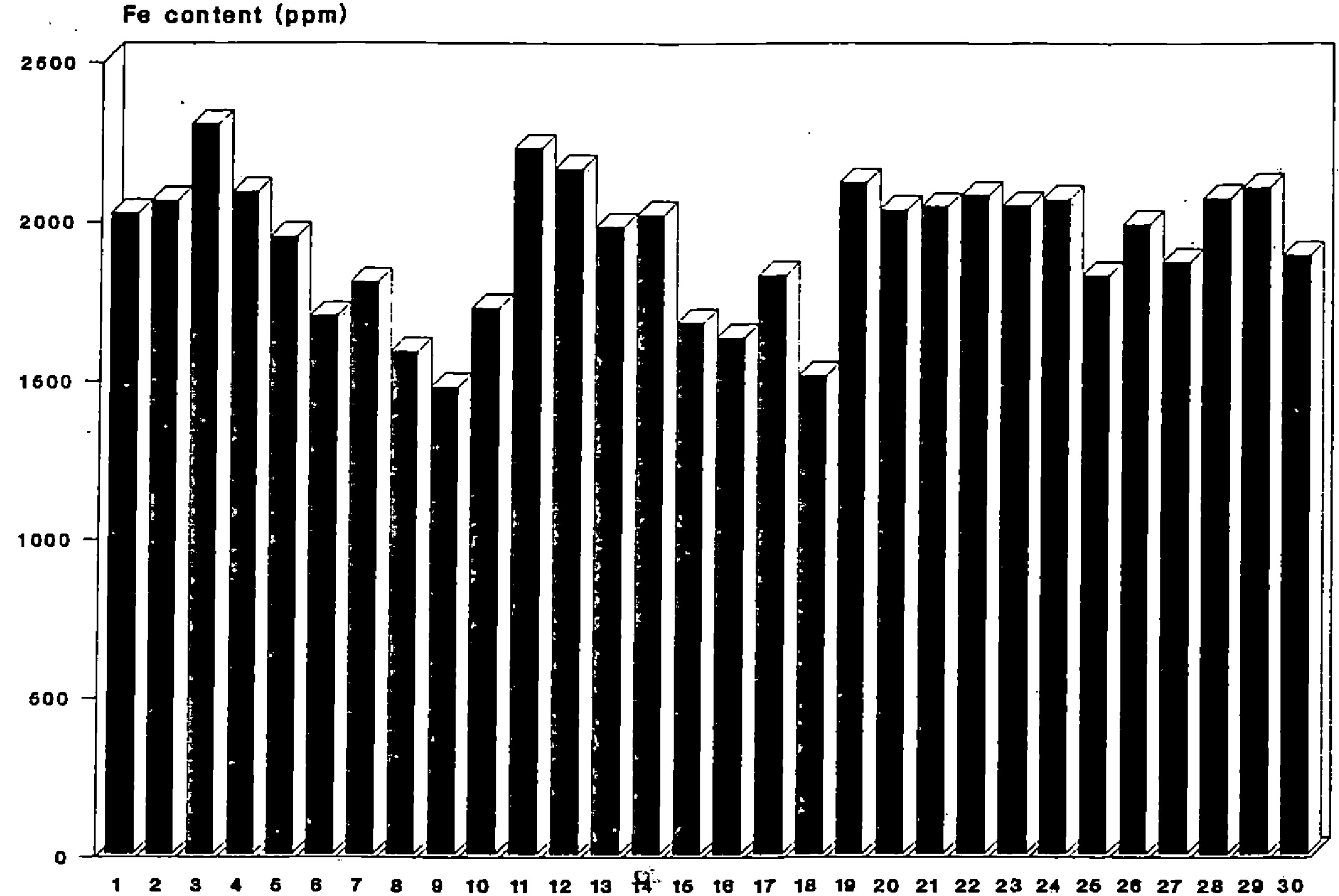
Varieties H_4, Mahsuri and Cherady performed satisfactorily right from the beginning. No noticeable iron toxicity symptom could be noticed and the growth of the crop was normal throughout the period. The score recorded was below 3 in these varieties at all stages of growth. Virmani (1976) reported from the results of screening trials on rice varieties that the rate of development of toxicity symptoms depended upon the level of tolerance of the cultivar.

Plant iron content

Data on the iron content of rice varieties furnished in Table 2. indicated that varieties with most severe iron toxicity symptoms and higher scores had the highest plant iron content and vice verse.

The performance of the three varieties viz., Asha, Jaya and Jyothi were far from satisfactory even from the early stages of transplantation or even prior to transplantation. Apart from exhibiting typical symptoms of iron—toxicity with higher score numbers, the variety Asha registered the highest plant iron content of 2297 ppm followed by Jaya with 2223 ppm and Jyothi with 2158 ppm. These high values are indicative of the highly susceptible

Fig. 2. Plant iron content in rice in solution culture



1 Annapoorna, 2 Aruna, 3 Asha, 4 Aswathy, 5 Bhadra, 6 Bhagya, 7 Bharathy, 8 Cheradi, 9 H4, 10 IR-36, 11 Jaya, 12 Jyothi, 13 Kanakom, 14 Karthika, 15 Keerthy, 16 Kochuvithu, 17 Makam, 18 Mashuri, 19 Neeraja, 20 Onam, 21 Ptb-2, 22 Ptb-10, 23 Ptb-20, 24 Pavizham, 25 Rasi, 26 Red Triveni, 27 Remya, 28 Sabari, 29 Santhosh, 30 White Triveni.

nature of the varieties. Hence in the present study the varieties Asha, Jaya, Jyothi were considered as highly susceptible.

In twelve varieties of rice viz., Annapoorna, Aruna, Aswathi, Karthika, Neeraja, Onam, Ptb-2, Ptb-10, Ptb-20, Pavizham, Sabari and Santhosh, the toxicity symptoms were not as severe as in the case of the varieties discussed earlier. However, the display of symptoms started early and persisted with the maintenance of higher scores, causing appreciable injury to the plant. The plant iron content in these varieties was also higher and ranged between 2013 ppm and 2114 ppm thereby again indicating the susceptible nature of the varieties towards iron toxicity. These varieties were thus considered as susceptible. Sahu (1968) reported a close relationship between the iron content and bronzing in rice. In all cultivars studied the toxicity symptoms as evaluated by score numbers were found to have a close relation with the plant iron content. Verma and Tripathi (1989) reported that bronzing is due to the absorption of excessive amounts of iron by the rice plant. Actually the phenotypic expression is confirmed by plant analysis.

Bhagya, IR-36, Bhadra, Bharathy, Kanakam, Makam, Remya,Rasi, White Triveni and Red Triveni had medium scores of 3-5 with reasonably lower plant iron content ranging between 1695 ppm and 1982 ppm and lesser intensity of visible symptoms compared to susceptible varieties explained earlier. The data indicated their capacity to resist iron toxicity to a reasonable extent. These ten varieties were therefore classified as moderately tolerant.

The varieties H_4, Mahsuri, Cherady, Kochuvithu and Keerthy scored the least iron toxicity symptoms. These varieties also recorded the lowest plant iron content ranging between 1471 ppm and 1674 ppm. In view of the lowest iron content and minimum display of toxicity symptoms, these five varieties were regarded as capable of resisting iron toxicity and hence evaluated as tolerant, particularly in light of the prescriptions contained in the IRTP Hand Book relating to classifications of varieties with scores 3 and below as tolerant.

Many species are able to grow well in highly iron toxic conditions without display of any symptoms of toxicity. Tolerance to iron by rice varieties may be a heritable trait. Studies on genetics of tolerance to iron toxicity carried out by Senaratne (1976) at Sri Lanka pointed to the complex nature of its inheritance.

Cherady and Kochuvithu are local traditional varieties of rice cultivated in central and southern Kerala with preference by farmers over the past several years. These two varieties have been adapted to local stresses and soil conditions. The field constraint of iron toxicity and its injurious effects on Cherady and Kochuvithu have never been reported by farmers as a cause for low yields. Virmani (1976) and Gunawardena (1979) observed that traditional farmer's lines generally developed larger root system under adverse soil stresses than the semi dwarf modern varieties. These features may provide the former with a more efficient nutrient extracting ability. Benckiser et al. (1984a) reported that in general, traditional varieties have adapted for centuries to local stresses and gained more tolerance for iron toxicity than modern high yielding lines. Results of comparative trials on these lines conducted by them revealed that in an iron toxic soil the traditional varieties developed considerably larger root system than susceptible varieties. The capacity of traditional varieties to extract P, K, Zn and other nutrients in a relatively efficient way is an important heritable ploygenic feature that should be crossed into modern lines with high yielding potential (Ottow et al. 1982).

H_4 and Mahsuri have been recognised as tolerant varieties from research done elsewhere also. Gunawardena (1975) during his screening work for iron toxicity at Sri Lanka, identified H_4 as a tolerant one. Similar work conducted at IRRI during 1977, 1978 and 1979 confirmed the tolerant nature of Mahsuri. Patra and Mohanty (1981) in a solution culture study on Jaya and Mahsuri with graded levels of K, Fe and Mn found that increased plant iron content and yield reduction were more pronounced in susceptible variety Jaya whereas not much difference was recorded by Mahsuri.

The variety Keerthy evolved at RARS, Pattambi, Kerala is a cross between IR-2061 and White Triveni. In the present study the variety White Triveni has been rated as moderately tolerant. This heritable character of White Triveni might be responsible for the tolerance to iron toxicity shown by Keerthy.

Literature reveals that the root oxidation capacity of the rice roots play a dominant role in the mechanism of iron absorption by rice. Reports from IRRI (IRPS, 1982) indicated that the efficiency of Fe^{2+} oxidising mechanism of roots (iron excluding power) of different rice varieties prevents entry of excessive reduced and mobile Fe^{2+} into free space and cytoplasm.

Bartlett (1961) noted that oxidised iron deposits were common on the roots of hydrophytes and showed that root oxidising activity was specifically correlated with the ability to tolerate waterlogged soil. Armstrong (1964) showed heavy iron deposits on plant roots together with evidence of penetration into the outer cortex and immobilisation by precipitation on cortical cell surfaces. Excessive iron oxide/hydroxide deposits of this sort usually formed around roots are termed "micropedotubules" by soil scientists (Brewer, 1964). Several workers have demonstrated oxygen diffusion from above ground atmosphere through cortical and other intercellular spaces and reaching the root epidermis and soil sink, which serves to protect the plant from accumulation of toxic iron both by radial oxygen loss to the rhizosphere and also by oxidation in the tissues external to the stele (Amstrong, 1964). Trolldenier (1981) observed that rice differs from many other plants in sofar as its roots are largely dependent of environmental oxygen. Rice roots obtain O_2 by intercellular air channels from shoots and surface roots O_2 may even be excreted into the rhizosphere as indicated by the brownish colour of the root surface. The excreted oxygen is utilised atleast in part by the rhizosphere organisms. In a densely populated rhizosphere, oxygen demand exceeds the supply, thus causing anaerobiosis even on the surface. As a consequence, excessive uptake of iron is not prevented by oxidation. Green and Etherington (1977) from the studies using advanced techniques have revealed the actual sites of iron deposition on roots, the outer cortex of cell walls and intercellular spaces. Root tips were, however, reported as perfectly healthy and without iron deposition.

Another mechanism of root oxidation through a modified biochemical pathway of oxygen secretion from rice roots and the involvement H_2O_2 decomposing enzyme catalase and the presence of glycolic acid oxidase in the root of aquatic plants such as lowland rice have been cited by Mitsui et al. (1961).

It is probable that the rice varieties rated as tolerant in the present study might be associated with an efficient root oxidation mechanism by which the entry of Fe^{2+} into the plant is checked. Susceptible varieties were unable to resist higher iron concentration due to the weaker iron excluding power of their root system.

Influence of different levels of iron concentration on growth and yield of rice varieties identified as tolerant to iron toxicity

Iron toxicity to rice is manifested by leaf bronzing symptom and stunted growth. Several growth parameters and yield attributes are adversely affected by growing rice in iron toxic situations. Physiological disorders of the rice plant due to iron toxicity may result in considerable yield reduction as well.

Toxicity symptom

Data furnished in Table 3. showed that no appreciable toxicity symptom could be noticed in H_4, Mahsuri and Cherady upto 400 ppm Fe^{2+} level at AT stage. However, at 500 ppm and 600 ppm Fe^{2+} level, H_4 and Mahsuri were affected by slight oranging discolouration on lower leaves, which continued at the flowering stage with score of 3.6. At active tillering stage, visual symptoms in Keerthy started appearing even at 400 ppm iron level. Reddish brown spots on lower leaves became more clear at 500 ppm Fe^{2+} level and extended to more leaves at 600 ppm Fe^{2+}. Cherady and Kochuvithu were also affected at AT stage as well as at flowering stage in more or less the same manner but with lesser intensity as indicated by the intermediate scores. Treatment effect significantly differed from each other.

Tolerance to the presence of excess iron in the soil is probably due to the higher oxidising power and other physiological activities of the rice roots which help to keep iron in the soil in the oxidised (ferric) form. Roots of such plants are heavily coated with oxidised iron. Traditional tall local varieties such as Cherady and Kochuvithu and long duration varieties such as H_4 and Mahsuri which have taller stature have more extended root system with greater oxidation capacity. They posses the genetic capacity to tolerate iron. Rice plants may differ in their ability to effect an improvement in the oxidative situation in the rhizosphere. The poor oxidisers may take up most iron into their tops while efficient oxidisers tend to be iron excluders. Tadano (1975) reported that rice roots have three devices to escape from iron toxicity even if iron concentration in the growth media is high; as (1) to make the iron concentration in the growth media lower; (2) to intercept the iron which reaches the root surface from entering the root and (3) to intercept the iron which entered into the root from translocating to the shoot.

Plant height

From the data on plant height affected by the different levels of iron contained in Table 4(A), it is evident that the different treatment levels of iron have influenced the plant height. Significant decrease in plant height was observed with increasing levels of iron. The maximum reduction in plant height was observed at 600 ppm iron level. The varietal effect was also significant. Minimum percentage reduction of plant height was observed in H_4 followed by Mahsuri, Cherady and Kochuvithu, the maximum reduction being in Keerthy. When the varietal means of plant height were compared, H_4 recorded the highest and Keerthy the lowest. The effect of toxic levels of iron in decreasing the growth of a plant is a well established fact. The number of elongated internodes determine the height of plants and this number is affected by the variety and various environmental conditions especially mineral nutrition (Ishizhuka and Tanaka 1963). The high level of iron has a suppressive effect on the absorption of other nutrients like P, K, Ca and Mg (Ottow et al. 1981, Benckiser et al. 1984b). Virmani (1976) during his investigations on the breeding of rice for tolerance to iron toxicity in Sree Lanka has noticed that high level of iron in solution inhibited the formation of new roots and the nutrient absorption capacity of the existing roots was reduced by iron oxide coating. Potassium has a major role in stomatal opening and regulating the entry of CO_2 and thereby effective photosynthesis is achieved (Tisdale et al. 1990). The deficiency of this element leads to dramatic changes in the metabolism of the plant, low synthesis of compounds and ultimate reduction in growth. This growth reduction is exhibited through reduction in plant height, tiller count etc.

Tiller count

The data on the tiller count in rice (Table 4(B)) revealed that high levels of iron had a decreasing effect of tiller count and the effect was significant. The reduction was maximum at 600 ppm iron level. The varietal effect was also significant. The percentage reduction in tiller count was minimum in Kochuvithu, followed by H_4, the maximum being in Keerthy. When the varietal means of tiller count were compared, Kochuvithu recorded the highest and Keerthy the lowest. Sekiya (1963) reported that tillering is closely associated with nutritional conditions of the mother culm because tiller receives carbohydrates and nutrients from the mother culm and phosphorus deficiency adversely affects development of tillering as it is an energy requiring process. In the present study also, the poor phosphorus absorption by rice under the conditions of high iron has been noticed. The absorption of other nutrients like K, Ca and Mg has also been adversely affected. The deficiencies of these elements might have caused nutrient imbalance and disturbed the normal metabolism, thereby leading to reduction in the number of tillers. At the highest level of iron, the maximum tiller count was observed in Kochuvithu. The variety Keerthy which recorded the lowest tiller count was found to contain the lowest plant contents of P, K, Ca and Mg as revealed by plant analysis.

The decrease in plant height and tiller count under the influence of toxic concentrations of iron can be supported by the findings of several workers (Ponnamperuma et al. (1955), IRRI (1964) and Patnaik and Bhadrachalam (1965)). Similar results have been reported by Abraham and Pandey (1989).

Productive tillers

The data on the productive tillers at different levels of iron presented in Table 5 (A), showed that the influence of increased iron levels and varieties on productive tiller count were significant. All iron levels suppressed the productive tillers. With increase in the levels, the number of productive tillers registered a progressive decrease with maximum decrease at 600 ppm. Among the varieties tested, Kochuvithu registered maximum productive tiller count, followed by H4. The minimum number of productive tiller could be observed in Keerthy. However, in terms of percentage reduction of productive tillers at 600 ppm iron level, lowest reduction could be noticed in H_4. The varieties Mahsuri and Cherady ranked second and third respectively. The percentage reduction in tiller count was highest in Keerthy. In these two expressions, Kochuvithu and H_4 stood first and Keerthy last while the other varieties varied in between. The variation in the observed data is due to the varietal effect which was also significant. As discussed earlier, high iron content will have adverse effect on the absorption of nutrients. Phosphorus has a major role in the formation of quality grain and emergence of ears (Hand book of Agriculture, 1992). A marked influence of K in the translocation of carbohydrates towards the panicle has been described by Russel (1973).

Grains per panicle

The data contained in Table 5(B) on grains per panicle also, showed that the influence of increased iron levels on grains per panicle was significant. The grains per panicle decreased with increasing levels of iron and the reduction was maximum at 600 ppm level. The lowest reduction percentage in grain yield was observed in Mahsuri followed by H_4. The highest percentage reduction could be noticed in Kochuvithu. The varietal effect was also significant. H_4 recorded the maximum mean grain number per panicle followed by Mahsuri and the minimum was observed in Keerthy. As in the case of productive tillers, here also the inherent quality of the variety has contributed towards the variation seen in the two expressions. The suppressive effect of high level of iron on the absorption of other nutrients resulted in reduction in grains per panicle. Kiuchi and Ishizuka (1960) revealed that potassium and magnesium contents of the plant have very effective role in determining the number of grains per panicle. A close relation between carbohydrate metabolism and phosphorus and effect of phosphorus on the translocation of starch in grain have been reported by Ishizuka and Tanaka (1963). High levels of iron affect yield attributing factors by its suppressive effect on the absorption of other nutrients which has been reflected in the reduction in productive tillers and or reduction in grains per panicle. Different works conducted by Park and Tanaka (1968) and at IRRI (1964) showed that high iron concentration in soil or solution culture could bring about reduction in productive tiller count and number of grains per panicle. Similar results have been reported by Virmani (1976) and Gunawardena et al. (1982).

Grain yield

From the data on grain yield (Table 6 (A)) it is seen that significant variation in grain yield could be obtained between the varieties and between the treatments. H_4 and Mahsuri recorded significantly higher grain yields. Comparison of varietal means showed that Kochuvithu and Keerthy had lower yields as compared to other varieties. Among the different levels of iron tried, the yield reduction in grain was maximum at the highest iron level of 600 ppm In terms of percentage reduction in grain yield over the control, resulting from the influence of highest iron level, Keerthy recorded maximum and H_4 recorded the minimum followed by Mahsuri. The much reduced grain yield in Keerthy must have occurred from the appreciable reduction noticed in the productive tiller count and grains per panicle as compared to other varieties. Similarly, the varieties H_4 and Mahsuri maintained significantly higher yield under the influence of all the levels of iron which is in agreement with the higher number of productive tillers and number of grains per panicle already noticed in these varieties. The decrease in grain yield due to high iron level may be attributed to the reduction in photosynthesis due to mineral deficiency and foliar bronzing.

Photosynthetic rate of diseased leaves (bronzed leaves) decreased to about three fourth of that of the normal leaves in spite of the increased respiration (Ota, 1968). Apart from the photosynthesis, the grain yield is a function of the number of productive tillers and grains per panicle as well (Fujiwara and Ohira, 1959). Murayam and Yoshino (1956) reported that yield components were affected by mineral deficiencies. The low grain yield may also be attributed to the possible nutrient imbalance or nutrient deficiencies under the toxic effect of higher concentrations of added iron. The varietal variation in grain yield may be due to the inherent yielding characters of the varieties (Epstein, 1972). The results showed that H_4, Mahsuri and Cherady have inherent ability to produce higher yields even under high iron toxic stress condition. The findings in the present study gets ample support from the observations in growth and grain yield recorded by several works viz., Park and Tanaka (1968) and Serayonakul (1972). Gunawardena et al. (1982) found that iron toxicity lead to yield losses. They attributed yield reduction to a decrease in productive tillers and panicle weight. Virmani (1976) from his breeding trial on iron toxicity tolerance to rice concluded that iron toxicity reduced the yield of all varieties but the extent of yield reduction differed. Tolerant varieties showed lower yield reduction than the susceptible varieties. This reduction was primarily due to reduced tillering and lower panicle weight.

Straw yield

The data given in Table 6(B) on the straw yield in rice as affected by the different iron levels showed significant differences between varieties and treatments. Highest straw yield was noticed in H_4 followed by Mahsuri. Comparison of straw yields indicated significantly lower values in Kochuvithu and Keerthy as compared to other varieties. Progressive reduction in straw yield with increased iron concentration could be noticed. Under the influence of 600 ppm iron level the straw yield reduction was maximum. At this level the percentage reduction in straw yield was lowest in Kochuvithu and highest in Keerthy. The inherent quality of tallness associated with varieties and the ability of these varieties to withstand iron toxic situations leading to reduced bronzing and leaf wilting have contributed towards the increased straw yield. High levels of iron, as discussed earlier has adverse effect on photosynthesis and other synthetic processes (Ismunadji, 1976) which can lead to reduction in growth and the growth characters which are reflected in the plant height, tiller number, grain and straw yields. The reduction in straw yield in rice at toxic levels of iron has been observed by Patra and Mohanty (1988). Venkatasubramanyam and Mehta (1974) reported significant reduction in dry matter production in rice by application of iron and they attributed the dry matter reduction to a decrease in tiller count. Similar findings have been reported by Ottow et al. (1982) and Fageria and Rabelo (1987).

Root weight

The data on the root weight of plants (Table 6 (C)) revealed that the different levels of iron significantly influenced the root weight. A progressive decrease in root weight could be noticed with increased levels of applied iron with maximum weight reduction at 600 ppm iron. The extent of reduction in root weight among the varieties at the highest iron level of 600 ppm was found to vary between 51 to 60 percent. Among the varieties Mahsuri registered the minimum root mortality percentage and this was closely followed by H_4. The variety Keerthy recorded the lowest root weight indicating maximum damage to root. The mean values of root weight revealed that the varietal effect was significant. When the varietal means were compared, the maximum mean value was noticed in H_4 followed by Mahsuri and the lowest in Keerthy and Kochuvithu. The effect of interaction (variety x treatment) was, however, not significant. The effect of high iron levels on the restricted root growth has been reported by many workers. Deficiency of essential elements like phosphorus which is needed for the development of root can lead to stunted growth of root system (Hand book of Agriculture, 1992). Murayam and Yoshino (1956) reported that potassium deficiency decreases the metabolic activity of roots and may invite root rot. Scanty and decayed roots in rice plant suffered from iron toxicity was reported by Ottow et al. (1982), Ota (1968) and Patra and Mohanty (1988). Fageria and Rabelo (1987) has reported that the root and shoot dry weight were most sensitive to excess iron. Iron toxic plants usually display a grey, grey brown or brown black root system that is stunted in growth, scanty and coarse. Detailed microscopic root observations reveal damaged and partly dissolved coatings. Older roots of the central part are mostly decayed and black. These morphological changes may be ascribed to the collapse of the iron oxidising and excluding mechanism in the rhizosphere. The determining factor of the activity of the rhizoflora is the permeability of the root membrance that regulates both influx and efflux (amount of organic exudates) (Rovira, 1969). The comparatively higher root weight noticed in H_4, Mahsuri and Cherady will be helpful to these varieties in extracting more nutrient from the medium and thereby resisting the stress condition to some extent. Tolerance to iron toxicity is attributed to large root system and higher extracting capacity of varieties by Gunawardena et al. (1982).

Several scientists viz., Takijima and Gunawardena, (1969) and Ottow et al. (1981) suggested that iron toxicity can be regarded as an indirect physiological disorder induced by low level of P, K and Ca rather than by a direct excessive uptake of high amount of mobile iron. The most suitable variety for an area is best selected based on the ability of that variety to give high yield under the climatic and soil conditions prevailing in that area. In the present study, the varieties H_4 and Mahsuri maintained higher yields under all levels of iron followed by Cherady. In Kochuvithu and Keerthy, yield was low compared to others.

These five varieties viz., H_4, Mahsuri, Cherady, Kochuvithu and Keerthy were identified as tolerant, based on the lower score numbers recorded during the preliminary screening trials (Experiment I) and applying the IRTP prescription for tolerant varieties with scores 3 and less than 3. These varieties though found tolerant have given significant yield reduction under the toxic influence of 500 ppm iron. However, the comparative yield reduction in the five varieties revealed the superiority of H_4 and Mahsuri.

Content and uptake of nutrients in rice

Nitrogen

From the data furnished in Table 7 and 8 and illustrated in Figs. 3 and 4, it could be seen that increasing levels of iron in the culture solution resulted in significant increase in the nitrogen content of grain, straw and root. In grain and straw, the varieties H_4 and Mahsuri recorded lower contents of nitrogen while Keerthy and Kochuvithu had higher values. In the case of roots, varieties Keerthy and Kochuvithu had relatively lower contents of nitrogen as compared to H_4, Mahsuri and Cherady. The uptake of nitrogen was

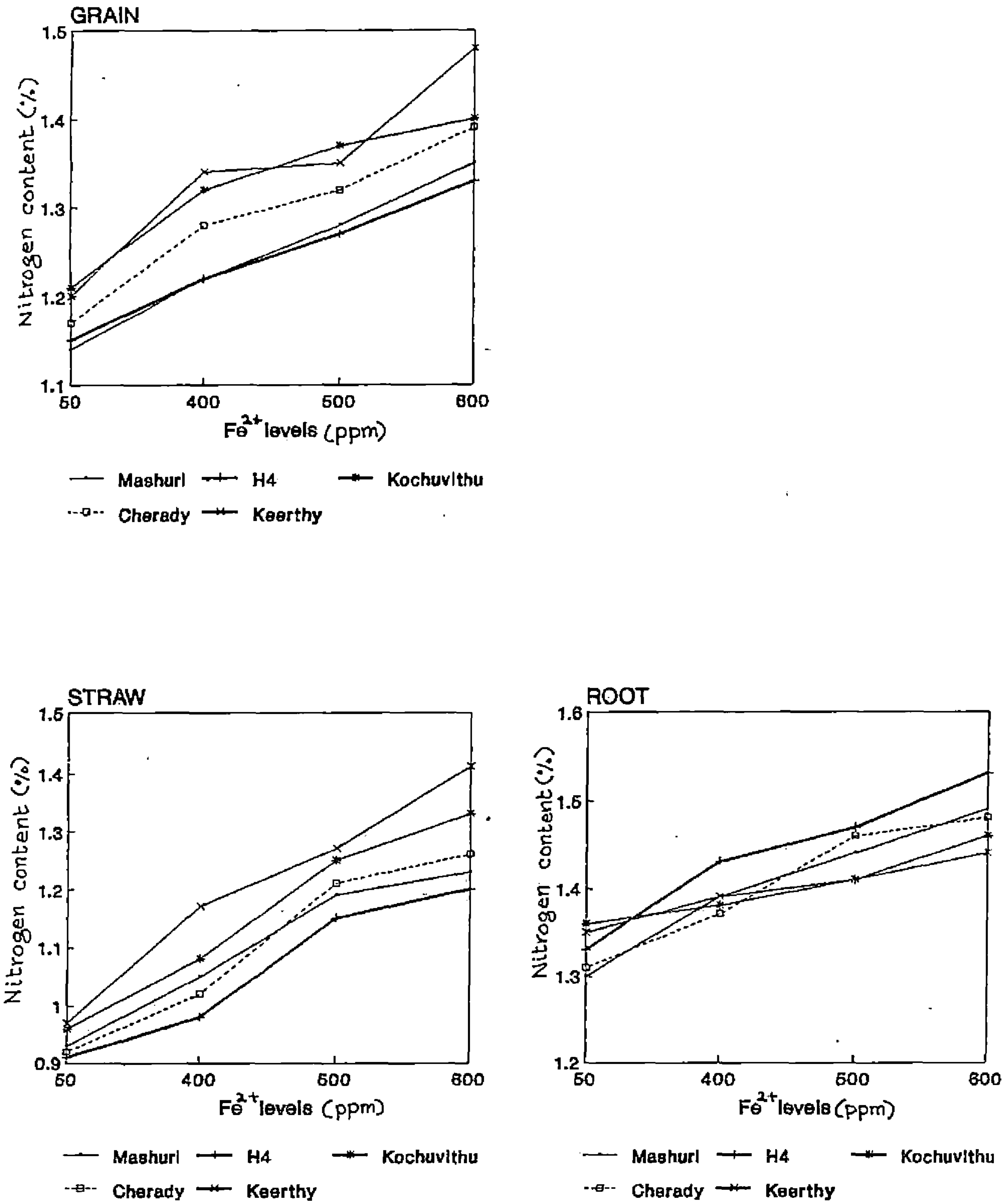


Fig. 3. Nitrogen content of the rice varieties as influenced by toxic levels of iron

seen decreasing with increasing levels of iron in grain, straw and root in all the varieties. Varieties H_4 and Mahsuri recorded higher uptake values for nitrogen as compared to other varieties, while relatively lower mean values of uptake could be observed in Keerthy and Kochuvithu. The higher uptake of nitrogen in all the plant parts despite lower nitrogen contents is attributed to increased dry matter production.

Usually the absorbed nitrogen is rapidly synthesised to protein, but a deficiency of phosphorus, potassium and other elements results in an increase in the content of non-protein nitrogen and a decrease of protein nitrogen (Fugiwara and Ohira,1959). The increased plant nitrogen content recorded during the advanced growth stages under the influence of toxic levels of iron, can also be attributed to the lower dry matter production as is evident in Table 6. High levels of iron had a suppressing effect on the absorption of these elements which leads to high non-protein nitrogen. In H_4 and Mahsuri, the nitrogen content in grain and straw was comparatively low compared to other varieties which showed their tolerant nature. The higher uptake values for N in the grain, straw and roots of H_4, Mahsuri and Cherady as compared to others can be attributed to the difference in the dry matter production. The findings of the study are in conformity with the results obtained by Ota and Yamada (1962) who found that plants growing in sandy soils

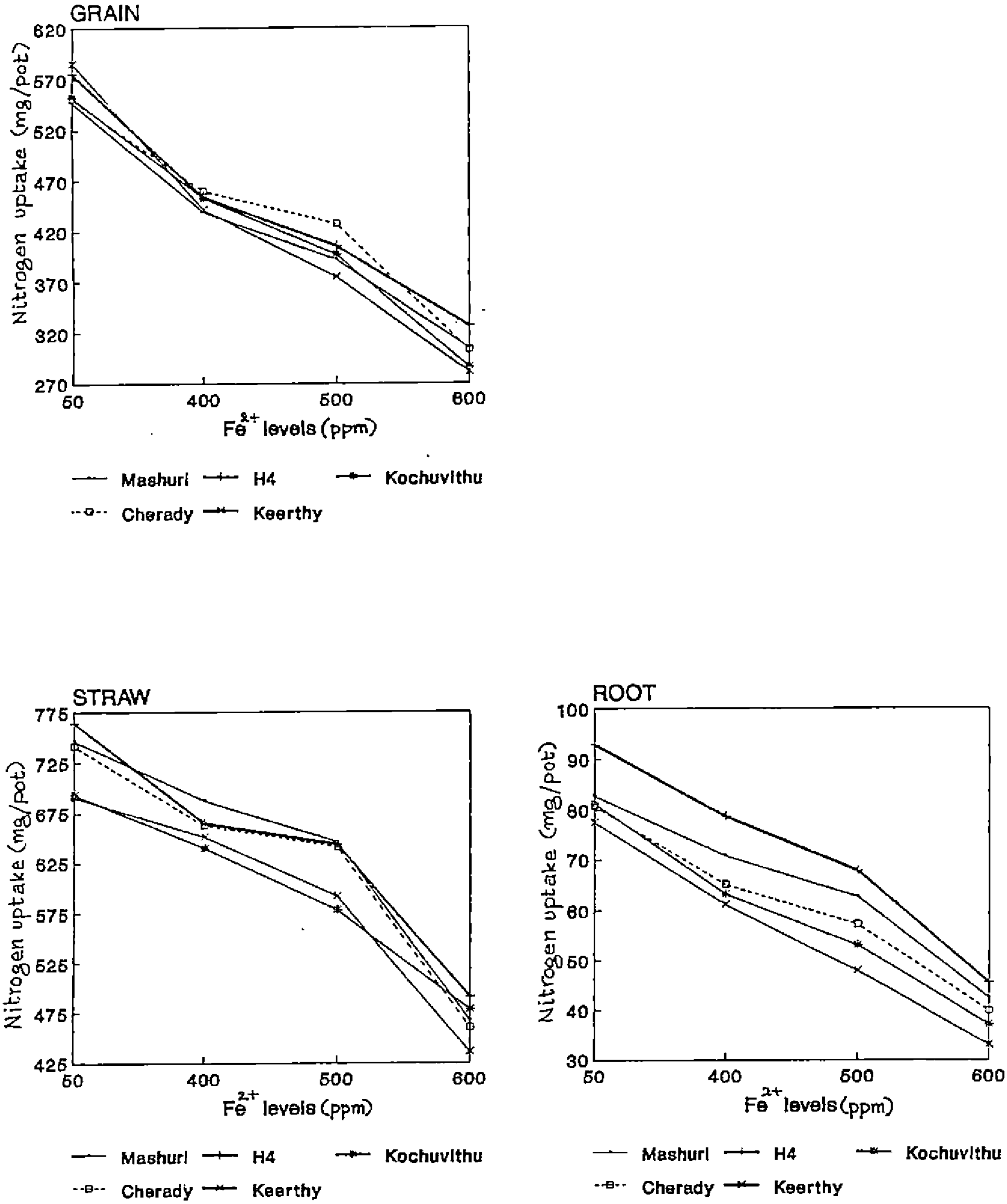


Fig. 4. Nitrogen uptake of the rice varieties as influenced by graded levels of iron

with moderate free iron contents and severe bronzing symptoms contained higher nitrogen when compared to the healthy plants. Inada (1965) also observed that the bronzed plants had higher nitrogen contents than the healthy plants. The relatively higher nitrogen content of rice when grown in high iron soil than that of unaffected plants has also been observed by IRRI (1966), Sahu (1968) Takijima and Gunawardena (1969), Takijima and Kanaganayagom (1970) and Benckiser et al. (1982).

Ota (1968) reported that the content of nitrogen was higher at higher grades of bronzing in rice plant. Protein synthesis was inhibited in the bronzed plants, the ratio of soluble nitrogen to total nitrogen was higher. Ismunadji (1976) reported that as a result of deficient metabolic processes in monocotyledons resulting from insufficient supply of K, P and Ca, an accumulation of low molecular weight carbohydrates (sugar) and soluble nitrogen compounds (amino acids, amides) occurs at the expense of higher molecular weight moieties, because several synthetic processes are delayed by the lack of these essential elements particularly potassium.

Phosphorus

The content of phosphorus and its uptake by grain, straw and roots as affected by toxic levels of iron are presented in Table 9 and 10 and illustrated in Figs. 5 and 6. In the present study

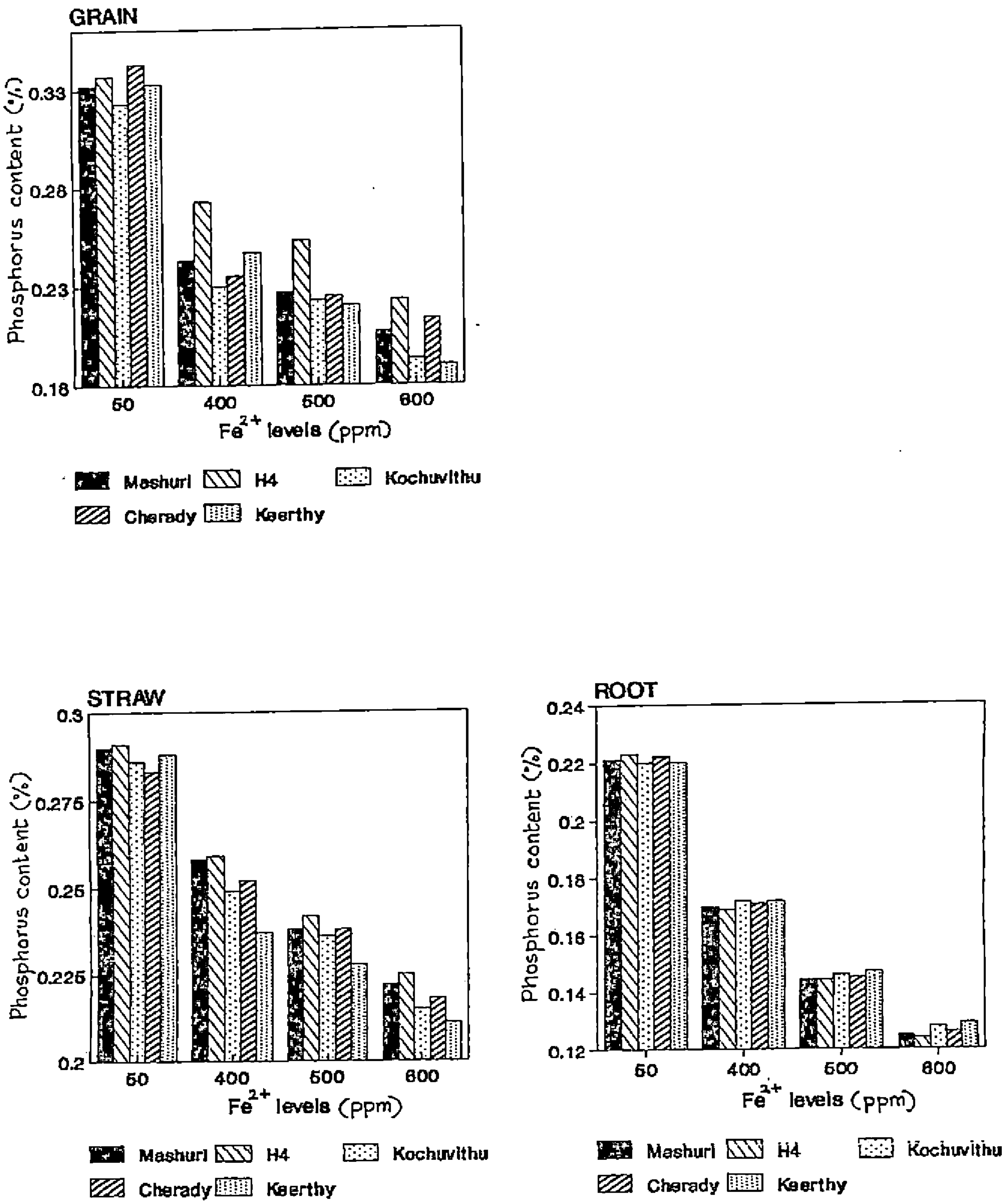


Fig. 5. Phosphorus content of the rice varieties under the influence of toxic levels of iron

increasing levels of iron in the culture solution were found to lower the phosphorus contents of grain, straw and roots which were significant. In all the varieties the highest contents of phosphorus as well as its uptake by rice were noticed in the control treatment, which however gradually declined with increase in the iron level and registered lowest content at the highest iron level of 600 ppm. The varietal effect was significant. Among the varieties, H_4 and Mahsuri recorded higher mean content of phosphorus in grain and straw compared to other varieties. Similarly P uptake was also higher in H_4, Mahsuri and Cherady compared to Keerthy and Kochuvithu.

Low content of phosphorus in bronzed plants tissue has been reported by several workers (Baba and Tajima, 1960; Takijima and Gunawardena, 1969; Tanaka and Yoshida, 1970; Tanaka and Tadano, 1972; Ottow et al. 1983; Benckiser et al. 1984a). Howeler (1973) noticed that bronzing was associated with excess absorption of iron and deficiency of phosphorus. Sakal and Sinha (1983) also reported low uptake of P in all parts of rice plant when iron concentration was very high.

It is generally accepted that in soils with high iron content, the iron can form insoluble precipitates of iron phosphate that is unavailable to the plant. At near neutral p^H, the phosphate

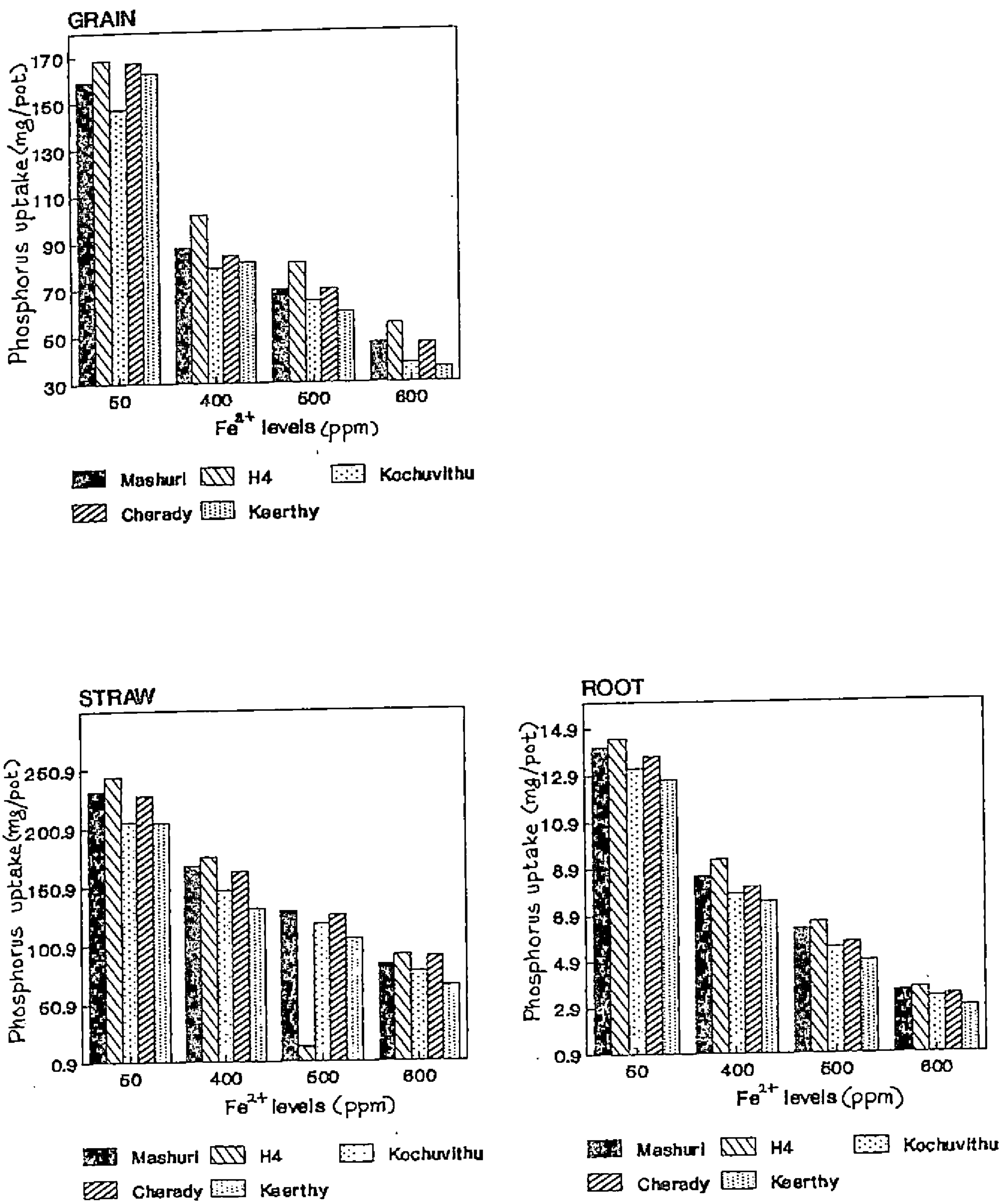


Fig. 6. Phosphorus uptake of the rice varieties as influenced by toxic levels of iron

combines with iron and the complex phosphate is precipitated on the absorbing surface of roots which impedes the entrance of phosphorus, resulting in phosphorus deficiency(Somers and Shive, 1942). As the content of iron increases the deficiency also increases. Earlier work by Ota and Yamada (1962) has revealed that when much iron is absorbed by plants; the iron combines with phosphorus and translocation of phosphorus is inhibited. In the present study also the application of iron has suppressed the phosphorus content of the plant. This may be due to the formation of ferric phosphate or hydroxy phosphate and restricted mobility of phosphorus. Antagonistic relationship between iron and phosphorus has been reported by Watanabe et al. (1965). Scherer and Hofner (1981) reported that increasing rates of iron application decreased the P content of plant showing Fe-P antagonism. Tadano (1975) observed that rice plants deficient in P are more susceptible to iron toxicity than the normal plants.

A diminished supply of P or K would result in breakdown of Fe(II) excluding mechanism in root zone and reduction of tissue tolerance to iron. A liberal supply of P results in exudation of relatively small amounts of organic compounds in the rhizosphere and maintenance of Fe (II) excluding mechanism (oxidation of iron through release of oxygen) at the surface of roots (Ottow et. al., 1983).

In the varieties Kochuvithu and Keerthy low uptake of P has been noticed under iron toxic situation and these varieties have given higher scores for the iron toxicity symptoms in plant. In H_4, Mashuri and Cherady the uptake of P was significantly higher than in the other varieties, which justifies the tolerant nature of these varieties.

Potassium

Potassium content and uptake in grain, straw and root of the rice varieties as influenced by toxic levels of iron are presented in Table 11 and 12 and illustrated in Fig.7 and 8. The data indicated a significantly decreasing trend in the content and uptake of potassium with increasing toxicity levels of iron in the culture solution. In all varieties the highest content and uptake were observed in the control treatment and the lowest values at 600 ppm iron. Among the varieties, significant difference could be noticed. Variety H_4 recorded the highest content of potassium in grain and straw at all levels of iron and this was followed by Mahsuri and Cherady in the decreasing order. Keerthy recorded the lowest content. The highest K uptake could be recorded in H_4 and Mahsuri and the lowest in Keerthy followed by Kochuvithu.

The influence of excessive iron supply in suppressing the K content and its uptake by rice has been observed by several workers. It is well known that the element potassium performs its

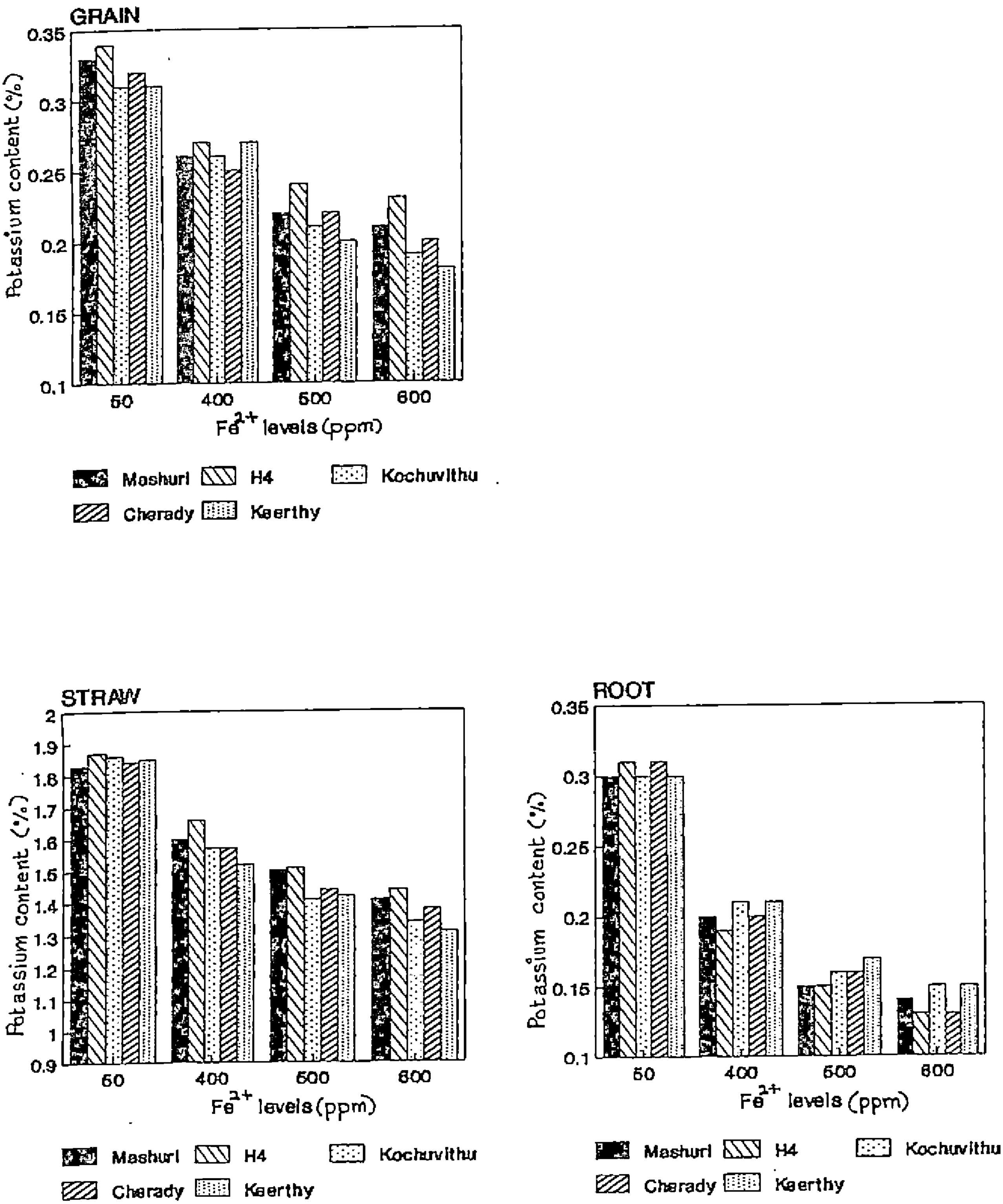


Fig. 7. Potassium content of the rice varieties as influenced by toxic levels of iron

major function of disease resistance and reduction in the physiological disorders in rice. Potassium can also influence the absorption of other nutrients. The deficiency of this element in the plant resulting from the reduced absorption by the root can lead to reduced absorption of other nutrients as well. In such situations, the nutrient imbalance caused in the plant can lead to suppressed activity of specific enzymes and a disturbance in metabolism followed by physiological disorder such as bronzing. Rediske and Biddulph (1953) has observed that the deficiency of potassium in the tissues probably retards protein synthesis while the clogging of vascular tissues by deposits of iron oxide probably interferes with translocation. These two factors may continue to produce necrosis of older leaves. The deficiency of potassium within the plant may be the result of root damage by the oxidation and deposition of iron and manganese oxides on the root surface and in the root cells. Yoshida (1971) reported that since there is physiological interaction between K and Fe, a low K content in the soil tends to aggravate iron toxicity. Exposure of plants to high iron would result in reduction of K content and this nutritional imbalance might have impaired the oxidising power of roots leading to susceptibility of plants to iron toxicity (Tanaka and Navasero, 1966). Yoshida (1971) concluded that high concentration of iron in the growth medium reduced the uptake of nutrients particularly K by plant due to reduction in absorbing power of roots. Roots of K deficient plant were unable to oxidise Fe^{2+} and excess Fe^{2+} would enter the plant.

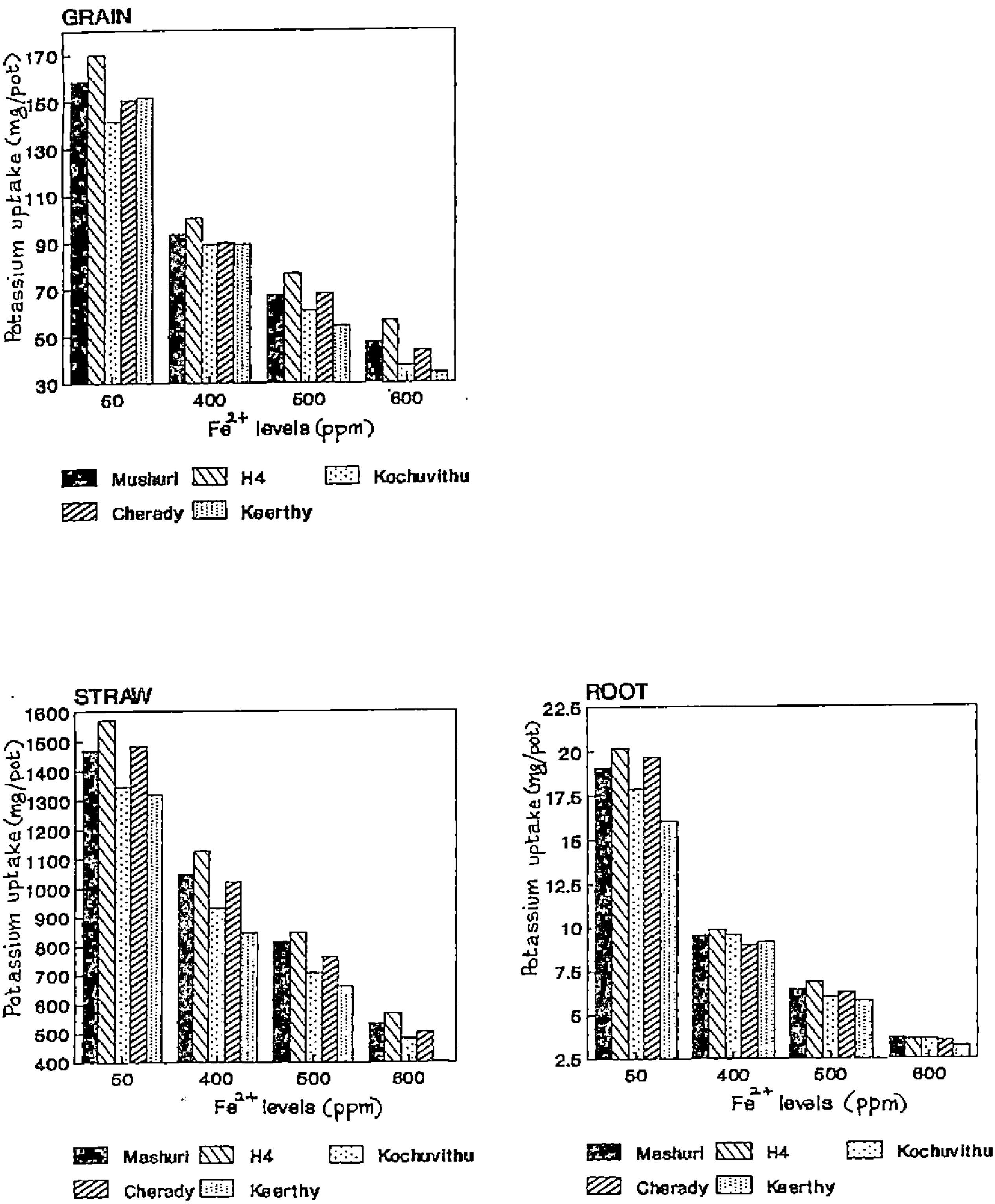


Fig. 8. Potassium uptake of the rice varieties as influenced by toxic levels of iron

Shibuya and Torri (1935) reported antagonism between potassium and iron and that the application of K reduced the injurious effect of iron. Baba and Tajima (1960) observed that uptake of excessive Fe^{2+} inhibitied the nutrient absorption of K in bronzed plants. Inada (1965) observed that by excessive ferrous iron uptake, the physiological activity of roots is impaired and absorption of other nutrients reduced. Low content of potassium in bronzed plants mainly due to the inhibition in the K absorbing ability of the roots, was reported by Ota (1968) and Tadano (1970). Similar results were revealed from the works of Sahu (1968), Tadano(1975) Trolldinier (1981), Ottow et al. (1982) Mohanty and Panda (1982), Benckiser et al. (1984a) and Patra and Mohanty (1988).

The better performance of H_4, Mahsuri and Cherady may be attributed to their relatively higher content and uptake of K which might lead to increased nutrient absorbing ability and root oxidation. More root development could also be noticed in these varieties compared to Keerthy and Kochuvithu. Trolldinier (1981) reported that the root oxidising power was highest with balanced nutrition and lowest when K content was low.

Calcium

The data presented in Table 13 and 14 and in Fig. 9 and 10 indicated that calcium content and uptake in all varieties got reduced

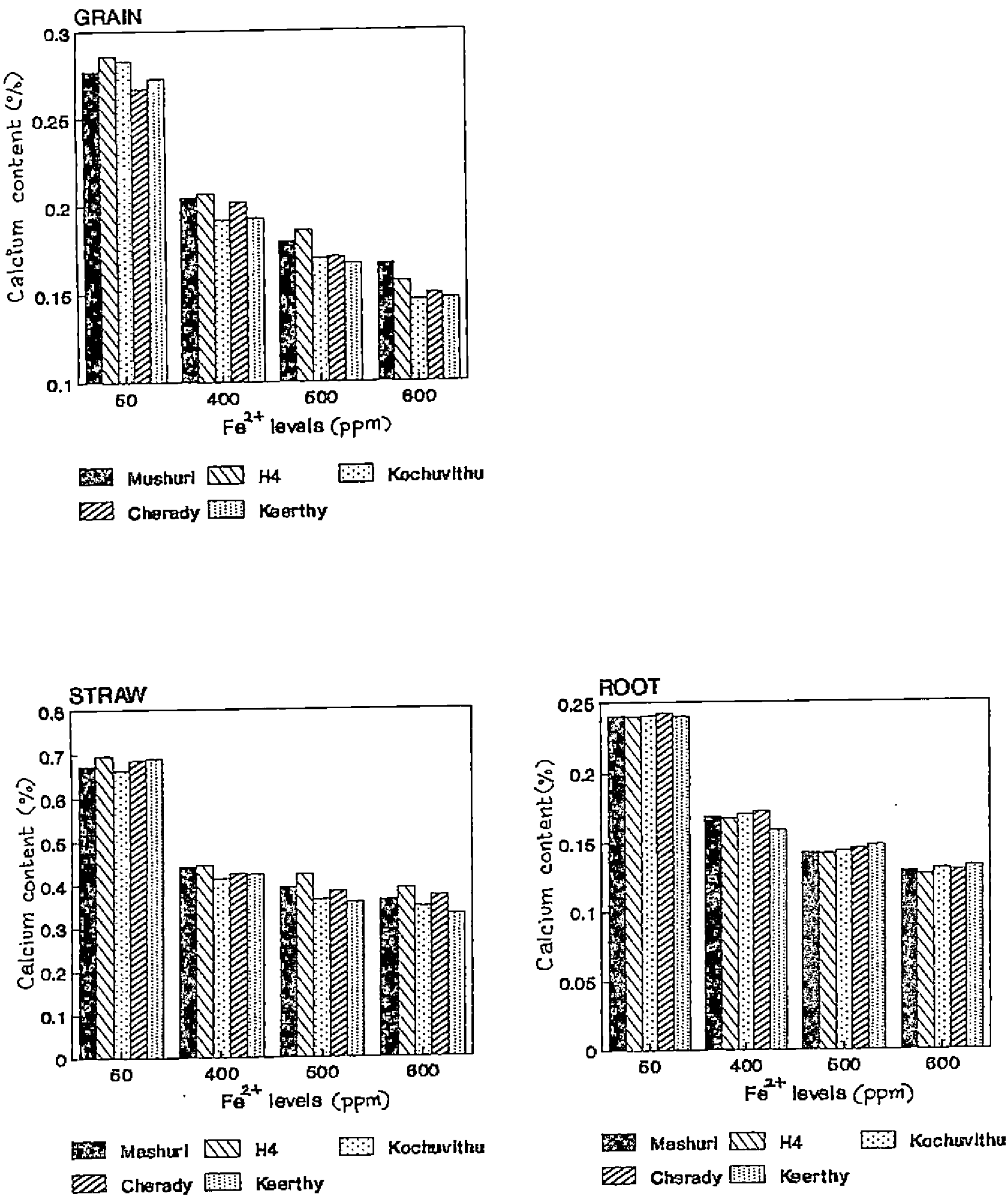


Fig. 9. Calcium content of the rice plant as influenced by toxic levels of iron supplied

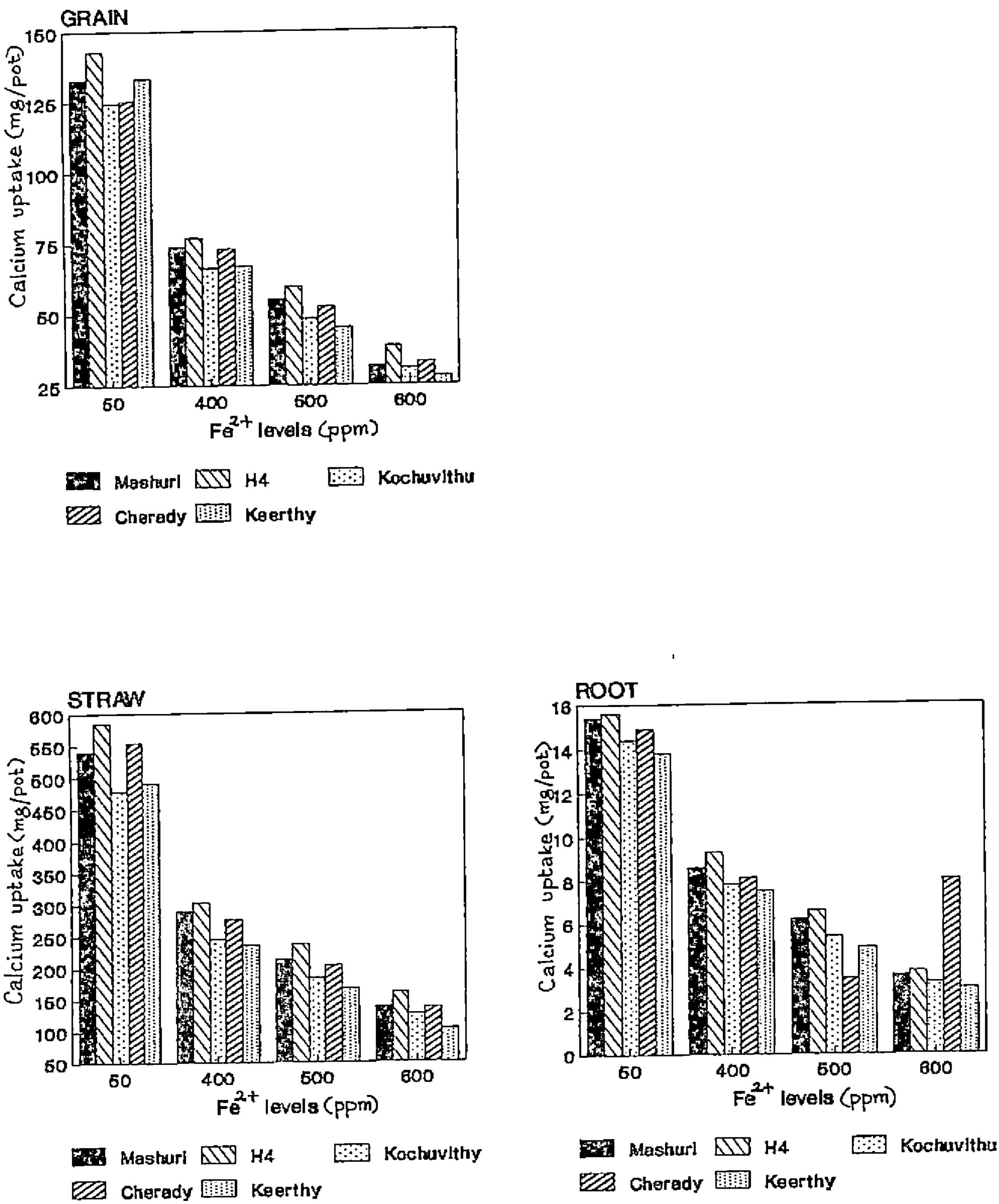


Fig. 10. Calcium uptake of the rice varieties as influenced by toxic levels of iron

significantly with increasing levels of iron. These values were highest in control and lowest at 600ppm iron treatment. The varietal effect was also significant. H_4, Mahsuri and Cherady recorded relatively higher content of calcium in grain and straw. However, Keerthy registered the highest content of calcium in roots. The mean uptake of calcium was also maximum in H_4 followed by Mahsuri and Cherady and the lowest in Keerthy followed by Kochuvithu.

Baba and Tajima (1960) observed that the excessive supply of iron inhibited the absorption of calcium and as a consequence the yield decreased considerably. Tadano (1970) observed that translocation of iron is accelerated significantly in calcium deficient plant. The decrease in calcium content and uptake due to presence of high iron content was observed by other workers as well (Ota and Yamada, 1962; Howeler 1973; Venkatasubramanyam and Mehta 1974; Benckiser et al. 1984a; Ottow et al. 1983 and Moore and Patrick 1989). The above workers have indicated that calcium might play an important role in iron toxicity to rice since the former has a major role in root permeability. The antogonistic effect of calcium and iron can lead to the above situation. Higher content of calcium in H_4, Mahsuri and Cherady compared to others may be one reason for better tolerance of these varieties to iron toxicity. Ottow et al. (1983) reported that calcium is associated with permeability of root membrane. Insufficient supply of calcium increases the root permeability resulting in excess iron flux of Fe(II) with mass flow.

Magnesium

The data presented in Tables 15 and 16 and illustrated in Figs. 11 and 12 revealed that in all the varieties magnesium content and uptake in the tissue decreased with increasing levels of iron. The maximum magnesium content and uptake were recorded in the control and the minimum in the treatment of 600 ppm iron. The magnesium content was more in H_4, Mahsuri and Cherady and less in Keerthy and Kochuvithu in straw and grain. In roots magnesium content was more in Keerthy. In case of uptake, in grain, straw and root maximum uptake could be obtained in H_4 and Mahsuri. The low magnesium status in the plant might have suppressed the chlorophll synthesis leading to yellowing and ultimate bronzing of the leaves. The suppression of magnesium by high iron has been reported by many workers (Ota and Yamada, 1962; Inada, 1965; Takijima and Gunawardena, 1969; Tadano,1975; Benckiser et al. 1984a).

Takijima and Gunawardena (1969) observed that bronzed plants are characterised by low magnesium content in the tissue. Tadano(1975) noticed that translocation of iron from roots to the shoot is accelerated significantly in the magnesium deficient plant.

The low content of magnesium may be due to its low absorption by the toxic effect of iron. Benckiser et al. (1984b) reported that iron toxicity was a physiological disorder caused by multiple nutritional soil stress and the magnesium content of leaves of affected plants was lower than that of affected normal plants.

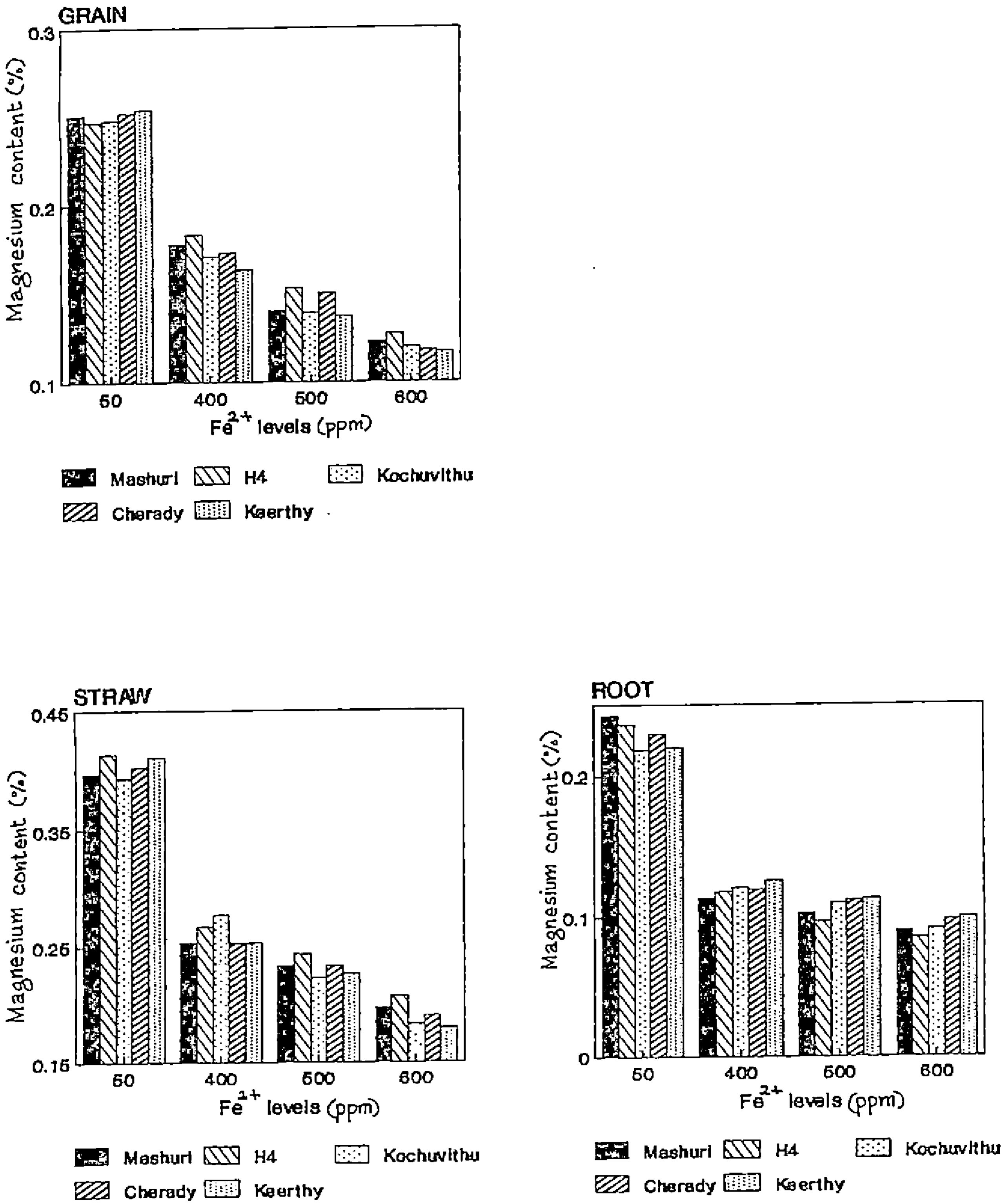


Fig. 11. Magnesium content of rice varieties as influenced by toxic levels of iron

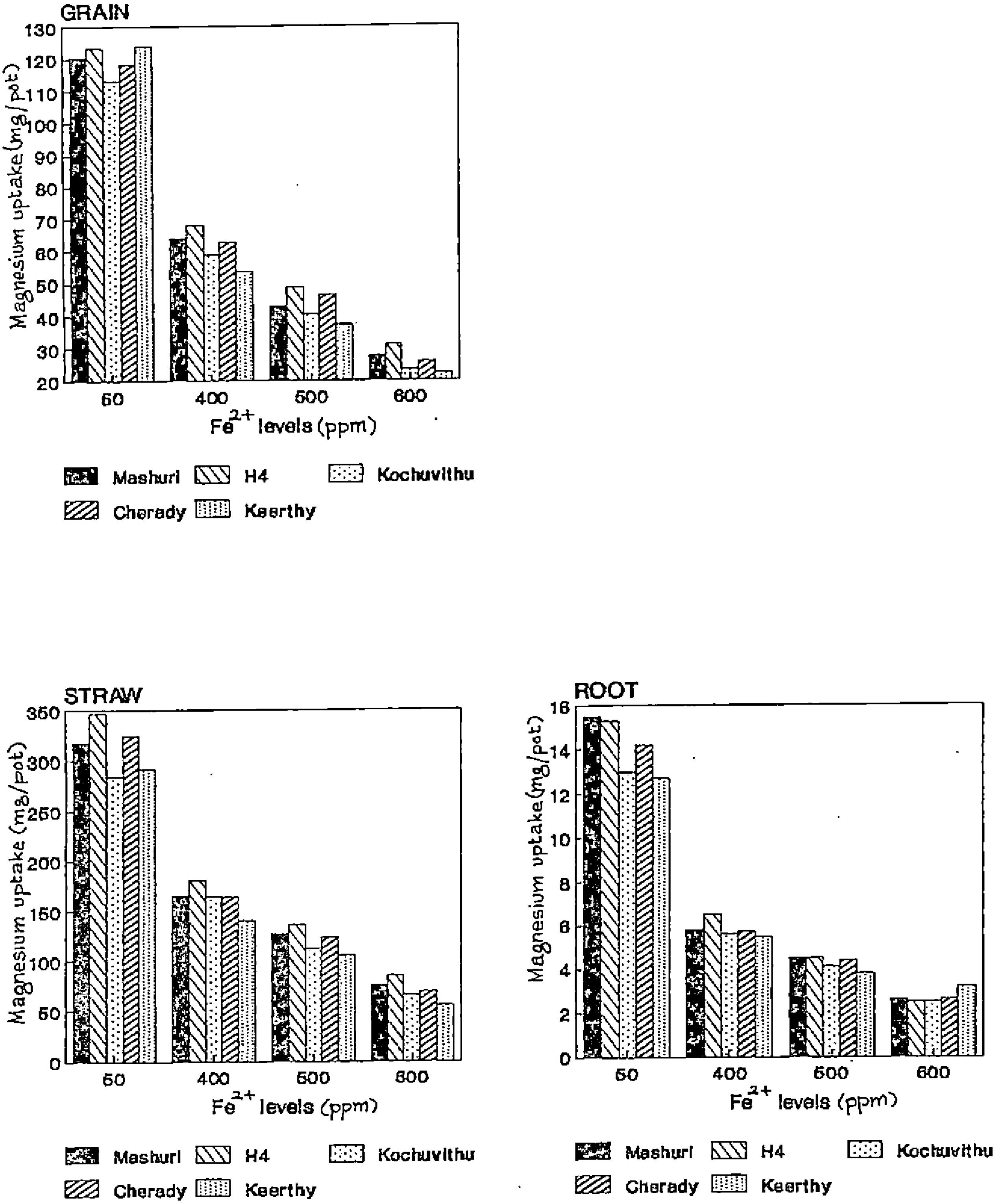


Fig. 12. Magnesium uptake of rice varieties as influenced by toxic levels of iron

Higher content and uptake of magnesium in tissue must have contributed to better iron tolerance by H_4, Mahsuri and Cherady. The uptake of magnesium in all the varieties got reduced due to lower dry matter production at higher levels. Yamanonchi et al. (1982) found that deficiency of magnesium in the tissue decreased the leaf tissue tolerance of rice to excess amounts of iron in solution.

Iron

Data furnished in tables 17 and 18 and illustrated in figs. 13 and 14 showed that in grain, straw and root the iron content increased significantly with increase in iron level in the growth medium. The grain and straw contents of iron in the variety Keerthy was the highest and this was followed by Kochuvithu. The lowest content of iron was noticed in H_4 followed by Mahsuri. However, in the case of root iron content, Keerthy recorded lowest and H_4 the highest. With regard to the uptake of iron, the values in all varieties progressively increased with increased iron level upto the 500 ppm. The reduced dry matter yield has contributed towards the reduced uptake of iron beyond 500 ppm level. Varietal comparison revealed that H_4, Mahsuri and Cherady had higher iron uptake presumably due to higher dry matter production in these varieties compared to others.

High iron concentration in growth medium has suppressing effect on the absorption of other nutrients. The deficiency of other

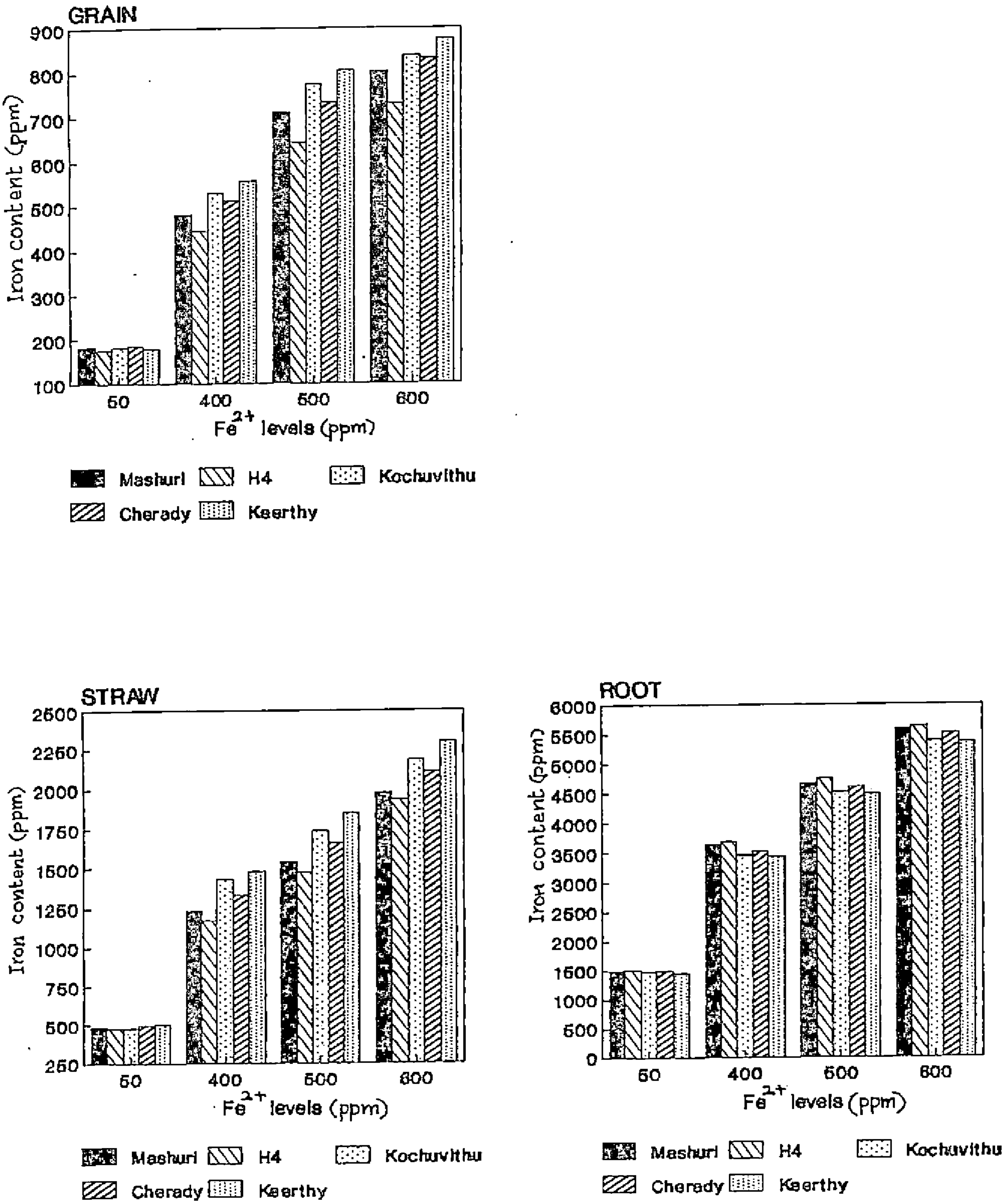


Fig. 13. Iron content of rice varieties as influenced by toxic levels of iron

elements especially potassium increases the root permeability and decreases the synthesis of macro molecules (Ismunadji,1976). Together with an increased membrance permeability the increased availability of low molecular weight compounds result in increased exudation by the roots into the rhizosphere. This results in Fe reduction in rhizosphere leading to drop in E^h finally causing low iron oxidising power and excluding power. Thus the low excluding power of the iron damaged roots had contributed to the excessive iron uptake in the plant.

The study revealed that increasing iron levels correspondingly increased the iron in the tissues of stem, root and grain of all varieties. Several workers observed that the bronzed plants contained higher amounts of iron. Park and Tanaka (1968) concluded that the cause of brown spotting in rice was iron toxicity which was due to high uptake of iron. Camargo (1984) reported that iron concentration of the leaves of all rice cultivars studied for tolerance to different levels of iron, increased when levels of iron increased in nutrient solution. Similar results were reported by Serayonakul (1968), Tanaka and Yoshida (1970), Tadano (1974) and Benckiser et al. (1984a).

Yamanonchi et al. (1982) noted clear varietal difference in the tolerance for iron toxicity, which was due to control of major

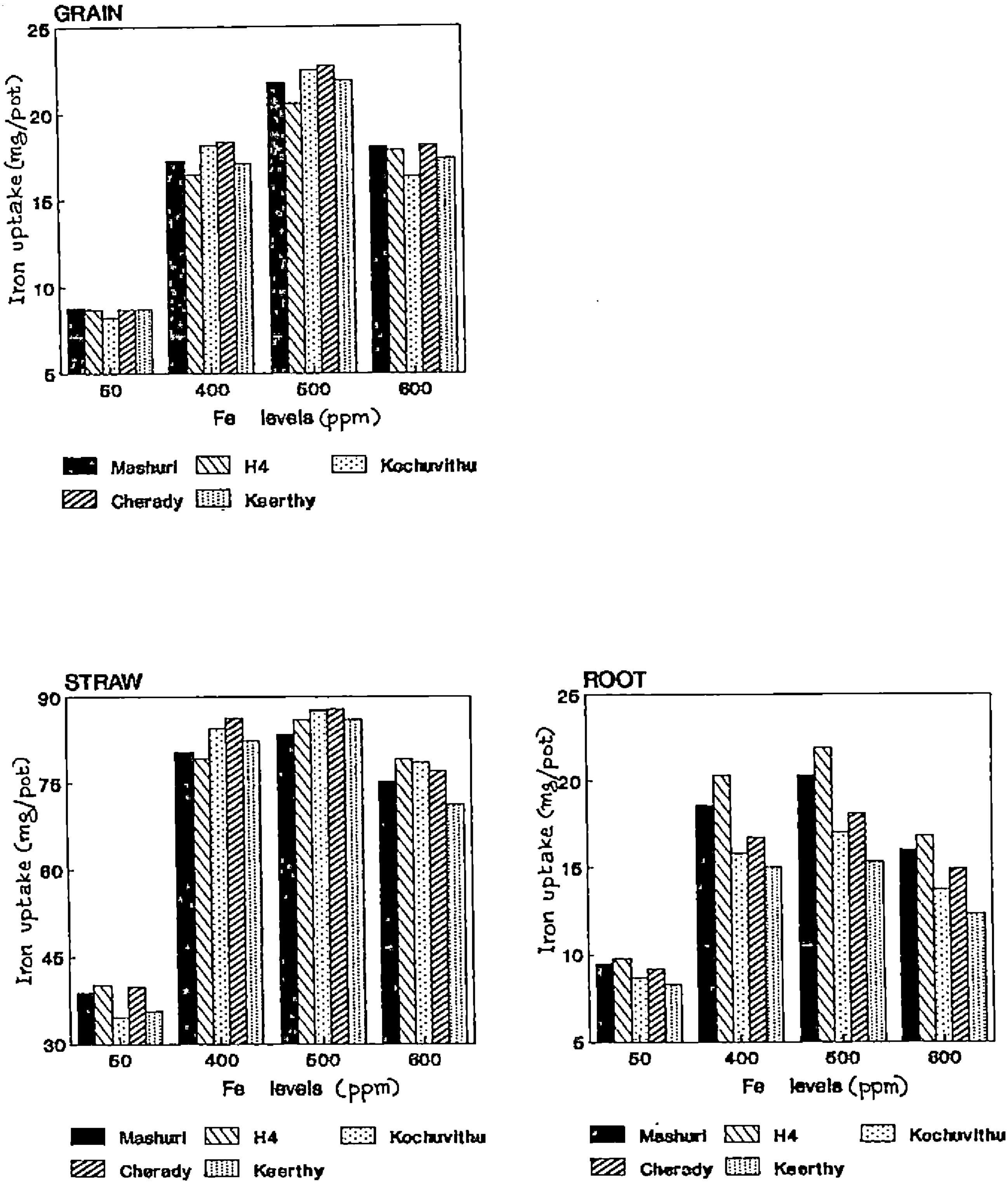


Fig. 14. Iron uptake of rice varieties as influenced by toxic levels of iron

gene. They also noted that the deficiencies of P,K,Ca and Mg in tissue considerably decreased the leaf tissue tolerance to iron toxicity. Better tolerance of H_4, Mahsuri and Cherady is evidenced by relatively high content of P,K,Ca and Mg also. Relatively low content of iron was recorded in grain and straw and high content in roots of these varieties. The result gets support from the findings of Mohanty and Panda(1982), Mohanty(1981) and Patra and Mohanty (1988) who reported that iron content in grain, straw and roots increased significantly with increasing levels of iron in the nutrient sloution in both susceptible and tolerant varieties and more iron was localized in the root portion of resistant variety and relatively higher content of iron was found in the aerial parts of susceptible variety.

In varieties where the absorption of iron is restricted and the uptake of other nutrients (P,K,Ca and Mg) is promoted, a relatively better growth and better tolerance are exhibited by the variety to stress conditions.

SUMMARY

Summary and Conclusion

With the objective of identifying rice varieties tolerant to iron toxicity situation in the soil, an attempt was made to screen thirty rice cultivars in solution culture supplied with high iron concentration. Five varieties exhibted low grade of bronzing and these were further examined for their relative tolerance under graded toxic levels of iron. The major findings from the above study are given below:

1. Varieties Annapoorna, Aruna, Asha, Aswathi, Jaya, Jyothi, Karthika, Neeraja, Onam, Ptb-2, Ptb-10, Ptb-20, Pavizham, Sabari and Santhosh were susceptible to iron toxicity with scores above 6. Among these varieties Asha, Jaya and Jyothi were worst affected with scores beyond 8.

2. The varieties Bhadra,Bhagya, Bhararthy, IR-36,Kanakam, Makam, Rasi, Remya, Red Triveni and White Triveni exhibited iron toxicity symptoms, but with lesser intensities and registered medium scores 3 to 5.

3. Relatively higher tolerance was exhibiited by five varieties viz., H_4, Mahsuri, Cherady, Kochuvithu and Keerthy as evidenced by their low scores of 3 and less than 3 on the bronzing symptoms of

iron toxicity. Based on the scores, the varieties were classified as highly susceptible, susceptible, moderately tolerant and tolerant.

4. The plant iron content of these varieties at the active tillering stage varied from 1471 ppm to 2297ppm. The highest iron content was found in the highly susceptible varieties viz., Asha, Jyothi, Jaya followed by varieties susceptible and less susceptible to iron toxicity in the decreasing order. Relatively tolerant varieties viz., H_4, Mahsuri, Cherady, Kochuvithu and Keerthy contained the lowest plant iron.

5. Among the varieties which showed tolerance to iron toxicity, significant reduction in the growth characters and yield attributing parameters could be noticed under the influence of graded toxic levels of iron in the growth medium. The varietal difference was also significant. Varieties H_4, Mahsuri and Cherady recorded relatively higher dry matter yield compared to Kochuvithu and Keerthy at all the iron levels tried.

5. The nitrogen content of tolerant varieties at harvest increased significantly with increase in iron levels in the growth medium. Uptake of nitrogen significantly reduced with more intense toxic levels of iron. Though the nitrogen content was significantly higher in Keerthy, the uptake was higher in H_4 followed by Mahsuri.

6. The phosphorus content and its uptake significantly decreased with increase in iron level in growth medium. Significant difference between varieties could be noticed in the content and uptake of grain and straw phosphorus, H_4 recording the highest and Keerthy the lowest.

7. Potassium content and its uptake significantly decreased with increase in iron level in the culture solution. Significantly higher content and uptake of grain and straw potassium were recorded in H_4 and Mahsuri. Keerthy recorded the lowest content and uptake of Potassium.

8. Significant decrease in the content and uptake of calcium with increase in the levels of iron in culture solution was noticed. Varietal differences were also significant, H_4 recording the highest content and uptake and Keerthy the lowest.

9. Increasing toxic levels of iron in culture solution brought about decrease in magnesium content. Its uptake also decreased significantly in all the varieties. Significantly higher content and uptake of magnesium were observed in H_4 and lower in Keerthy.

10. The iron content of all the varieties significantly increased with increase in levels of added iron in the growth medium. In the case of iron uptake, a progressive increase could not be noticed.

The uptake increased upto 500 ppm iron level and thereafter decreased. Significant difference was noticed between varieties. Varieties H_4 and Mahsuri which showed relatively higher tolerance contained lower content of iron in aerial part whereas the root content was higher than that of the Cherady, Kochuvithu and Keerthy.

12. A significant negative correlation was obtained between the score and grain yield and positive correlation between score and iron content.

13. The score and iron content were positively and significantly correlated with nitrogen content whereas a significant negative correlation was obtained for nitrogen uptake. The plant content and uptake of phosphorus, potassium, calcium and magnesium were negatively and significantly correlated with score and iron content.

From the investigation it became clear that higher iron had deleterious effect on the growth, yield and nutrient composition of the rice varieties. Varietal difference existed in combating the iron toxic conditions. Varieties H_4, Mahsuri and Cherady showed relatively higher tolerance. The varietal difference may be due to the difference in the iron excluding capacity of the variety which is reflected in the iron content in the plant tissue. In addition to this the inherent genetic ability of the varieties to absorb other nutrients contributed towards the relative tolerance of H_4, Mahsuri and Cherady as evidenced by chemical analysis.

Multiple nutritional stress can bring about iron toxicity to rice and several workers have suggested that proper management of rice fields, improved drainage condition and use of iron tolerant varieties can alleviate the iron toxicity problem to an appreciable extent. In the present study the number of varieties screened for iron tolerance under solution culture had to be restricted to thirty. Screening of more rice varieties under the conditions of extreme iron toxicity will be helpful in the identification of tolerant varieties. Though solution culture is recommended for screening, the ideal procedure would be the field screening. Varieties differ in their root oxidation capacity. The root oxidising power of the rice varieties has not so far been studied. A comparative study of the root oxidation capacities of different varieties will be helpful in locating suitable strains of rice for the iron toxicity situations. Further research on the above lines will be desirable.

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*Originals not seen.

INFLUENCE OF IRON TOXICITY ON GROWTH, YIELD AND PLANT COMPOSITION OF MAJOR RICE VARIETIES CULTIVATED IN KERALA

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ABSTRACT

A study was made to identify rice cultivars tolerant to iron toxicity situation in solution culture using Hoagland solution. Thirty cultivars popular among the Kerala farmers were screened under the toxic level of 500ppm iron and toxicity symptom displayed was scored on 1-9 scale. The varieties included high yielding and local ones.

The varieties viz., Asha, Annapoorna, Aruna, Aswathi, Jaya, Jyothi, Karthika, Neeraja, Onam, Ptb-2, Ptb-10, Ptb-20, Pavizham, Sabari and Santhosh exhibited severe toxicity symptoms with high scores, exceeding five. The plant iron content of these varieties at AT stage was found relatively higher than that of the remaining ones. Asha, Jaya and Jyothi were seriously affected with scores more than 8 and was therefore treated as highly susceptible. In varieties Bhagya, Bhadra, Bharathy, IR-36, Kanakam, Makam, Rasi, Red Triveni, Remya and White Triveni, the intensity of visible symptom was lesser with scores ranging between 3 and 5. The iron content of the varieties was lower than in the susceptible varieties. These varieties were classified as moderately tolerant since they had the capacity to resist iron toxicity to a reasonable extent.

Display of the least symptoms of iron toxicity and scoring were noticed in five varieties viz., H_4, Mahsuri, Cherady, Kochuvithu and Keerthy. Plant analysis of these varieties at the

AT stage indicated the least iron content. In view of the comparatively better performance, these varieties were further examined to find out the comparative effect of increased iron levels at 400, 500 and 600 ppm on their growth and yield. The study indicated that, in general, growth and yield attributing characters as well as the yield decreased with progressive increase in iron level. H_4 and Mahsuri recorded relatively higher grain and straw yields as compared to Cherady, Kochuvithu and Keerthy.

In all the varieties, the nitrogen content increased with increase in levels of iron whereas the uptake decreased. Keerthy recorded the highest content of nitrogen while H_4 recorded the highest uptake of nitrogen.

The content and uptake of P, K, Ca and Mg decreased in all the varieties as the level of iron was progressively increased. H_4 and Mahsuri recorded significantly higher content and uptake of these elements in grain and straw while Keerthy recorded the lowest.

The content of iron in all the varieties increased with increase in levels of iron in growth medium. Relatively lower content of iron was recorded in the aerial parts of H_4, Mahsuri and Cherady compared to other varieties, whereas roots of these varieties had higher iron content. The uptake of iron increased upto 500ppm level and thereafter decreased in all the varieties.

The study revealed that the varieties H_4, Mahsuri, Cherady Kochuvithu and Keerthy exhibited better performance even with toxic concentrations of iron. Among these varieties H_4, Mahsuri and Cherady performed reasonably well and H_4 performed better with regard to tolerance to iron toxicity. These varieties contained higher P, K, Ca and Mg and lesser iron as revealed by plant analysis. Better performance can be attributed to their genetic superiority such as better root development, improved root oxidation capacity and higher nutrient absorbing ability.