RESPONSE OF RICE TO APPLICATION OF MICRONUTRIENTS

By

P. MURALIDHARAN

THESIS

Submitted in partial fulfilment of the requirement for the degree of

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Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
Vellanikkara 680654
THRISSUR

DECLARATION

I hereby declare that this thesis entitled **"Response of rice to application of micronutrients"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similiar title, of any University or Society.

Vellanikkara,

25th August, 1992.

P. MURALIDHARAN

Dr.A.I. Jose
Professor and Head
Department of Soil Science &
Agricultural Chemistry

College of Horticulture
Vellanikkara
25th August, 1992

CERTIFICATE

Certified that this thesis entitled "Response of rice to application of micronutrients" is a record of research work done independently by **Mr.P. Muralidharan** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

A.I. Jose
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr.P. Muralidharan,** a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled "Response of rice to application of micronutrients" may be submitted by Mr.P. Muralidharan in partial fulfilment of the requirement for the degree.

Chairman — Dr.A.I. Jose
Professor

Members — Dr.K. Kumaran
Professor

Sri.V.K.G. Unnithan
Associate Professor

Dr.K.A. Mariam
Associate Professor

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Dedicated

to

Those who inspire me

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Introduction

INTRODUCTION

Chemical analysis of plants has revealed the presence of some sixty elements in the plant tissue. Extensive research carried out in plant nutrition has established the essentiality of sixteen elements. Nine of these elements are required in relatively larger amounts and are designated as macronutrients. The remaining seven, B, Fe, Mn, Mo, Zn, Cl and Cu, are needed by plants in smaller amounts and are called micronutrients or trace elements. Each of the nutrients plays a specific role in the growth and development of the plant, many playing the role as metalloenzymes.

Although trace elements are needed in much smaller quantities as compared to primary nutrients like N, P, K they are as important as major nutrients. In practice the trace elements are not regularly applied to soil in the form of common fertilizers and their removal from soil has been going on for centuries without any systematic replacement. With the adoption of intensive cropping and cultivation of high yielding varieties, it is quite possible that deficiencies of trace elements may occur on a large scale in future. Therefore, without the use of trace elements it would not be possible to get the maximum benefit from applied NPK fertilizers and cultivation of high yielding varieties.

Biochemical investigations conducted in many parts of the world have revealed the importance of micronutrient-plant-animal relationship. It may eventually be proved that some of the fatal diseases of animals and human beings are the outcome of toxicity or deficiency of trace elements. The five elements which have been proved to be essential in human health are Mn, Fe, Co, Cu and Zn. Many metalloenzymes have been found to be essential in animal and human nutrition.

Rice, being the most important food crop of India and Kerala, deserves much attention with regard to its nutrient requirement. The response of rice to application of micronutrients varies with the status of micronutrients in the soil, crop variety and nutrient interactions. This study is undertaken to examine the response of different secondary and micronutrients applied individually and in combination both through soil and foliage to a high yielding medium variety of rice in a typical laterite soil during the kharif and rabi seasons. The study was also intended to reveal the pattern of uptake of these nutrients by the test crop at different stages of its growth.

The results of studies on the response of rice to application of secondary and micronutrients are by and large inconsistent. Significant increase in yield has been reported in some cases while the response has not been conspicuous in other cases. Various micronutrient formulations are now available in the market. The study was therefore undertaken with the following objectives in view:

1) To study the response of rice to application of micronutrients.
2) To study the interaction effects of micronutrients in soil and plant with the major plant nutrients; and
3) To test the performance of a commercial micronutrient formulation in comparison with the application of individual micronutrients separately or in combination.

Review of Literature

REVIEW OF LITERATURE

Secondary and micronutrients play a very important role in crop growth and animal nutrition. In recent years, the importance of these nutrients in increasing agricultural production and correcting deficiencies in plants has been greatly realized in the country. This review concerns mainly with the research done on zinc, copper, manganese, boron, molybdenum, sulphur and magnesium in rice. From the results of experiments conducted so far it is evident that the application of Zn, Cu, Mn and B has increased the grain yield of rice crop in certain regions but not universally. The response depends largely on several soil factors such as soil reaction, soil texture, organic matter content, microbial activity and availability of micronutrients in the soil (Padhi, 1971; Somani, 1982).

The micronutrient status of the soils of Kerala has been investigated by a few workers (Pisharody, 1965; Rajagopalan, 1969; Praseedom, 1970; Nair, 1970 and Valsaji, 1972). In general, these studies indicate that the soils are adequately supplied with iron and manganese and are most deficient in available copper and zinc. The response of rice to the application of micronutrients in the soils of Kerala has also been investigated by a few workers which are discussed under each nutrient.

Zinc

Although zinc was recognized as an essential micronutrient some 55 years ago, it was only in 1966 that zinc deficiency was identified as a field problem of low land rice in India (Nene, 1966). The average zinc content of most of the mineral soils in India is between 10 and 300 ppm (Swaine, 1955) and depending on the type of extractants used, available zinc content varied from less than 1 ppm to a few ppm.

Nair (1970) reported the values for total and available zinc in Onattukara soils were 31-158 ppm and 0.51-5.01 ppm and in Kuttanad soil 59-93 ppm and 0.52-2.47 ppm respectively. In studies conducted on the distribution of zinc in soils of Kerala, Praseedom (1970) found that total zinc in the surface layer in different soil samples ranged from 3.5 ppm in a red soil to 72 ppm in an alluvial soil. Values of available Zn content in the range of 1.2 to 6.2 ppm was reported by Varughese (1971) in alluvial soils of Kerala. A level of 0.55 ppm DTPA-extractable Zn and 1 ppm HCl + H_2SO_4 extractable Zn in soils were found to be critical below which response to Zn application was expected, whereas in top half of plant tissue, 16.3 ppm Zn was estimated to be critical (Sharma et al., 1986).

Aiyer (1946) reported that zinc deficiency symptoms appeared in rice when zinc concentration in solution culture was less than 0.2 ppm.

On the basis of analysis of the third leaf of rice from the top, Venkateswarlu (1969) proposed that at a concentration of 5 ppm response to zinc is very high whereas at 15-20 ppm response may not be expected. According to Sakal et al. (1981a) the critical Zn concentration in 52-day old rice plants below which response to applied Zn may be expected was 37 ppm.

Pillai (1967) reported that application of $ZnSO_4$ @ 56 kg ha^{-1} recorded an increase of 15.6 per cent in yield over control but the 11.2 kg ha^{-1} level proved superior to this level. A trial conducted in sandy loam soils at Sindri revealed definite yield responses in the case of soil and foliar applications of zinc (Roy and Dhua, 1967). Grewal et al. (1969) obtained significant yield response to spray of 0.6% $ZnSO_4$ (2.4 kg ha^{-1}) on soils that contained 0.68 ppm available Zn. Zinc application increased dry matter production of rice under flooded conditions significantly in a green house study in silty clay loam soil (Gangwar and Mann, 1972). It was also concluded that 'Khaira' disease of rice may be caused by Fe and Mn induced Zn deficiency. Experiments in a zinc deficient soil showed that zinc application with a basal NPK treatment increased the calorific value and protein and carbohydrate contents of rice grain (Dwivedi and Randhawa, 1973). Panda and Nayak (1974) reported that the yield of grain and straw, plant height, panicle length, number of grains per panicle and thousand grain weight increased with increase in the level of zinc sulphate application. Further, the application of $ZnSO_4$

through soil at transplanting was found to give better response than foliar spraying during boot leaf stage. In a field trial where rice was grown in a soil having 0.6 ppm available Zn, dry matter yield increased by 15 per cent when 5 ppm Zn was applied compared with the untreated control (Subramani and Mehta, 1974). Prabha et al. (1975) reported that yields of grain and straw were significantly increased by the application of both Zn and P. The optimum combination of P and Zn was found to be 72.5 kg P_2O_5 ha^{-1} and 25 kg $ZnSO_4$ ha^{-1} and high levels of P led to Zn deficiency. According to Samui and Bhattacharya (1976) paddy yields increased with increasing $ZnSO_4$ rates upto 20 kg ha^{-1}, were not affected by P and the highest yield was obtained with 60 kg P_2O_5 + 20 kg $ZnSO_4$ ha^{-1}. Yield significantly decreased with higher rates of P + Zn. An increase in yield of 21 per cent over control was recorded by the application of Zn in rice var. IR-8 by Shukla and Mishra (1976). Premkumar et al. (1979) obtained 17.8 per cent increase in yield of paddy by foliar application of zinc. In an alluvial clay loam soil containing 3.5 ppm available Zn, crop yields were increased by applying 4 kg Zn ha^{-1} (Sarkar and Chakraborty, 1980). At Moncompu, Kerala, higher yields were obtained in rice by soil application of $ZnSO_4$ @ 40 kg ha^{-1} as well as by soaking the seeds in one per cent $ZnSO_4$ solution (Anon., 1981). Sakal et al. (1981b) reported that application of Zn significantly increased the grain yield in all the soils testing below 0.75 ppm. Foliar application of 0.5 per cent and soil application of 20 kg ha^{-1} $ZnSO_4$ resulted in significantly higher yield of grain (Nampoodiri and Ramasubramaniam, 1982). Rathore et al. (1982) observed that alluvial soils with less than 3 ppm HCl-extractable Zn showed yield responses to Zn application. Sarkar et al. (1989) found that applying zinc to the nursery soil or dipping seedling roots in 0.2 per cent $ZnSO_4$ solution with and without one foliar spray of zinc have yields upto 6.3-7.0 t ha^{-1}. In a green house experiment conducted on Zn deficient soils of Tarai region, U.P., rice responded to Zn application through chelated forms viz., Zn-humate and Zn-fulvate (Muralidharadu, 1991).

George and Sreedharan (1966) in a study conducted in Kayal lands at Vellayani, found that application of zinc individually or in combination with other micronutrients did not significantly increase the grain and straw yield of paddy over NPK alone. In a pot culture experiment using red loam soil of Kerala, application of zinc did not have any effect in increasing the yield of paddy (Sreedharan and George, 1969). The yield of rice was not found increased by soil application of Zn, in a field trial at Pattambi using the rice var. Aswathi (Anon., 1975). Neither rice nor wheat plants showed a significant response in terms of dry weight of Zn application in green house experiments using an alluvial soil (Deb and Zeliang, 1975). Mariam and Koshy (1977) found that effect of Zn on the yield of grain and straw was inconsistent when applied in combination with lime using Vellayani

Kayal soil. Two experiments conducted at Mannuthy on the soil application of micronutrients revealed lack of significant effect on yield (Anon., 1978). Effect of pre-soaking of seeds in solutions of Zn on the growth and yield of rice tried at Moncompu and Chalakudy did not reveal much significance in yield (Anon., 1978; Anon., 1986). Ramarao and Sreeramamurthy (1978) reported that foliar application of Zn did not have significant response over NPK in all the four seasons of study at Marutem, Andhra Pradesh. Shirval et al. (1978) obtained consistent yield increase over NPK at recommended level when $ZnSO_4$ was sprayed @ 10 kg ha^{-1} but the difference in yield was not significant. In an investigation conducted at Pattambi to study the response of low land rice to zinc it was found that there was no significant response to applied zinc (Anon., 1979). In studies conducted at Louisiana, grain yield of rice cv. Saturn was not significantly affected by application of 1.75 kg Zn ha^{-1} (Sedberry et al., 1980). Sasidhar et al. (1983) observed no general trend in the yield of grain and straw for the various treatments of zinc in combinations with NPK in all seasons tried. The lack of significant response may be because of the fact that acidic nature of the soil (pH 5.2) would have enhanced the availability of the micronutrient to the required level.

Wells (1980) concluded that as soil pH increased, Zn uptake and content decreased and so did the grain yield of rice. According to Saravanan and Ramanathan (1988) increasing zinc rates increased zinc uptake in grain and the available zinc content in soil. Yield was positively correlated with soil zinc content at the tillering and panicle initiation stages. Available Zn content of the soils had significant positive correlation with its concentration in rice plants (Sahu et al., 1990). Swarup (1991) stated that Zn requirement of the rice crop which invariably suffered from Zn deficiency in sodic soils could be met through organic sources like green manure and farm yard manure which contained 20 and 24 ppm of Zn on dry matter basis respectively.

Copper

The essentiality of copper as a plant nutrient was established only in 1931. Copper deficiency, except perhaps on organic soils, is rarely a constraint to high yields of low land rice. Tanaka and Yoshida (1970) did not observe any copper deficient plant or soil sample during their nutrient survey in Asia.

Swaine (1955) has quoted several workers who estimated the total copper to range from one to less than 100 ppm in normal agricultural soils of the world.

According to Nair (1970), total and available copper ranged from 27 ppm to 136 ppm and from 1.68 ppm to 5.50 ppm in Onattukara soils and from 49 ppm to 97 ppm and 0.30 to 3.3 ppm in Kuttanad soils. Praseedom (1970) reported that the range of variation of total copper in the surface layers was from 5 to 189 ppm and available Cu extracted by neutral normal ammonium acetate ranged from 0.13 ppm in an alluvial soil to 4.65 ppm in a sandy soil. An available Cu content of 0.7 to 4.4 ppm in alluvial soils of Kerala was reported by Varughese (1971). Xu and Dong (1989) found that DTPA-extractable Cu in the permanently water-logged paddy soil was 1.24 ppm and was 2.18 ppm in the long term water-logged soils.

According to Chimania (1969) copper content of paddy grain (IR-8) ranged from 2.9 - 3.8 ppm. Symptoms of Cu deficiency have been obtained in rice in culture solutions by Aiyer (1946).

Joshi and Joshi (1952) reported that in a field experiment conducted on agricultural soils of Maharashtra, application of 1 kg ha^{-1} of $CuSO_4$ was found to give an increase in paddy yield of nearly 70 per cent over control. Application of copper proved beneficial at some parts of Uttar Pradesh and in the form of foliar spray Cu combined with B and Mn proved the best under Lucknow conditions (Mehrotra and Saxena, 1967). In a comparitive study of the micronutrients by Pillai (1967) copper proved beneficial after zinc and manganese in increasing the yield of paddy. Sreedharan and George (1969) in a pot culture study using red loam soils obtained significant increase in grain and straw yield by the application of copper. Application of copper produced 20 per cent increase in grain yield over control in rice var.

IR-8 (Shukla and Mishra, 1976). A study conducted in Pattambi soils revealed that copper application had good effect in increasing the yield during Kharif in Eruthampathy and Chittoor soils (Anon., 1978). At Moncompu, higher yields were obtained in rice by the application of $CuSO_4$ @ 20 kg ha^{-1} (Anon., 1981).

George and Sreedharan (1966) observed that in kayal lands of Vellayani, soil application of Cu to PTB-10 rice variety did not significantly increase the yield of grain and straw. Grewal et al. (1969) reported that response of paddy to application of copper was inconsistent. In a field trial at Pattambi with soil application of Cu using rice var. Aswathi, no significant increase in yield was noted (Anon., 1975). Two experiments conducted at Mannuthy on the soil application of copper revealed lack of significant effect on the yield (Anon., 1978). Effect of pre-soaking of seeds in solution of Cu on the growth and yield of rice tried at Moncompu and Chalakudy did not reveal much significance in yield (Anon., 1978; Anon., 1986). Ramarao and Sreeramamurthy (1978) reported that the response of rice to foliar application of Cu was not significant over control in all the four seasons of study in Andhra Pradesh. In an investigation conducted at Pattambi to study the response of low land rice to Cu, it was found that there was no significant response to applied Cu (Anon., 1979). Sarkar and Chakraborty (1980) found that rice grown on alluvial clay loam soil containing 3 ppm available Cu did not respond to the application of Cu. In a field trial at Louisiana, the application of Cu eventhough increased the leaf Cu and Zn contents, did not significantly affect the grain yield in rice var. Saturn (Sedberry et al., 1980). Sasidhar et al. (1983) observed no general trend in the yield of grain and straw for various treatments of Cu in combination with N, P and K.

Valsaji (1972) observed that available Cu is positively and significantly correlated with organic carbon in soils. The ratio of DTPA-extractable Fe/Cu in soils was highly correlated with the ratio of Fe/Cu in plants (r = 0.947) (Xu and Dong, 1989). The ratio of Fe/Cu in both soils and plants correlated closely with the yield response to applied Cu with correlation coefficients of 0.9308 and 0.9801 respectively. In the water-logged soils, if DTPA-extractable Cu was less than 1.5 ppm or the ratio of Fe/Cu in soil was higher than 120, a yield response to applied Cu could be expected. Sahu et al. (1990) observed that clay content had significant positive correlation with available copper in soil which had a significant positive correlation with its concentration in rice plants.

Manganese

Although the stimulating effect of manganese on plant growth was reported in the first decade of 20th century, its essentiality as a micronutrient element for green plants was established in

1922. Manganese deficiency seldom occurred in rice because availability of manganese increased upon submergence, as shown by the rise in the concentration of DTPA-extractable exchangeable or water-soluble manganese (Ponnamperuma, 1955).

According to Swaine (1955), the total content of Mn of most soils in the world is in the range of 200-3000 ppm, however, most of the Indian soils have been reported to contain from 250 to 1,600 ppm of Mn.

Pisharody (1965) reported that total Mn content of rice soils of Kerala varied from 355 to 625 ppm in the surface soils and from 367 to 764 ppm in the subsoils of water-logged profiles. Water soluble Mn ranged from 1.8 ppm to 14.8 ppm. In studies conducted on the distribution on Mn in Kerala soils, Rajagopalan (1969) observed that the level of total Mn was maximum in the black soil (950 ppm) and minimum in the sandy soil (103.8 ppm). On the basis of information so far available soils containing less than 15 ppm of active Mn may be designated as deficient, 15 to 100 ppm as critical and greater than 100 ppm as high in available Mn (Kanwar and Randhawa, 1974). Gajendragadkar and Rathore (1987) suggested that 3.8 ppm of 1 N NH_4OAC (pH 7.0) extractable soil Mn may be taken as the critical limit below which rice can be expected to respond to applied Mn.

The manganese content of plants grown under natural conditions varies considerably. It is expected that plants growing on acid soils and on water-logged soils are rich in Mn.

Pillai (1967) reported that manganese sulphate application at 11.2 kg ha^{-1} resulted in a maximum yield increase of 18.5 per cent over control in a field experiment conducted at Coimbatore. Definite crop yield responses were noticed in the case of Mn application in sandy loam soil at Sindri by Roy and Dhua (1967). Grewal et al. (1969) obtained yield increase in paddy by the application of 0.6 per cent $MnSO_4$ (15 kg ha^{-1}) on soil that contained upto 3.1 ppm exchangeable Mn. Manganese application significantly increased straw yield in a red loam soil of Kerala (Sreedharan and George, 1969). Singh and Singh (1975) found that Mn application significantly increased the grain yield of rice both under water-logged and well drained conditions. Premkumar et al. (1979) recorded the highest grain yield of 6550 kg ha^{-1} under the foliar application of Mn @ 5 kg ha^{-1} which gave 19.1 per cent increase over control. In trials with rice on alluvial clay loam soil containing 42 ppm available Zn, crop yield was increased by applying 5 kg Mn ha^{-1} (Sarkar and Chakraborty, 1980). The height of plant and the number of total and effective tillers per plant were influenced by the application of MnO_2. Though total grain yield was increased, the yield of straw was little influenced (Harikrishnan and Koshy, 1981).

George and Sreedharan (1966) obtained no significant difference in the yield of grain and straw of rice by the application of Mn in kayal lands at Vellayani. In a field trial with rice var. IR-8, application of Mn did not give a significant increase in yield (Shukla and Mishra, 1976). The response of rice to foliar application of Mn was not significant over NPK in all the four seasons of study in Marutem, Andhra Pradesh (Ramarao and Sreeramamurthy, 1978).

Positive correlation was obtained between total and active (water soluble + exchangeable) Mn with the percentages of clay and the organic matter content of the soil (Rajagopalan, 1969).

According to Gangwar and Mann (1972) flooding greatly increased the Mn content of the rice plants in silty clay loam soils. The available Mn content of the soil was increased by the application of lime plus fertilizer plus organic matter in two acid alluvial soils (Krishnasamy and Raj, 1975). Swarup (1982) stated that contents of extractable Mn increased with submergence upto 60 days of crop growth but thereafter remained constant and declined slightly. Sahu et al. (1990) observed significant positive correlation of clay content with available Mn.

Boron

Boron is an essential plant nutrient. But deficiencies of boron is rare in lowland rice; on the contrary, their contents in submerged soils are at times excessive for normal plant performance (Randhawa and Katyal, 1982).

According to Swaine (1955) the total boron content of most of the soils in the world is in the range of 2 to 100 ppm and that of Indian soils has been found to vary from 7 to 38.5 ppm (Sastry and Viswanath, 1946). The range of available boron in Indian soils is traces to 12.2 ppm. Unlike other nutrients, the difference between optimum and toxic boron levels seems to be narrow for rice as well as for other crops. Lockard et al. (1972) observed boron toxicity symptoms at 5 ppm level of boron application to three potted soils (hot-water soluble B, 1.5 ppm) from the Philippines.

Aiyer (1946) obtained symptoms of B deficiency in rice in culture solutions but not in the field. According to Rao (1962), the absorption of boron by rice plants ran parallel with the dry matter production. There was a heavy demand for the element at flower emergence. Gandhi and Mehta (1960) estimated the boron concentration in the paddy plants to be in the range of 18-26 ppm. The critical values of boron in leaves of 48 day old paddy plants var. IR-8 were 18.0 ppm for deficiency, 20.0-72.0 ppm for sufficiency and 400 ppm for toxicity (Agarwala, 1968).

Mehrotra and Saxena (1967) observed an increase in rice yield from soil application of 1.12 to 2.24 kg B ha^{-1} as borax (11% B) in Uttar Pradesh. Significant increase in straw yield was obtained by Sreedharan and George (1969) in a red loam soil of Kerala by the application of B. Foliar application of B along with Mn resulted in an increase in yield of 16.48 per cent over control (Premkumar et al., 1979).

No significant increase in the yield of grain and straw of rice was observed by the application of B in kayal lands at Vellayani (George and Sreedharan, 1966). Grewal et al. (1969) found that response of paddy to application of B was inconsistent. Application of B either to soil or foliar did not give significant increase in yield of rice (Shukla and Mishra, 1976; Ramarao and Sreeramamurthy, 1978; Sarkar and Chakraborty, 1980).

According to Kumar et al. (1981) the B content in rice plants increased with increasing rates of applied B (0-10 ppm). Clay content had significant positive correlation with available B but negative correlation with Fe (Sahu et al., 1990). Also, available B content of the soil had significant positive correlations with its concentration in rice plants.

Molybdenum

The research carried out during the last 40 years has transformed molybdenum from an element of unknown biological significance to that of considerable importance. Biological importance of Mo was not realized until 1930. Deficiency of molybdenum is rare in lowland rice. Eventhough its content in submerged soils is at times excessive than normal; unlike boron, it is not known to produce any perceptible growth depression in rice.

The total Mo content of soils from different parts of the world varies from 0.2 to 5 ppm with a mean value of 2 ppm (Swaine, 1955). According to Chatterjee and Dakshinamoorthy (1962), the total Mo content in alluvial and laterite soils of India ranged from 1.0 to 5.6 ppm. The available Mo content of Indian soils (extractable with ammonium oxalate solution adjusted to pH 3.3) varied from traces to 1.65 ppm.

Plant species differ widely in their Mo content. According to Lal and Rao (1955), the optimum requirement of Mo in sand culture for rice was 1.6 ppm. Much lower sufficiency levels of Mo (0.001 ppm) have been reported by Mehta _et al_. (1964) for normal growth of rice grown in sand culture.

Das Gupta and Basu Choudhary (1974) suggested that rice may benefit from Mo application (40 g ammonium molybdate ha^{-1}) through its favourable effect on N metabolism. Notwithstanding the improvement in availability of Mo through flooding, positive response of rice to Mo has recently been reported by Ponnamperuma (1977) on an organic soil. Basak _et al_. (1982) found that application of Mo along with P increased both shoot dry matter yield and shoot Mo level. Beyond these results, Mo deficiency has not been reported widely.

No significant increase in the grain and straw yield of rice was observed by the application of Mo either individually or in combination with other micronutrients (George and Sreedharan, 1966; Grewal et al., 1969; Sreedharan and George, 1969; Anon., 1975; Shukla and Mishra 1976; Ramarao and Sreeramamurthy, 1978; Sarkar and Chakraborty, 1980).

Sulphur

Sulphur, as an essential element for plant growth, ranks in importance with nitrogen and phosphorus in the formation of plant proteins. Only recently this element has received the attention it deserves as a plant nutrient.

Naik and Das (1964) using Aspergillus niger method reported the mean available S contents of laterite and alluvial soils as 8.31 and 4.74 ppm respectively. Soils containing less than 10 ppm of sulphate sulphur are considered to be S deficient soils.

Jacob (1966) found that Kerala soils in general are rich in total S. The mean values for total S in wetlands were 114.8, 548.4 and 280.8 ppm whereas in drylands these were 523.0, 194.2 and 125.5 ppm for the surface, subsurface and sub-soils respectively. Yield of rice showed strong positive response to sulphate sulphur levels of upto 10 ppm under pot culture conditions (Wang, 1979).

Wang (1979) observed that the critical S contents in the straw at the harvest stage was 0.05 per cent for several cultivars grown under pot and field conditions. The straw indicated the S status of the soil more closely than did the grain.

Verma et al. (1981) reported that in rice grown with NPK on calcareous soil (pH 8.6 - 8.8), application of pyrite at 0.75 - 1.5 t ha^{-1} markedly increased paddy yield and further increases in pyrite rate were not effective. Grain yield, grain : husk ratio and grain N, S, sugar and starch contents in rice increased with increasing levels of applied N and S. Grain P was increased by S application alone (Dikshit and Paliwal, 1989). Ismunadji (1991) observed that S application can affect yield, yield components and grain quality of rice in Indonesia.

In different trials, it was found that potassium sulphate, ammonium sulphate, gypsum, elemental sulphur and S-coated urea were equally effective as S sources for rice (Samosir and Blair, 1983; Ismunadji, 1991).

Magnesium

Magnesium is the fifth element in the group of six micro-nutrients. It is the only mineral constituent of chlorophyll and, therefore, essential for plant growth. Magnesium deficiency in Indian soils is not of the same magnitude as that of primary nutrients (N, P and K). Magnesium content of most soils generally lies in the range of 0.05 per cent for sandy soils to 0.5 per cent for clay soils.

According to Varghese (1963), the Mg content of soils of Kerala varied from 0.047 per cent in Vellayani soil to a maximum of 0.171 per cent in Alathur soil. Eleven soil samples contained less than 0.1 per cent MgO. Prema (1992) reported that the average available Mg content of laterite, red and brown hydromorphic soils taken together was 231.9 ppm in Kerala.

The contents of Mg in plant tissues were usually in the order of 0.1 to 0.5 per cent of the dry matter (Kinkby and Mengel, 1976).

Pot-culture experiments on paddy conducted by Varghese and Money (1965) with Vellayani sandy clay loam and by Padmaja and Varghese (1966) with Vellayani red loam soils indicated that Mg eighter alone or in combination with Ca and Si appreciably improved crop growth and significantly increased grain yield. Magnesium improved the ratio of grain to chaff. The P_2O_5 content in grain was maximum for the Mg applied plants. It was also found to produce a more extensive root system. According to Thomas and Koshy (1977) there was a positive beneficial effect of Mg silicate on the yield of grain and straw in rice. Increasing levels of Mg enhanced grain yield from 58 g pot^{-1} in control (no Mg) to 70 g pot^{-1} with the addition of one equivalent of exchangeable

Mg in soil, but higher dose of Mg depressed grain and straw yields (Narayana and Rao, 1982). Yamauchi and Winslow (1989) found that Mg and Si were involved in the protection of rice plants against grain discolouration and their application increased the grain yield of three rice varieties by an average of 34 per cent in Nigeria's humid tropics.

The form or level of Mg had no significant effect on tillering. The yields of grain and straw were not significantly influenced by the different forms of Mg at the rates of 25 and 50 kg MgO ha^{-1} (Nayar and Koshy, 1966). Grewal et al. (1969) observed that response of rice to Mg application was inconsistent. Lack of significant response of rice to applied Mg has been reported by Kurup and Ramankutty (1969), Anon. (1975) and Varughese (1992).

Kabeerathumma (1969) noticed that the uptake of Mg increased with liming. Liming increased readily available Ca and Mg also.

Interactions of micronutrients

Venkateswarlu (1964) observed that N application induced increased uptake of Mn, and when extra S was supplied as sulphate, it resulted in further significant increase in the Mn content of rice. A combined application of micronutrients, B, Cu, Mn, Mo and Zn tended to show a depressing effect on the yield of grain and straw of paddy in kayal lands at Vellayani

(George and Sreedharan, 1966). According to Reddy (1968) foliar application of trace elements (Zn, Fe, Cu and Mo) to three week-old rice seedlings had pronounced effect on the distribution of rhizosphere microflora as well as the percentage occurrence of certain soil fungi. Iron or Zn eiither alone or in combination significantly influenced uptake of Fe and Zn (Chavan and Banerjee, 1969). The highest dry matter yield was recorded with 10 ppm Fe + 10 ppm Zn at which the highest uptake of zinc was noted.

Nair (1970) observed that there was a significant positive correlation between the available and total Cu contents and available and total Zn contents. The uptake of Cu and Zn by the plants increased significantly by the application of these elements. Manganese was found to antagonistically affect the content of Fe in grain under both water-logged and well-drained conditions (Singh and Singh, 1975). Significant positive correlation between Zn and P uptake was observed by Sarkunan and Venkaturamanan (1977) and Tiwari and Pathak (1978). Singh et al. (1978) suggested that the addition of Zn decreased the Mn and Fe concentrations indicating the antagonistic effect of Zn on the absorption of Mn and Fe by rice plants. Chavan and Banerjee (1980) also observed a decrease in the uptake of Zn with increased doses of applied Fe. According to Kumar et al. (1981) the reduction in plant dry weight with higher B rates was possibly due to its antagonistic effect on Ca absorption. Application of P was found to decrease the content of DTPA-extractable Cu, Zn and Fe but increased that of Fe.

At the same time, Cu reduced the content of extractable Zn and available P, but increased that of extractable Fe and Mn (Patra *et al.*, 1981). Chaterjee *et al.* (1982) stated that P and Zn application influenced absorption and translocation of Zn, P, Cu, Fe and Mn especially at the early growth stage. A reduction in the concentration of Zn and Fe in various plant parts was observed when they are applied together (Sinha and Sakal, 1983) but the depressing effect of Zn on Fe content was more pronounced than that of Fe on Zn. Indulkar and Malewar (1990) found that zinc blended with N and NP carriers increased the availability of N, P and Zn in a rice-grass cropping system.

Materials and Methods

MATERIALS AND METHODS

The studies reported herein were designed to obtain information on the response of rice to applied micronutrients, magnesium and sulphur. The factors under investigation were the different micronutrients (Zn, Cu, Mn, B and Mo), magnesium, sulphur, a combination of the above said nutrients and Stanes Microfood, a micronutrient formulation. A field experiment was conducted during the first and second crop seasons of 1991 for this purpose.

1. Details of the field experiment

1.1 Site, climate and soil

The experiment was conducted at the Agricultural Research Station, Mannuthy under the Kerala Agricultural University. The research station is located at 12° 32' N latitude and 74° E longitude. The experimental field lies at an altitude of 22 m above MSL. This area enjoys a typical humid tropical climate.

The experimental area is a double-crop wetland and has been under banana and vegetables during the previous two seasons.

The soil of the experimental field was sandy clay loam in texture. The physical and chemical properties of the soils are presented in Table 1.

1.2 Variety

Rice variety Jyothi with a duration of 110-125 days was used for the experiment. This variety evolved at the Rice Research Station, Pattambi, possessed red kernel, long and bold grains. It is moderately tolerant to brown plant hopper and blast and is susceptible to sheath blight (Anon., 1989).

1.3 Fertilizer materials

Urea (46% N), Factomphos (16% N and 20% P_2O_5) and muriate of potash (60% K_2O) were used as the sources of N, P and K respectively in this study.

1.4 Treatments

he treatments consisted of application of Zn, Mn, B, Cu, Mo, S and Mg individually, a combination of all these treatments, Stanes Microfood and control with no micronutrients. There were 10 treatments as detailed below.

Sl.No.	Treatment	Notation
1	Control (No micronutrients; NPK and cultural practices are given as per the package of practice recommendations of KAU (Anon., 1989)	T_1
2	Zinc ($ZnSO_4$ 20 kg ha^{-1} in soil + 1% foliar 250 l ha^{-1} at the active physiological stage)	T_2
3	Manganese (Manganous sulphate monohydrate 2.5 kg ha^{-1} in soil + 0.5% foliar 250 l ha^{-1})	T_3

Sl.No.	Treatment	Notation
4	Boron (Boric acid 750 g ha^{-1} in soil + 0.1% foliar 250 l ha^{-1})	T_4
5	Copper (Cupric sulphate 5 kg ha^{-1} in soil + 0.1% foliar 250 l ha^{-1})	T_5
6	Molybdenum (Sodium molybdate 1.25 kg ha^{-1} in soil + 0.1% foliar 250 l ha^{-1})	T_6
7	Sulphur (Biologically activated with <u>Thiobacillus</u> and <u>Aspergillus</u> <u>avomerii</u> 10 kg ha^{-1} in soil + 1% foliar 250 l ha^{-1})	T_7
8	Magnesium ($MgSO_4 \cdot 7\ H_2O$ 20 kg ha^{-1} in soil + 1% foliar 250 l ha^{-1})	T_8
9	Combination of nutrients given in the above treatments	T_9
10	Stanes Microfood (12.5 kg ha^{-1} in soil + 1% foliar 250 l ha^{-1})	T_{10}

The Stanes Microfood meant for soil application had a nutrient content of 4 per cent Mg as MgO, 3 per cent Zn, 10 per cent S, 1.6 per cent Fe, 0.3 per cent Mn, 0.2 per cent B and 0.4 per cent Cu. Foliar formulation contained 5, 0.5, 0.05, 5.0, 6.0, 1.0 and 0.35 per cent of Zn, Mn, B, S, Mg(MgO), Fe and Cu respectively in addition to N (2 per cent w/w), P (100 ppm as orthophosphate) and K (90 ppm as $KMnO_4$).

The soil application of micronutrients was carried out 15 days after transplanting and foliar application was effected during the active tillering stage @ 250 l of spray solution ha^{-1}. Care was taken to see that the quantity of N, P and K applied to all the plots was uniform to compensate the effect of Stanes Microfood.

1.5 Design and layout

The experiment was laid out in randomized block design and was replicated thrice. The layout plan is given in Fig. 1.

1.6 Spacing and plot size

a. Spacing : 20 x 15 cm for the first crop
15 x 10 cm for the second crop

b. Plot size : 6 x 3.4 m

Total experimental area: Gross - 41 x 18.5 m

Net - 36 x 17 m

c. Border rows : Two rows of plants were left as border rows all around each plot

1.7 Field culture

Cultural operations for rice, as recommended by the Kerala Agricultural University (Anon., 1989) were followed. Main field was prepared by puddling the previously ploughed and harrowed field after laying out the individual plots. Final puddling was done after application of fertilizers to the levelled plots.

Thirty-day-old seedlings of uniform growth were transplanted on 26th June 1991 at the rate of two or three seedlings per hill.

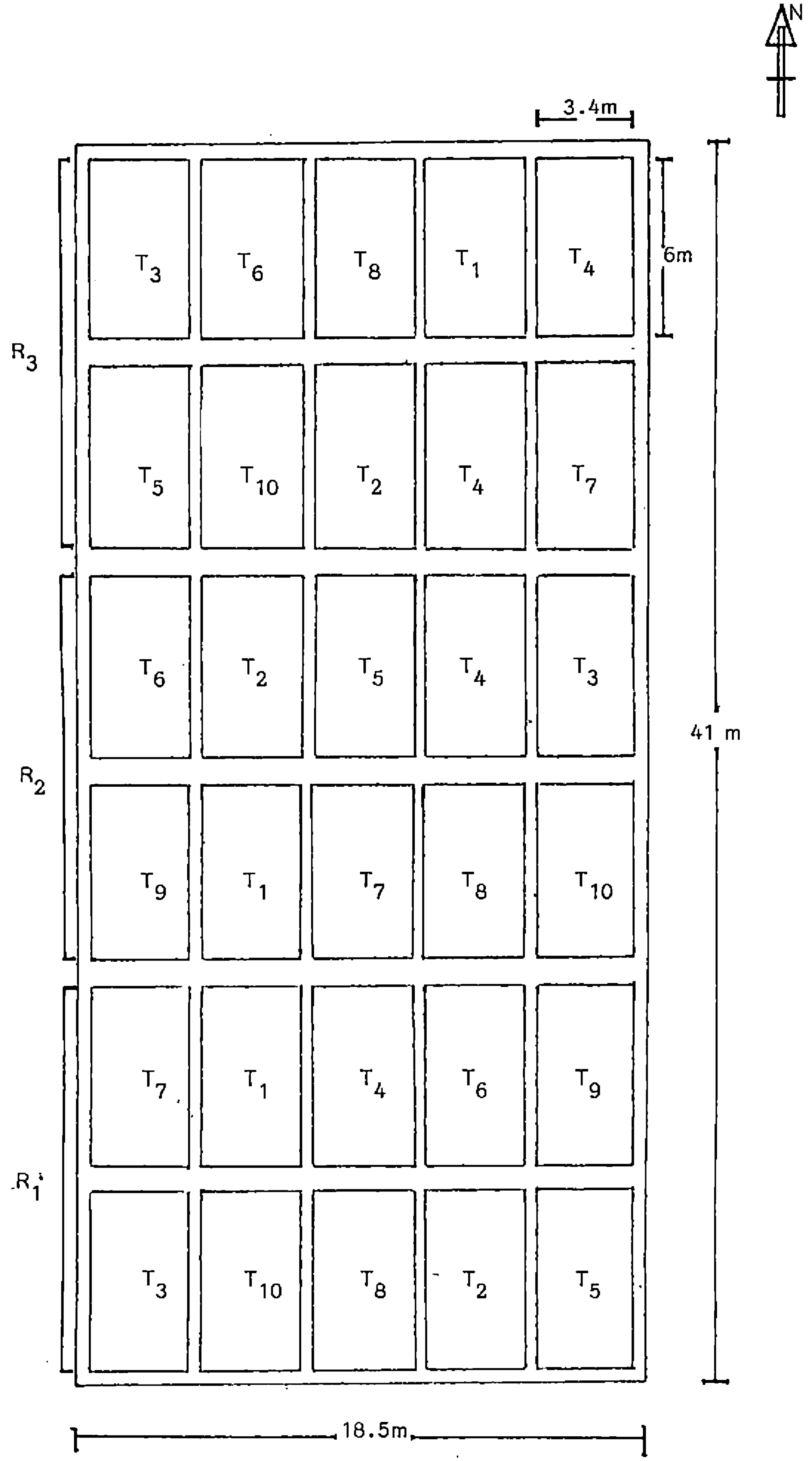

Fig. 1. Lay out of the experimental field

The crop was given two handweedings. The first handweeding was done 30 days after transplanting and the second 30 days after the first one. The plots were kept under 5 cm continuous submergence from the date of planting to 15 days before harvest.

1.7.1 Application of fertilizers

The fertilizers were applied at the recommended rates. The fertilizer doses were so chosen as to give the required quantities of N, P and K.

The full dose of phosphorus as well as half the doses of nitrogen and potassium were broadcast uniformly on the soil surface. Final puddling and levelling was done after this. Top dressing with the remaining half doses of nitrogen and potassium was done at the maximum tillering stage.

The experiment was continued during the second crop season with the same set of treatments in order to assess the continued effect of treatments. The crop was planted on 23rd October 1991. The cultural practices and application of fertilizers and treatments were done in the same manner as that of the first crop.

1.7.2 Plant protection

Carbaryl one per cent plus BHC one per cent was sprayed to control leaf rollers during the first crop. During the second crop, carbaryl 2.0 per cent was sprayed at the maximum tillering stage to control leaf rollers and methyl parathion 0.05 per cent was sprayed at flowering to control rice bugs.

1.7.3 Harvesting

Harvesting was done when more than 80 per cent of grains of the panicle had matured (90 days after planting). Border plants were harvested and removed first. The individual plots were then harvested and threshed separately.

1.8 Observations

1.8.1 Growth characters

a. Plant height: Ten hills were selected randomly for growth observations in each plot. Height was recorded from the base of the plant to the tip of the top-most leaf at active tillering stage and the mean height was worked out.

b. Number of tillers: The total tillers of the above 10 hills were counted at active tillering stage and then average was expressed as number of tillers per hill.

c. Dry matter production: The dry weights of samples collected at the tillering, flowering and harvesting stages were taken as the dry matter production at the respective stages. The dry weights of grain and straw were added together to get the total dry matter production at harvest.

1.8.2 Yield characters

a. Number of spikelets per panicle: The total spikelets of the selected 10 panicles were counted and the average calculated.

b. Hundred grain weight: One hundred grains were counted from the cleaned produce from each plot and the weight recorded in grammes.

c. Grain yield: The grain yield from each plot was dried, cleaned, winnowed, weighed, and expressed in kg ha^{-1}. The weight was adjusted to 14 per cent moisture.

d. Straw yield: The straw from each plot was dried under sun. The weight was recorded and expressed in kg ha^{-1}.

2. Collection of samples

Soil samples were taken replication-wise (composite) before planting to study the basic characteristics of the soil. Soil samples were collected from all the individual plots at different stages of crop growth viz., tillering, flowering and after harvest of crop. Plant samples were collected at different stages of crop growth as above.

Before planting, soil samples were collected with the help of spade. Soil samples at different stages of crop growth and at harvest were drawn using a wet soil sampler.

The results obtained were subjected to analysis of variance technique for RBD (Panse and Sukhatme, 1985). CD values are given in respective tables only when F test is significant. Correlation and regression between various factors were worked out, as described by Snedcor and Cochran (1967).

Plant samples were collected randomly from each plot. Three hills were pulled out, roots were removed and washed with water.

3. Laboratory studies

3.1 Soil samples

3.1.1 Preparation of the sample

The collected sample was air-dried, powdered gently and passed through a 2 mm sieve. The samples were kept in labelled plastic containers for further analysis.

3.1.2 Analysis of the sample

3.1.2.1 Physical properties

Particle size distribution of the initial soil was found out by hydrometer method (Piper, 1942).

3.1.2.2 Chemical properties

The pH of the soil-water suspension was determined using a soil water ratio 1:2.5 by a pH meter (Jackson, 1958). For the determination of organic carbon content of soil, Walkley and Black's method (Piper, 1942) was followed. Cation exchange capacity of soil was determined by normal ammonium acetate method (Piper, 1942).

For the determination of total N, Kjeldahl's digestion and distillation method (Jackson, 1958) was followed. Available P in the soil was extracted by Bray No.1 extractant and the P content was determined colorimetrically by the ascrobic acid blue colour method (Watanabe and Olsen, 1965). Available K in the soil was extracted by neutral normal ammonium acetate and was read in EEL flame photometer (Jackson, 1958).

Determinations of exchangeable Ca and Mg were made using ammonium acetate leachate in an atomic absorption spectrophotometer.

For the determination available micronutrients (Zn, Cu, Fe and Mn), the soil samples were extracted with 0.05 N HCl + 0.025 N H_2SO_4 in the ratio of 1:4 for 15 min and the elements were estimated in an atomic absorption spectrophotometer (Perkins, 1970). Available S content of the soil was estimated by turbidimetric method (Hesse, 1971). Available B content of the soil was extracted by hot water and estimated colorimetrically using curcumin method (Jackson, 1958). For the determination of available Mo, soil samples were extracted with ammonium oxalate solution (pH 3.3) and estimated colorimetrically by the thiocyanate orange-red colour method (Jackson, 1958).

3.2 Plant samples

3.2.1 Preparation of the sample

Plant samples were dried in a hot air oven at 70°C and the dry weights were recorded. The samples were powdered and composite samples were stored for further analysis.

3.2.2 Analysis of the sample

The total N content of the samples was determined by micro-kjeldahl digestion and distillation method (Jackson, 1958). For the determination of P, K, Ca, Mg and micronutrient elements, triacid extract (HNO_3 : H_2SO_4 : $HClO_4$ in the ratio of 10:1:4) of the plant material was made use of. For the determination of S, diacid extract (HNO_3 : $HClO_4$ in the ratio 2:1) was prepared. Phosphorus was determined by vanado-molybdo phosphoric yellow colour method (Jackson, 1958). Potassium was determined using EEL flame photometer. Ca, Mg, Zn, Cu, Fe and Mn were determined in the extract using an atomic absorption spectrophotometer. Sulphur was determined by turbidimetric method. Determinations of B and Mo were made colorimetrically by curcumin method and thiocyanate orange-red colour method, respectively.

Analysis of the grain was done in the same way as that of the plant samples. Uptakes of nutrients by crop at different growth stages and by grain and straw were computed from the respective nutrient contents and yields of dry matter, grain and straw.

4. Statistical analysis

The results obtained were subjected to analysis of variance technique for RBD (Panse and Sukhatme, 1985). CD values are given in respective tables only when F test is significant. Correlation and regression between various factors were worked out, as described by Snedcor and Cochran (1967).

Results and Discussion

RESULTS AND DISCUSSION

In order to assess the response of rice to application of secondary and micronutrients, a field experiment was conducted the results of which are discussed hereunder.

A. First Crop

1. Biometric characters

Results on the effect of the various nutrients on the major biometric characters such as number of tillers and height of plants at maximum tillering stage, number of spikelets per panicle, dry weight of 100 grains are presented in Table 2.

The mean number of tillers did not vary significantly between the treatments. There was no considerable variation in the number of tillers, the range being 8.63 to 10.57. There was no significant difference between the treatments in the height of plants, the range of height being 63 to 70 cm. The number of spikelets per panicle was not found influenced by the treatments.

In general, the results indicate that the morphological characters of the plant are not influenced by the application of micronutrients. The micronutrients serve as co-factors in the enzyme catalysed biochemical reactions associated with plant metabolism. The lack of response to the application of micronutrients reveals that the plants are provided with the optimum level of micro-nutrients from the soil to meet their requirement as co-factors

Table 1. General characteristics of the soil

Characteristics	
Coarse sand, %	27.2
Fine sand, %	23.8
Silt, %	22.6
Clay, %	26.4
Total N, %	0.244
Available P, kg ha^{-1}	118.3
Available K, kg ha^{-1}	310.6
Exchangeable Ca, cmol(+) kg^{-1}	4.422
Exchangeable Mg, cmol(+) kg^{-1}	0.537
Available S, ppm	65.63
Available Zn, ppm	3.955
Available Cu, ppm	4.218
Available Mn, ppm	72.73
Available Fe, ppm	120.6
Available B, ppm	2.213
Available Mo, ppm	2.80
Organic carbon, %	0.68
pH	5.65
Specific conductance, dS m^{-1}	0.086
Cation exchange capacity, cmol(+) kg^{-1}	30.77

Table 2. Biometric observations of rice in the field experiment, first crop (mean of three replications)

Treatment	No. of tillers at maximum tillering	Height of plant at tillering stage, cm	No. of spikelets per panicle	Dry weight of 100 grains, g	Grain yield, kg ha^{-1}	Straw yield, kg ha^{-1}
T_1	9.70	63.87	8.40	2.823	2065	4049
T_2	10.43	69.23	8.37	2.883	1774	3663
T_3	8.73	65.67	8.37	2.990	2127	3731
T_4	10.17	65.80	7.97	2.817	2314	3961
T_5	10.00	68.77	8.37	2.817	2314	3770
T_6	10.57	66.00	8.13	2.833	2087	3416
T_7	10.37	70.70	8.50	3.030	2460	4197
T_8	9.00	65.57	8.10	2.950	2276	3680
T_9	9.83	70.10	8.87	3.183	2232	3712
T_{10}	8.63	65.70	8.53	3.183	2606	3755

in anabolic reactions responsible for the synthesis of protoplasm and consequent vegetative growth. The lack of response to applied micronutrients in rice has been reported by different workers (George and Sreedharan, 1966; Mariam and Koshy, 1977; Sasidhar et al., 1983 etc.)

2. Yield of straw and grain

2.1 Yield of straw

Effects of various treatments on the yield of straw at harvest are given in Table 2.

There was no significant difference between the different treatments tried in the experiment. Application of biologically activated S (T_7) gave the maximum straw yield of 4197 kg ha^{-1}. In all the other treatments, the yield of straw obtained was less than that of the control which reveals the lack of positive response of the crop to the application of these nutrients. This may be because of the fact that the soil contained these nutrients at the required level and further application may not be beneficial.

Mean straw yield of the rice plant at harvest was highly significantly correlated with the total dry matter yield (r = 0.818**), total K uptake (r = 0.722*) and available Mn content of the soil (r = 0.701*) (Table 21). The correlation between straw yield and total dry matter yield is expected since the straw yield is a component of the dry matter yield. The significant correlation of total K uptake with straw yield shows that K uptake constantly increases with increasing straw yield without undergoing dilution in the level of K in straw due to increased straw yield.

2.2 Yield of grain

Influence of various treatments on the yield of grain is presented in Table 2 and Fig. 2.

Eventhough there was an increase in yield of grain from 2065 kg ha^{-1} for control to 2606 kg ha^{-1} by the application of Stanes Microfood, the difference was not statistically significant. The second highest yield was observed in plots with received the application of biological activated S (T_7). All the treatments except Zn application tended to have an increase in the grain yield compared to the control. Here again the lack of increase in yield to the extent of statistical significance may be attributed to the fair availability of these nutrients in the soil. Considering the critical limits of the micronutrients in soil, the experimental soil was relatively rich in the content of micronutrients. The critical limits of Zn, Cu, Mn and B for Kerala soils are reported to be 0.8, 0.2, 1.0 and 1.0 ppm respectively (Jose et al., 1985) whereas the initial status of these nutrients in the experimental soil was found to be 3.955, 4.218, 72.73 and 2.213 ppm respectively which evidently shows the fair availability of these nutrients. Available Fe content of 120.6 ppm in the initial soil was considered plentiful.

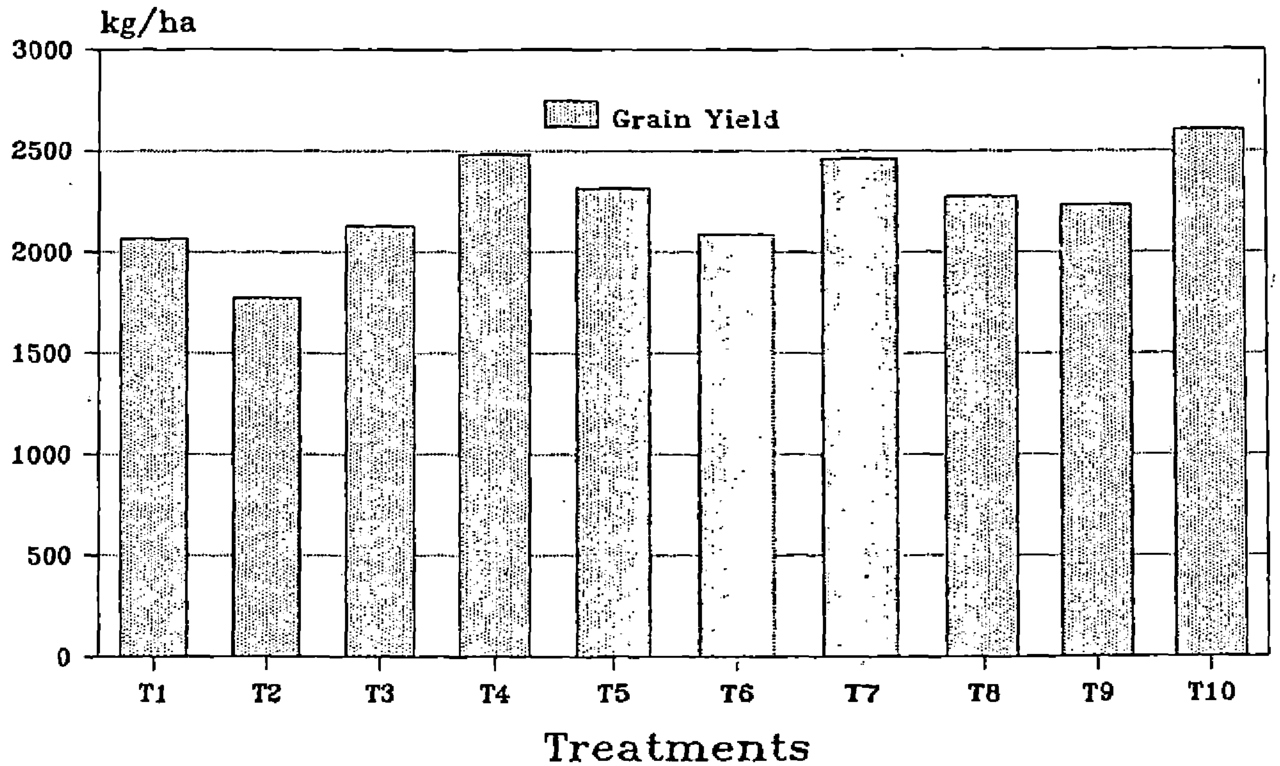

Fig. 2. Grain yield of rice in the first crop

The mean value of grain yield was relatively higher in plot treated with Stanes Microfood. This could not be exclusively attributed to the role of micronutrients since such a yield performance was not exhibited in the treatment which comprised the combination of all the micronutrients tried. Most probably, it could be assigned to the effect of formulation of the Stanes Microfood which contained growth promoting substances, neem extract, nicotine sulphate etc. In a field trial conducted at the Tamil Nadu Agricultural University using sugarcane as the test crop, the positive influence of Stanes Microfood on cane yield was reported.

The earlier studies conducted in Kerala revealed the inconsistency in the response of rice to application of micronutrients. While a few workers reported the positive response of rice to micronutrient application (Sreedharan and George, 1969; Anon., 1981; Nampoodiri and Ramasubramonian, 1982 and Harikrishnan and Koshy, 1981) most of the studies revealed the lack of influence of micronutrients on growth and yield of rice (George and Sreedharan, 1966; Anon., 1975; Mariam and Koshy, 1977; Anon., 1978; Anon., 1979; Sasidhar et al., 1983 and Anon., 1986). Hence the results of the present study are in line with those of the former set of studies.

Observations on the dry weight of 100 grains reveal that the maximum weight of 3.183 g was obtained by the application of combination of nutrients and Stanes Microfood. However, the values did not differ significantly between the treatments.

Grain yield was highly significantly correlated with the total dry matter yield ($r = 0.851^{**}$) (Table 21) evidently because the grain yield is a component of the total dry matter yield.

3. Content and uptake of nutrients

3.1 Nitrogen

Results on the effect of various treatments on content and uptake of N by straw at different growth stages of the crop are presented in Table 4.

The N per cent of the straw was found to decrease continuously from the initial to final stages of growth. This can be assigned to the increase in the dry matter production with less vigorous nutrient absorption resulting in the dilution of nutrient concentration. Comparing the different treatments, the variation in N per cent of the straw was inconsistent showing a lack of significant effect of these treatments on the N content of straw. In all the treatments, the uptake of N by the straw was found to increase rapidly in the flowering stage and then decreased. This increase in the initial stages may be due to the increase in dry matter content and the decrease in the final stage can be assigned to the translocation of the nutrients to the grain from the straw. Nitrogen uptake by straw at tillering stage was maximum in plants applied with biologically activated S. Rest of the treatments did not affect the N content. At the flowering stage N uptake by straw was found to be in uniform range except a comparatively lower uptake by plants applied with Zn and the combination of nutrients. Combined application of nutrients might have resulted in an interaction between nutrients and would have lowered the uptake. At the harvesting stage, the uptake of N by straw in plants applied with Stanes Microfood was lesser. This can be attributed to the higher uptake by grain by these plants.

Data on the influence of various treatments on the content and uptake of N by grain and total N uptake are presented in Table 3.

Nitrogen content of the grain as influenced by the different treatments did not vary considerably. Application of B resulted in a maximum uptake of 40.38 kg ha^{-1}. Boron is said to function in carbohydrate metabolism and to facilitate the movement of sugars by forming a permeable boron-sugar complex or by joining the cell membrane in such a way that it is made more permeable to sugars. It is also believed to influence cell development by its control over the polysacharide formation. The rate of cell division in plants is considered as a function of B content. Thus the increased availability of B would have resulted in enhanced

Table 3. Mean values of nutrient per cent and nutrient uptake of straw and grain at harvest as influenced by different treatments (first crop)

Treatment	N % of straw	N uptake by straw, kg ha^{-1}	N % of grain	N uptake by grain, kg ha^{-1}	Total N uptake, kg ha^{-1}	P % of straw	P uptake by straw, kg ha^{-1}	P % of grain	P uptake of grain, kg ha^{-1}	Total P uptake, kg ha^{-1}
T_1	1.521	61.58	1.301	26.87	88.45	0.248	10.04	0.326	6.73	16.77
T_2	1.464	53.63	1.627	28.85	82.48	0.244	8.94	0.320	5.67	14.61
T_3	1.681	62.72	1.220	25.95	88.67	0.282	10.52	0.343	7.30	17.82
T_4	1.518	60.13	1.627	40.38	100.50	0.219	8.67	0.362	8.99	17.66
T_5	1.735	65.41	1.464	33.88	99.29	0.247	9.31	0.318	7.36	16.67
T_6	1.627	55.58	1.627	33.95	89.53	0.254	8.68	0.350	7.30	15.98
T_7	1.410	59.18	1.301	32.00	91.18	0.183	7.68	0.355	8.73	16.41
T_8	1.627	59.87	1.627	37.03	96.90	0.255	9.38	0.320	7.29	16.67
T_9	1.464	54.34	1.301	29.04	83.38	0.202	7.50	0.334	7.45	14.95
T_{10}	1.247	46.82	1.383	36.05	82.87	0.203	7.62	0.332	8.65	16.27

Contd.

Table 3. Continued

Treatment	K % of straw	K uptake by straw, kg ha^{-1}	K % of grain	K uptake by grain, kg ha^{-1}	Total K uptake, kg ha^{-1}	Ca content of straw, ppm	Ca uptake by straw, kg ha^{-1}	Ca content of grain, ppm	Ca uptake by grain, kg ha^{-1}	Total Ca uptake, kg ha^{-1}
T_1	2.300	93.13	0.55	11.38	104.5	143.7	0.582	38.0	0.078	0.660
T_2	2.717	99.52	0.60	10.68	110.2	181.7	0.666	65.0	0.115	0.781
T_3	2.583	96.37	0.45	9.53	105.9	170.7	0.637	27.0	0.057	0.694
T_4	2.433	96.37	0.55	13.63	110.0	132.0	0.523	35.0	0.087	0.610
T_5	2.483	93.61	0.55	12.69	106.3	174.3	0.657	64.0	0.148	0.805
T_6	2.133	72.86	0.55	11.48	84.3	146.7	0.501	53.0	0.111	0.612
T_7	2.750	115.40	0.55	13.48	128.9	104.7	0.439	45.0	0.111	0.550
T_8	1.900	69.92	0.50	11.38	81.3	155.3	0.572	75.0	0.171	0.743
T_9	2.333	86.60	0.45	10.04	96.6	157.3	0.584	35.0	0.078	0.662
T_{10}	2.633	98.87	0.65	16.93	115.8	170.3	0.639	60.0	0.156	0.795

Contd.

Table 3. Continued

Treatment	Mg content of straw, ppm	Mg uptake by straw, kg ha^{-1}	Mg content of grain, ppm	Mg uptake by grain, kg ha^{-1}	Total Mg uptake, kg ha^{-1}	S content of straw, ppm	S uptake by straw, kg ha^{-1}	S content of grain, ppm	S uptake by grain, kg ha^{-1}	Total S uptake, kg ha^{-1}
T_1	172.3	0.698	158	0.326	1.024	599.9	2.429	752.5	1.554	3.983
T_2	179.0	0.656	127	0.225	0.881	1166.0	4.271	988.2	1.753	6.024
T_3	292.7	1.092	189	0.402	1.494	799.8	2.984	826.0	1.757	4.741
T_4	225.3	0.892	224	0.557	1.449	883.1	3.498	721.5	1.791	5.289
T_5	224.7	0.847	184	0.426	1.273	766.5	2.890	766.5	1.773	4.663
T_6	199.7	0.682	212	0.443	1.125	666.5	2.277	702.8	1.467	3.744
T_7	185.0	0.776	182	0.448	1.224	1233.0	5.175	1024.0	2.519	7.694
T_8	144.0	0.530	216	0.493	1.023	1166.0	4.291	846.5	1.927	6.218
T_9	188.0	0.698	192	0.428	1.126	1233.0	4.577	902.5	2.014	6.591
T_{10}	186.0	0.698	227	0.592	1.290	766.5	2.878	804.6	2.097	4.975

Contd.

Table 3. Continued

Treatment	Zn content of straw, ppm	Zn uptake by straw, kg ha^{-1}	Zn content of grain, ppm	Zn uptake by grain, kg ha^{-1}	Total Zn uptake, kg ha^{-1}	Cu content of straw, ppm	Cu uptake by straw, kg ha^{-1}	Cu content of grain, ppm	Cu uptake by grain, kg ha^{-1}	Total Cu uptake, kg ha^{-1}
T_1	114.1	0.462	34.2	0.070	0.532	9.733	0.039	5.2	0.011	0.050
T_2	155.8	0.571	53.7	0.095	0.666	70.430	0.258	3.8	0.007	0.265
T_3	96.8	0.361	31.5	0.067	0.428	6.733	0.025	6.1	0.013	0.038
T_4	90.2	0.357	25.6	0.064	0.421	38.230	0.151	7.4	0.019	0.170
T_5	102.1	0.385	[illegible]1.2	0.118	0.503	6.667	0.025	8.2	0.019	0.044
T_6	78.7	0.269	33.4	0.069	0.338	20.230	0.069	7.6	0.016	0.085
T_7	184.3	0.774	30.5	0.074	0.848	12.130	0.051	6.5	0.016	0.067
T_8	72.7	0.268	32.4	0.073	0.341	8.530	0.031	5.6	0.013	0.044
T_9	126.1	0.468	34.6	0.077	0.545	23.070	0.086	6.5	0.014	0.100
T_{10}	111.7	0.419	87.5	0.228	0.647	6.900	0.026	7.1	0.018	0.044

Contd.

Table 3. Continued

Treatment	Mn content of straw, ppm	Mn uptake by straw, kg ha^{-1}	Mn content of grain, ppm	Mn uptake by grain, kg ha^{-1}	Total Mn uptake, kg ha^{-1}	Fe content of straw, ppm	Fe uptake by straw, kg ha^{-1}	Fe content of grain, ppm	Fe uptake by grain, kg ha^{-1}	Total Fe uptake, kg ha^{-1}
T_1	799	3.236	104	0.215	3.451	443.0	1.794	212	0.438	2.232
T_2	1327	4.861	100	0.176	5.037	448.7	1.644	224	0.397	2.041
T_3	1307	4.876	114	0.243	5.119	451.0	1.683	146	0.311	1.994
T_4	1101	4.361	148	0.366	4.727	351.3	1.391	192	0.477	1.868
T_5	935	3.526	152	0.352	3.878	427.0	1.610	168	0.389	1.999
T_6	810	2.768	160	0.334	3.102	700.3	2.392	177	0.369	2.761
T_7	1002	4.205	136	0.335	4.540	518.3	2.175	162	0.399	2.574
T_8	627	2.308	124	0.283	2.591	375.0	1.380	198	0.451	1.831
T_9	886	3.290	146	0.326	3.616	847.7	3.147	152	0.339	3.486
T_{10}	1011	3.796	235	0.614	4.410	403.3	1.514	184	0.480	1.994

Contd.

Table 3. Continued

Treatment	B content of straw, ppm	B uptake by straw, kg ha^{-1}	B content of grain, ppm	B uptake by grain, kg ha^{-1}	Total B uptake, kg ha^{-1}	Mo content of straw, ppm	Mo uptake by straw, g ha^{-1}	Mo content of grain, ppm	Mo uptake by grain, g ha^{-1}	Total Mo uptake, g ha^{-1}
T_1	116.5	0.472	28.85	0.059	0.531	2.66	10.770	0.98	2.020	12.790
T_2	93.2	0.341	68.46	0.122	0.463	1.68	6.154	1.12	1.987	8.141
T_3	46.6	0.174	42.52	0.090	0.264	1.54	5.746	1.19	2.531	8.277
T_4	122.3	0.484	41.60	0.104	0.588	1.26	4.991	0.98	2.432	7.423
T_5	58.2	0.220	62.82	0.145	0.365	2.24	8.445	1.26	2.915	11.360
T_6	81.5	0.279	48.21	0.100	0.379	1.40	4.782	1.12	2.338	7.120
T_7	110.7	0.465	63.62	0.156	0.621	1.54	6.463	1.26	3.100	9.563
T_8	116.5	0.429	34.60	0.078	0.507	1.40	5.152	0.84	1.912	7.064
T_9	104.8	0.389	56.52	0.126	0.515	1.33	4.937	0.98	2.187	7.124
T_{10}	52.4	0.197	58.36	0.152	0.349	1.40	5.257	1.12	2.919	8.176

Table 4. Nitrogen per cent and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	N content, per cent			N uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	1.735	1.735	1.521	43.86	157.4	61.58
T_2	1.952	1.518	1.464	49.35	123.2	53.63
T_3	1.790	1.627	1.681	44.25	133.8	62.72
T_4	1.898	1.681	1.518	49.29	145.7	60.13
T_5	2.006	1.843	1.735	50.71	158.4	65.41
T_6	1.789	1.952	1.627	40.75	172.0	55.58
T_7	2.061	1.789	1.410	66.71	157.1	59.18
T_8	1.844	1.681	1.627	48.66	158.8	59.87
T_9	2.115	1.572	1.464	55.81	119.4	54.34
T_{10}	1.844	1.844	1.247	47.11	159.8	46.82

cell development and the consequent increase in the uptake of N.

Total N uptake ranged from 82.48 kg ha^{-1} to 100.5 kg ha^{-1}. The highest N uptake of 100.5 kg ha^{-1} was due to the application of B followed by Cu with 99.29 kg ha^{-1}. The importance of B on cell development and growth and consequently on N uptake has already been explained. Copper is a metal activator of several enzymes responsible for vital metabolic activities including ascorbic acid oxidase, butyryl Co-A dehydrogenase etc. It has been suggested that Cu is one of the metals concerned with the light reaction in plants. It is therefore possible that the increased metabolic activities due to enhanced availability of Cu would have resulted in the better uptake and utilization of N in the rice plant.

Total N uptake by the rice plant at harvest was significantly positively correlated with total P uptake ($r = 0.643^{*}$) (Table 21). In general, the uptake of P is very much dependent on the uptake of N due to significant NP interaction. Increased N uptake due to enhanced dry matter production invariably necessitates increased uptake of P in order to meet the minimum requirement of P for the synthesis of protoplasm.

3.2 Phosphorus

Data on the effect of the different treatments on the content and uptake of P at different growth stages of the crop are given in Table 5.

Table 5. Phosphorus per cent and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	P content, per cent			P uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	0.358	0.363	0.248	9.050	32.93	10.04
T_2	0.361	0.358	0.244	9.126	29.04	8.94
T_3	0.389	0.351	0.282	9.616	28.86	10.52
T_4	0.376	0.370	0.219	9.765	32.07	8.67
T_5	0.406	0.390	0.247	10.260	33.51	9.31
T_6	0.375	0.395	0.254	8.543	34.82	8.68
T_7	0.382	0.395	0.183	12.370	34.68	7.68
T_8	0.390	0.391	0.255	10.290	36.93	9.38
T_9	0.384	0.382	0.202	10.130	29.01	7.50
T_{10}	0.430	0.389	0.203	10.987	33.71	7.62

Phosphorus per cent of straw decreased slightly in almost all the treatments from tillering to the flowering stage, but considerably at the harvesting stage. Application of various nutrients resulted in an increased uptake of P in the straw compared to the control in the tillering stage but in the later stages, the values were inconsistent. The P per cent of straw was not found to be significantly affected by any particular treatment at the harvesting stage. Uptake of P by straw also followed almost the same pattern as that of N. Application of biologically activated S resulted in an increase in P uptake from 9.05 kg ha^{-1} to 12.37 kg ha^{-1} at the maximum tillering stage. This may be due to the vigorous growth and thus increased dry matter production by application of biologically activated S.

Data on the influence of the application of secondary and micronutrients on uptake of P by grain and total P uptake are presented in Table 3.

There was not much difference in the P per cent of grain in the various treatments applied. The lowest uptake was recorded by the application of Zn which may be due to the possible negative interaction between these two nutrients in the soil. It can be said that P-Zn interactions in soil, such as the formation of insoluble $Zn_3(PO_4)_2.4H_2O$ would have resulted in a low uptake of P by the Zn treated plants. Similar observations were earlier reported by Patra _et_ _al_., 1981.

Total P uptake was found to be uniform in all the treatments except T_2 and T_9. Application of Zn and a combined application of the nutrients resulted in a decreased uptake of P compared to the other treatments. This may be because of the possible antagonism between Zn and P in the soil. Total P uptake was positively correlated with total Mg uptake ($r = 0.751^*$) and total N uptake ($r = 0.643^*$) and negatively correlated with pH ($r = -0.813^{**}$) and available Zn in soil ($r = -0.645^*$) (Table 21). Magnesium acts as a P carrier and helps in better P utilisation of crop plants, hence the positive correlation between total P and Mg uptake can be expected. Positive correlation with total N uptake and negative correlation with available Zn in soil are already discussed.

3.3 Potassium

Data on the influence of various treatments on the content and uptake of K by straw at different growth stages of the crop are given in Table 6.

Potassium per cent was maximum during the active tillering stage and there was a gradual decline till the harvesting stage. As explained in the case of N and P, the decline in the content of K in the advanced stages of plant growth may be due to the dilution effect as a result of increased dry matter production coupled with slow uptake of nutrients. The K content of straw

Table 6. Potassium per cent and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	K content, per cent			K uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	3.233	2.683	2.300	81.73	234.4	93.13
T_2	3.483	2.567	2.717	88.05	208.3	99.52
T_3	3.417	2.400	2.583	84.47	197.3	96.37
T_4	3.367	2.667	2.433	87.44	231.1	96.37
T_5	3.483	2.800	2.483	88.05	240.6	93.61
T_6	3.533	2.717	2.133	80.48	239.5	72.86
T_7	3.533	2.850	2.750	114.40	250.2	115.40
T_8	3.500	2.650	1.900	92.37	250.3	69.92
T_9	3.467	2.600	2.333	91.49	197.4	86.60
T_{10}	3.600	2.750	2.633	91.98	238.3	98.87

in all the treatments did not show much variation eventhough in the early stage, application of secondary and micronutrients showed an increase in the K level in straw compared to the non-treated control. The lowest K per cent was obtained in plants applied with Mg, showing a possible antagonism between these nutrients in the soil. Both Ca^{2+} and Mg^{2+} compete with K for entry into plants. According to the activity ratio concept, potassium uptake would be reduced as Ca and Mg are increased and conversely uptake of these two cations would be reduced as the supply of K is increased. Antagonism between K and Mg has been reported by Varughese (1992). Potassium uptake showed the same trend as that of N and P during the different stages of growth. Maximum K uptake was exhibited by plants which received the application of S in all the three stages of growth which reveals the possible influence of biologically activated S in the growth and uptake of nutrients by plants.

Content and uptake of K by grain and total K uptake as influenced by various treatments are presented in Table 3.

In general, per cent of K in the grain was not significantly affected by any of the treatments. A maximum content of 0.65 per cent was obtained by the application of Stanes Microfood which may be due to the increased availability of the nutrient. The highest uptake of K by grain was resulted by the application of Stanes Microfood. This is the combined effect of higher per cent K in grain and yield of grain resulted by the application of Stanes Microfood.

The highest K uptake of 128.9 kg ha^{-1} was exhibited by plants applied with sulphur, followed by the application of Stanes Microfood (115.8 kg ha^{-1}). Potassium uptake was found to be less than that of the control by the application of Mg, further revealing an antagonism between K and Mg. Total K uptake was significantly and positively correlated with total Zn uptake (r = 0.848**), total Mn uptake (r = 0.764*) and available Mn content of the soil (r = 0.687*) (Table 21). Regression equations were also worked out (Table 22).

3.4 Calcium

The micronutrient treatments tried in the study did not contain calcium. However, Ca in the straw and grain was estimated to evaluate the influence of other nutrients on the uptake of Ca by plants.

Influence of various treatments on content and uptake of Ca by straw at different stages of growth is presented in Table 7.

Calcium per cent of the straw did not show a uniform trend in all the three stages of growth considered. At the maximum tillering stage, application of all the treatments caused an increased

Table 7. Calcium content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Ca content, ppm			Ca uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	112.7	244.0	143.7	0.285	2.214	0.582
T_2	127.3	134.7	181.7	0.322	1.093	0.666
T_3	331.3	389.0	170.7	0.819	3.198	0.637
T_4	325.3	151.3	132.0	0.845	1.311	0.523
T_5	167.3	126.6	174.3	0.423	1.088	0.657
T_6	121.0	124.3	146.7	0.276	1.096	0.501
T_7	125.7	109.3	104.7	0.407	0.960	0.439
T_8	131.3	104.7	155.3	0.347	0.989	0.572
T_9	135.7	126.7	157.3	0.358	0.962	0.584
T_{10}	159.3	70.7	170.3	0.407	0.613	0.639

Ca level of the straw than the control, the maximum contents being observed in plants applied with Mn and B, which are 331.3 ppm and 325.3 ppm respectively. Other treatments did not vary much in this regard. A maximum Ca content of 389 ppm was obtained by the application of Mn in the flowering stage. Ca contents due to all the other treatments were less than that of the control, the least being in plants applied with Stanes Microfood. At the harvesting stage, the Ca content of straw did not vary considerably with treatments. Except in T_3 and T_4, Ca uptake by straw was not found to be affected by different treatments at the maximum tillering stage. Application of B and Mn resulted in an increase of Ca uptake from 0.285 kg ha^{-1} to 0.845 and 0.819 kg ha^{-1} respectively. Effect of Mn on Ca uptake is further evidenced by the highest uptake of Ca at the flowering stage. The lowest uptake in this stage was shown by the plants applied with Stanes Microfood. There appears to be a functional relationship between Ca and B in plants (Tisdale <u>et al.</u>, 1985). When Ca nutrition is high, there is a greater requirement of B and vice versa. Boron is involved in a variety of physiological activities and synthesis of amino acids and proteins which necessitate the uptake of Ca also.

Results on the effect of different treatments on the content and uptake of Ca by grain and total Ca uptake are given in Table 3.

Calcium content of the grain did not show much variation due to treatments. The application of micronutrients could not enhance the uptake of calcium probably because the level of these micronutrients in soil was not low enough to consider them as limiting factors in the absorption and utilization of calcium.

Application of Cu and Stanes Microfood resulted in higher total uptake of Ca, the values being 0.805 and 0.795 kg ha^{-1} respectively. The lowest Ca uptake was recorded in the case of S application (0.55 kg ha^{-1}). A decrease in the soil pH as a result of the application of S is obvious due to the production of sulphuric acid and thus can result in a decreased availability and uptake of Ca by the plants, consequent to heavy leaching of calcium ions from the soil.

3.5 Magnesium

Data on the influence of different treatments on the content and uptake of Mg by straw at different stages of crop growth are given in Table 8.

Magnesium level of straw at different growth stages did not show a uniform trend, instead inconsistent values were obtained. Boron and Cu applications showed very high values of Mg per cent in straw compared to other treatments at the tillering stage. At this stage, the lowest Mg content was observed in the control

Table 8. Magnesium content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Mg content, ppm			Mg uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	263.7	163.3	172.3	0.598	1.482	0.698
T_2	207.3	570.7	179.0	0.524	4.630	0.656
T_3	241.7	185.3	292.7	0.597	1.523	1.092
T_4	571.0	1166.0	225.3	1.483	10.110	0.892
T_5	477.0	264.7	224.7	1.206	2.275	0.847
T_6	231.0	214.3	199.7	0.526	1.889	0.682
T_7	209.3	223.7	185.0	0.678	1.964	0.776
T_8	224.7	223.7	144.0	0.593	2.113	0.530
T_9	178.0	181.0	188.0	0.470	1.374	0.698
T_{10}	220.7	244.3	186.0	0.564	2.117	0.698

plants and highest in plants applied with B. No general conclusion could be drawn based on the data obtained. Application of Mg did not result in increased Mg content of straw in any of the growth stages. Uptake of Mg followed the same pattern as that of the content of Mg. At the harvesting stage, the lowest uptake was recorded in plants applied with Mg. Varughese (1992) also observed that application of Mg sources to rice did not increase the plant uptake of Mg.

Influence of various treatments on the content and uptake of Mg by grain and total Mg uptake is presented in Table 3.

Content and uptake of Mg by grain was found to be maximum due to the application of Stanes Microfood followed by B and Mg. Application of Zn resulted in the lowest uptake of Mg by grain. The relatively higher Mg uptake by grains observed due to the application of Stanes Microfood is due the increased grain yield under this treatment which has already been explained.

Except in T_2, the total uptake of Mg ranged from 1.023 kg ha^{-1} to 1.494 kg ha^{-1} in all the treatments. The lowest uptake of 0.881 kg ha^{-1}, obtained by the application of Zn (T_2) may be attributed to the lower contents of Mg in the grain and straw. The adverse effect of Zn on Mg uptake cannot be explained with the help of available information on the interaction between these nutrients. Probably, Zn^{2+} ions would have competed with Mg ions for exchangeable sites on the soil colloids as a result of which retention of Mg ions in the soil is hindered by the preponderance of Zn^{2+} consequent to application of soluble Zn salts. The Mg^{2+} ions released in the soil solution would have subjected to leaching resulting in a decreased Mg uptake.

Total Mg uptake was significantly and negatively correlated with available K ($r = -0.770^{**}$) (Table 21 and Fig. 3) which could be attributed to K-Mg antagonism in soil as reported by Varughese (1992).

3.6 Sulphur

Effects of various treatments on the content and uptake of S by straw at different stages of growth of rice crop are presented in Table 9.

In general, sulphur level of straw was found to be maximum at the maximum tillering stage. The decline in S per cent at flowering stage may be accounted for the dilution due to the increased dry matter production. The highest content of S at the harvesting stage was observed in plants applied with biologically activated sulphur. As already explained this may be due to the continued availability of S under this treatment.

Uptake of S by straw was considerably higher at all the stages of growth. It may be concluded that application of biologically activated sulphur has resulted in a vigorous growth

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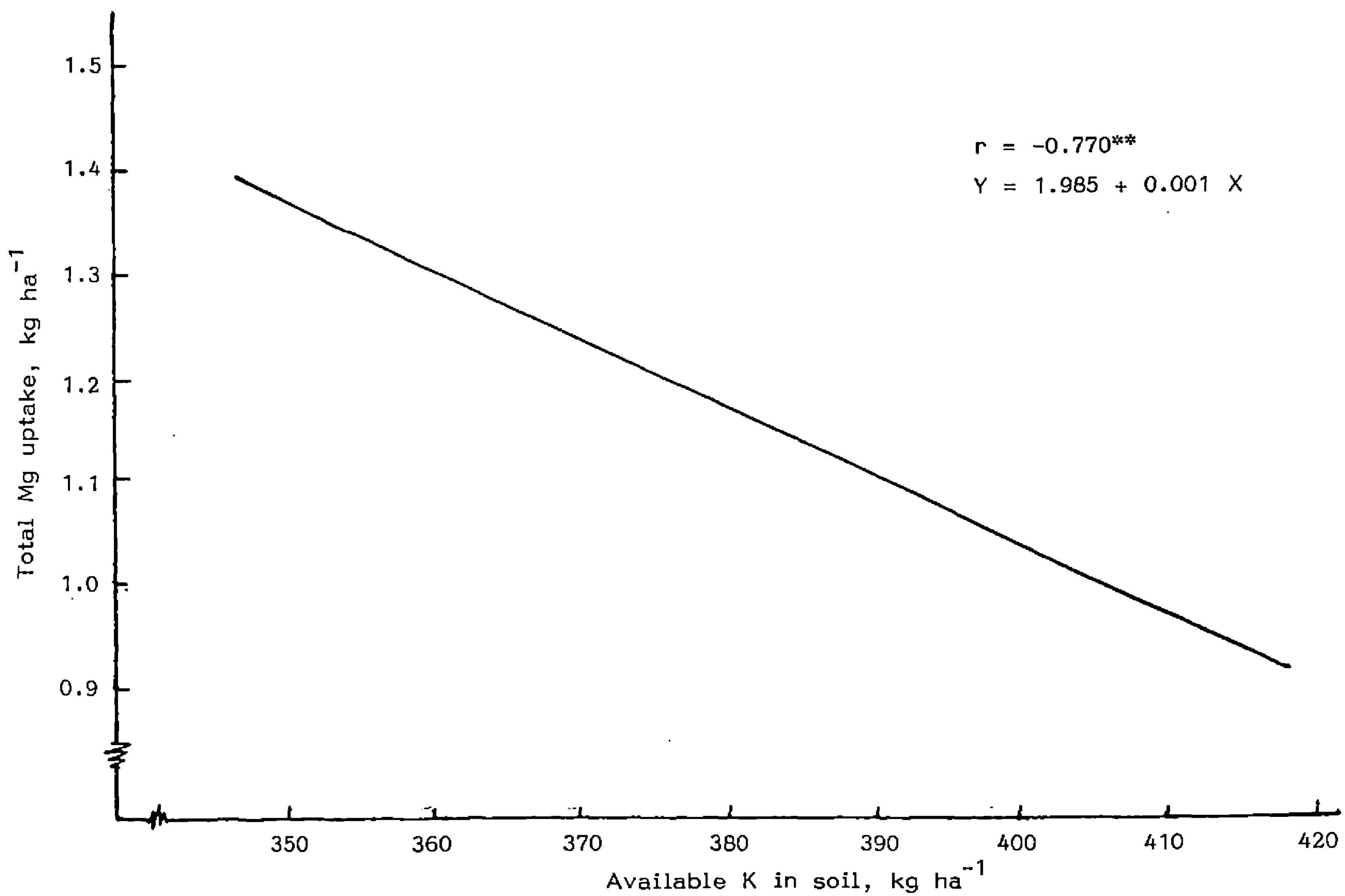

Fig. 3. Relationship between available K in soil and total Mg uptake by rice (first crop)

Table 9. Sulphur content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	S content, ppm			S uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	1133	1166.0	599.9	2.864	10.580	2.429
T_2	900	666.5	1166.0	2.275	5.407	4.271
T_3	1033	666.5	799.8	2.554	5.479	2.984
T_4	1133	666.5	883.1	2.942	5.777	3.498
T_5	1333	599.9	766.5	3.370	5.155	2.890
T_6	1066	766.5	666.5	2.428	6.756	2.277
T_7	1366	866.5	1233.0	4.422	7.607	5.175
T_8	1500	733.2	1166.0	3.959	6.926	4.291
T_9	1500	1500.0	1233.0	3.959	11.390	4.577
T_{10}	1333	699.8	766.5	3.406	6.065	2.878

and higher dry matter production. The uptake of S in control plot as well as in treatment plots was fairly good which shows that the status of available sulphur in the soil (65.63 ppm) can be rated as high (Mathew, 1989).

Data on the influence of various treatments on the content and uptake of S by grain and total S uptake are given Table 3.

Sulphur application considerably increased the per cent of S in grain. Considerable variation among the other treatments was not noticed, thus confirming the influence of S application on the S content of grain. Uptake of S by grain also followed almost the same trend, which is accounted by the increased grain yield resulted by the application of biologically activated S. The highest total S uptake was recorded by the application of biologically activated sulphur. But significant correlation with any of the other characteristics was not observed.

3.7 Zinc

Results on the effect of various treatments on the content and uptake of Zn by straw at the different growth stages of the crop are presented in Table 10.

Significant difference in the Zn level of straw was obtained by different treatments at the maximum tillering stage. The maximum Zn per cent was observed in plants applied with Zn and the

Table 10. Zinc content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Zn content, ppm			Zn uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	56.60	98.10	114.1	0.143	0.890	0.462
T_2	82.03	137.20	155.8	0.207	1.113	0.571
T_3	64.77	79.33	96.8	0.160	0.652	0.361
T_4	60.37	83.37	90.2	0.157	0.727	0.357
T_5	65.70	98.37	102.1	0.166	0.845	0.385
T_6	59.07	98.93	78.7	0.135	0.872	0.269
T_7	68.07	91.40	184.3	0.220	0.802	0.774
T_8	69.67	106.20	72.7	0.184	1.003	0.268
T_9	80.60	166.90	126.1	0.213	1.267	0.468
T_{10}	72.60	97.10	111.7	0.185	0.842	0.419

For Zn content at tillering stage, CD (0.05) for comparison of treatment means is 16.989 and for Zn content at flowering stage, CD (0.01) for comparison of treatment means is 52.357

combination of nutrients. Other treatments did not show considerable variation. At the flowering stage also, this significant difference was noticed revealing the influence of these treatments on Zn uptake by plants. Per cent of Zn in the straw showed a gradual increase from the initial to the harvesting stages barring exceptions. It is also observed that the lowest Zn content of 72.7 ppm at the harvesting stage was exhibited by plants applied with Mg. One of the mechanisms functioning in acid soils resulting in non-specific adsorption of Zn^{2+} ion is the retention of Zn by Fe and Al hydroxides releasing a hydrogen ion. The retained Zn^{2+} is less firmly held and therefore can easily be replaced by other cations like Ca^{2+} and Mg^{2+}. Application of Mg would have resulted in the release of adsorbed Zn^{2+} from the soil thus giving rise to loss of this nutrient through leaching.

Zinc uptake also followed the same trend but application of biologically activated S also, along with application of Zn and the combination of nutrients, showed the maximum Zn uptake at the tillering stage. When Zn uptake was considered, in addition to the application of Zn and the combination of nutrients, application of biologically activated S also gave rise to enhanced uptake of Zn at the tillering stage. This may be attributed to the vigorous growth and increased dry matter production caused by S application. Plants which received application Zn recorded higher Zn uptake in all the stages of growth studied.

Content and uptake of Zn by grain and total Zn uptake as influenced by various treatments are given in Table 3.

Significant increase in the Zn content of grain was resulted by the application of Stanes Micofood. Zn content of grain as a result of independent application Zn and Cu were on par. A positive correlation between Zn and Cu has been earlier reported by Nair (1970).

The highest total Zn uptake of 0.848 kg ha^{-1} was recorded by plants applied with biologically activated sulphur whereas those applied with Zn recorded 0.666 kg ha^{-1}. Application of Stanes Microfood also resulted in an increased uptake of Zn. The maximum uptake due to S treatment may be attributed to the increased dry matter production. It may be noted that application of Stanes Microfoods lead to an increase in the uptake of other nutrients like K, Ca, etc. Total Zn uptake was found to be positively correlated with total K uptake (r = 0.848**) and available Mn in soil (r = 0.705*) (Table 21 and Fig. 4).

3.8 Copper

Results on the content and uptake of Cu by straw as influenced by various treatments at different stages of crop growth are presented in Table 11.

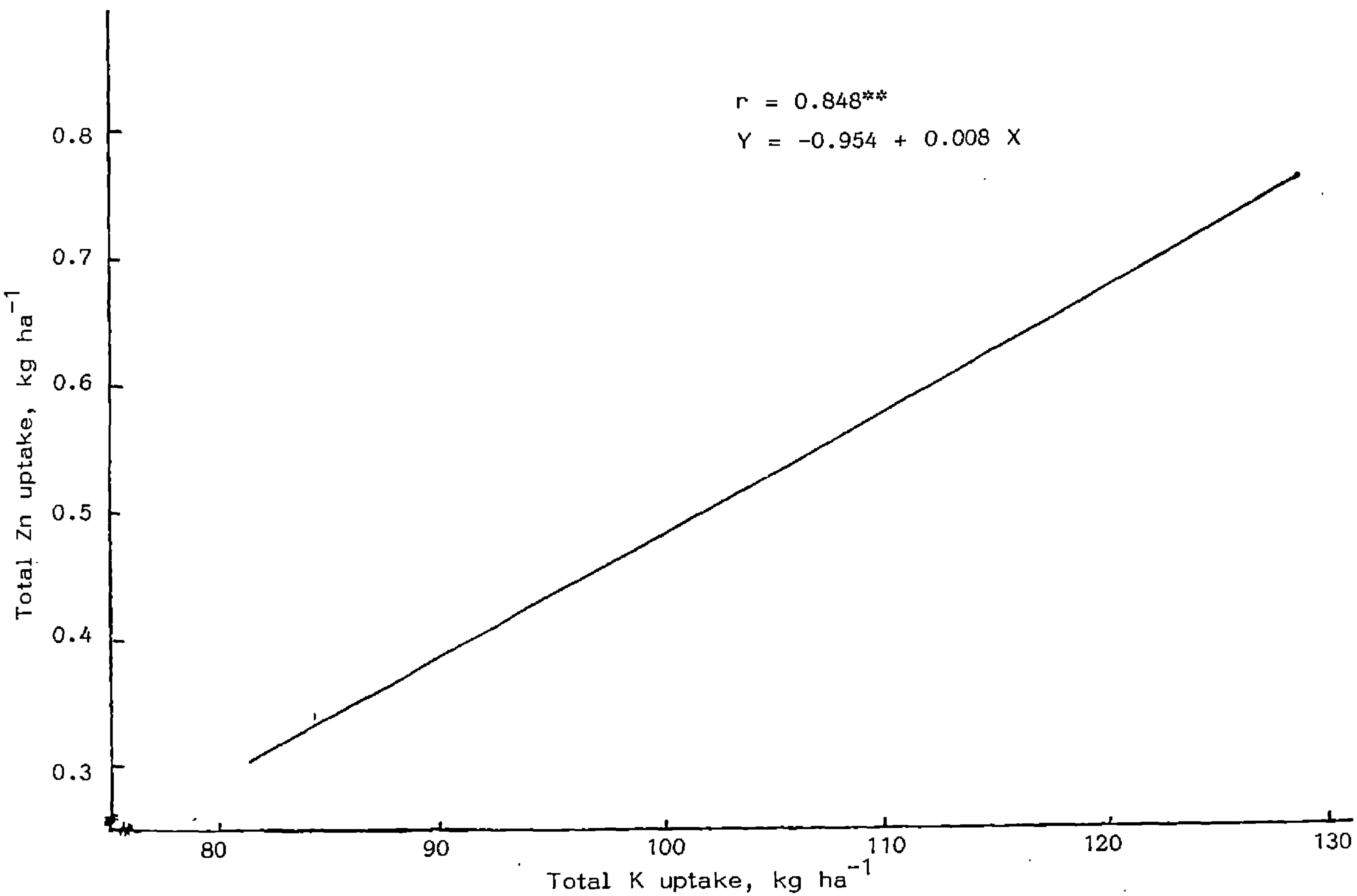

Fig. 4. Relationship between total K uptake and total Zn uptake by rice (first crop)

Table 11. Copper content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Cu content, ppm			Cu uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	13.30	15.07	9.73	0.034	0.137	0.039
T_2	11.20	10.43	70.43	0.028	0.085	0.258
T_3	11.80	10.83	6.73	0.029	0.089	0.025
T_4	11.40	11.40	38.23	0.030	0.099	0.151
T_5	13.97	11.77	6.67	0.035	0.101	0.025
T_6	9.73	11.27	20.23	0.022	0.099	0.069
T_7	12.40	9.57	12.13	0.040	0.084	0.051
T_8	10.73	15.10	8.53	0.028	0.143	0.031
T_9	11.77	12.20	23.07	0.031	0.093	0.086
T_{10}	12.37	13.10	6.90	0.032	0.114	0.026

There was no significant difference between the treatments with regard to the Cu content of straw in any of the growth stages studied. There was a slight increase from 13.3 ppm to 13.97 ppm in the Cu content of straw by the application of Cu and in all the other treatments the Cu content was less than the control at the maximum tillering stage. At the flowering stage, maximum Cu content of straw was observed in untreated control and Mg applied plants. The data showed a wide variation at the harvesting stage, where application of Zn showed the highest content of 70.43 ppm. Copper uptake by straw did not show a uniform trend with regard to a particular treatment revealing a lack of influence on the uptake.

Data on the effect of various treatments on the content and uptake of Cu by grain and total Cu uptake are given in Table 3.

Percentage of Cu in grain was the highest in plants supplied with Cu and was the lowest in plants applied in Zn. The low Cu content in the grains of Zn applied plants may be the result of a very high content of Cu in straw of these plants at the harvesting stage of the crop indicating that translocation of Cu from straw to grain has been improved by the application of zinc. All the other treatments showed an increase in the Cu content of grain compared to control. Copper uptake by grain also followed the same pattern as that of the percentage of Cu in grain.

The total uptake of Cu was found to be significantly affected by the application of Zn. The highest Cu uptake of 0.265 kg ha^{-1} was recorded by this treatment. Similar results are obtained by Nair (1970). Total Cu uptake was significantly and positively correlated with available P (r = 0.846**), available K (r = 0.646*), pH (r = 0.680*) and available Zn (r = 0.783**) in soil (Table 21 and Fig. 5, 6). It may be concluded that increased availability of P, K and Zn results in an increased uptake of Cu and there is positive correlation between Cu and Zn uptake by the rice crop.

3.9 Manganese

Results on the influence of different treatments on the content and uptake of Mn by straw at different growth stages are presented in Table 12.

A general trend of decrease in the Mn level of straw was followed from the initial to the harvesting stages except for T_2, T_3 and T_4 where an increase in Mn level was noticed at the harvesting stage. Mean per cent of Mn in the straw was found to be comparitively higher in all the treatments which may be due to the higher availability in the acidic soil conditions. Application of Mn did not result in any significant difference in the Mn level in plant revealing a required status of the nutrient in the soil. While the critical Mn level of the soil is reported to be 1 ppm, the experimental soil had an available Mn content of

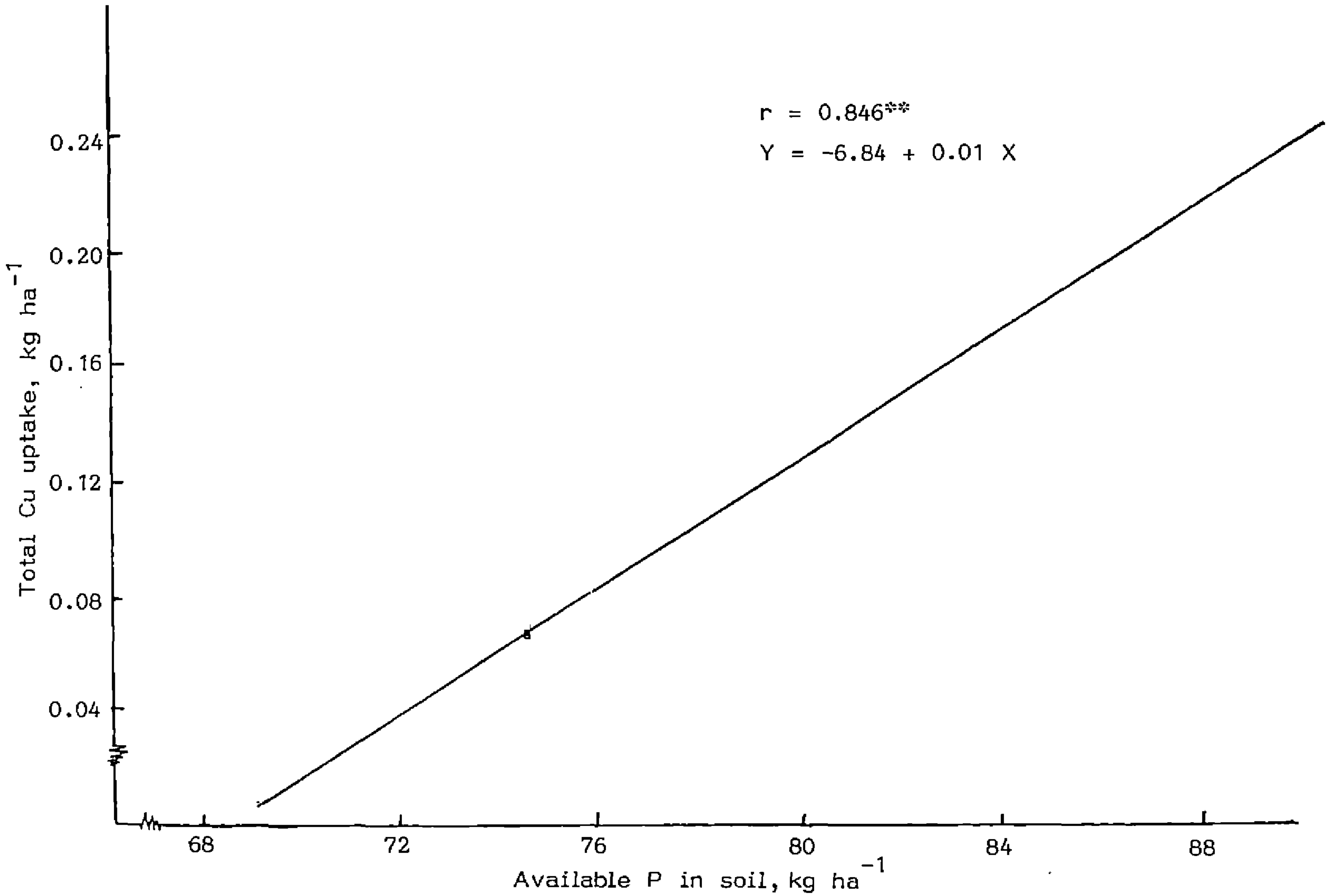

Fig. 5. Relationship between available P in soil and total Cu uptake by rice (first crop)

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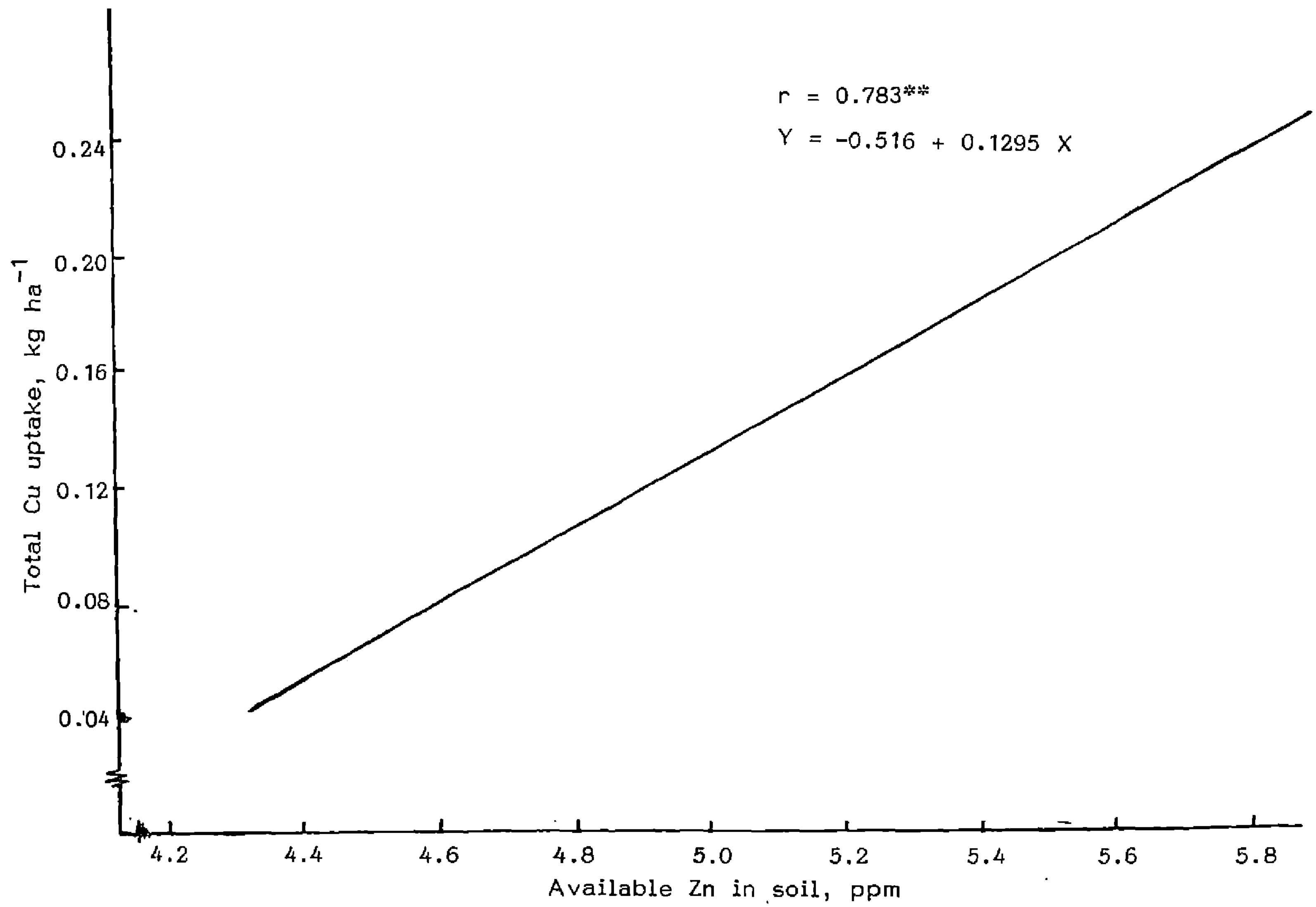

Fig. 6. Relationship between available Zn in soil and total Cu uptake by rice (first crop)

Table 12. Manganese content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Mn content, ppm			Mn uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	1143	866	799	2.890	7.857	3.236
T_2	1023	992	1327	2.586	8.051	4.861
T_3	1116	1076	1307	2.759	8.846	4.876
T_4	1098	1091	1101	2.852	9.456	4.361
T_5	1127	1117	935	2.849	9.598	3.526
T_6	1105	990	810	2.517	8.729	2.768
T_7	1091	1050	1002	3.532	9.218	4.205
T_8	1037	1097	627	2.737	10.360	2.308
T_9	1056	882	886	2.787	6.699	3.290
T_{10}	1220	1141	1011	3.117	9.889	3.796

72.73 ppm. The maximum Mn percentage of plants at tillering and flowering stages was resulted by the application of Stanes Microfood. Manganese uptake in straw at tillering stage was almost uniform except a slightly higher uptake by the application of biologically activated S and Stanes Microfood which were due to the higher dry matter production and higher Mn level in straw, respectively. Maximum uptake at harvesting stage was recorded by the application of Mn.

Data on the effect of various treatments on the content and uptake of Mn by grain and total Mn uptake are furnished in Table 3.

Application Stanes Microfood resulted in a very high level of Mn in grain (265 ppm) whereas the application of Zn and control treatment recorded the lower most levels. Independent application of Mn also did not record higher values. Manganese uptake by grain also followed the same pattern, the highest being recorded by Stanes Microfood. The high Mn content of grain and high grain yield have together caused the highest uptake of Mn by plants applied with Stanes Microfood.

Total Mn uptake was not significantly affected by various treatments, eventhough higher values were obtained in the case of Mn and Zn applications. Significant positive correlation was observed between total Mn uptake and total K uptake ($r = 0.764^{*}$) (Table 21).

3.10 Iron

The micronutrient treatments tried in the study did not contain iron. However, iron in straw and grain was estimated to evaluate the influence of other nutrients on the uptake of iron by plants.

Content and uptake of Fe by straw as influenced by various treatments at different stages of growth of rice crop are presented in Table 13.

Comparatively higher level of Fe in the straw was observed at the maximum tillering stage which might have been resulted by the increased availability, immediately after submergence. It was observed that application of other secondary and micronutrients resulted in a lower content of Fe in the straw at the maximum tillering and flowering stages compared to the control. At the harvesting stage, the Fe level of straw declined, possibly because of the translocation to the grain but the application of the combination of nutrients recorded a high value for Fe content.

Data on the influence of various treatments on the content and uptake of Fe by grain and total Fe uptake are given in Table 3.

Among the treatments, maximum Fe per cent in grain was obtained by the application of Zn, followed by the control. The

Table 13. Iron content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Fe content, ppm			Fe uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	2108	1165	443.0	5.329	10.570	1.794
T_2	1259	665	448.7	3.183	5.395	1.644
T_3	1979	831	451.0	4.892	6.829	1.683
T_4	1035	516	351.3	2.688	4.472	1.391
T_5	1613	703	427.0	4.078	6.043	1.610
T_6	1089	589	700.3	2.481	5.189	2.392
T_7	1714	542	518.3	5.548	4.761	2.175
T_8	1211	799	375.0	3.196	7.550	1.380
T_9	1453	519	847.7	3.834	3.938	3.147
T_{10}	1786	666	403.3	4.563	5.772	1.514

drop in the iron level of straw at the harvesting stage of the crop in the control plants may be explained by the increased translocation to the grain. Application of all other treatments except Zn, reduced the Fe content of the grain.

Significantly higher uptake of Fe was showed by plants which received application of the combination of nutrients. Total Fe uptake was increased from 2.232 kg ha^{-1} to 3.486 kg ha^{-1} in this case. Probably the supply of all the micronutrients at a desired level would have favourably influenced the mechanism of Fe absorption and utilization by the rice plants in acidic soil conditions.

3.11 Boron

Data on the influence of various secondary and micronutrients on the content and uptake of B by straw at different growth stages of the crop are furnished in Table 14.

Boron per cent of straw increased considerably from the earlier stage to the harvesting stage by the application of B. Effects of all the other treatments on the B level of straw were inconsistent. Application of Mo facilitated the maximum per cent of B at the tillering stage, while at the harvesting stage, maximum level of B in straw was resulted by B application. Since the B level of straw increased as the crop advanced, it may be concluded

Table 14. Boron content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	B content, ppm			B uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	40.77	23.30	116.50	0.103	0.211	0.472
T_2	34.95	81.54	93.19	0.088	0.662	0.341
T_3	64.07	34.95	46.57	0.158	0.287	0.174
T_4	34.95	81.54	122.30	0.091	0.707	0.484
T_5	69.89	93.19	58.24	0.177	0.801	0.220
T_6	116.50	69.89	81.54	0.265	0.616	0.279
T_7	52.42	40.77	110.70	0.170	0.358	0.465
T_8	69.89	81.54	116.50	0.184	0.770	0.429
T_9	40.77	46.59	104.80	0.108	0.354	0.389
T_{10}	40.77	81.54	52.42	0.104	0.707	0.197

that the availability and uptake of B are rather slow. The increase from the tillering to the flowering stage can be accounted for the foliar application of treatments. Similar trend in B uptake also was observed at the maximum tillering stage. But at the flowering stage, maximum uptake of 0.801 kg ha^{-1} was obtained by Cu application, and application of all the treatments resulted in a higher uptake compared to the control. Plants applied with B recorded the highest uptake at the harvesting stage followed by the control and all the other treatments showed lower values. The decrease in per cent of B in straw at harvesting stage may be as a result of the increased translocation of the absorbed nutrient to the grain. But the presence of adequate amounts in the soil helps better uptake as evidenced by the B treated plots.

Results on the influence of various treatments on the content and uptake of B by grain and total B uptake are given in Table 3.

Unlike the results for the B per cent of straw, application of every treatment resulted in an increased B level in grain, the highest being in Zn applied plants. Boron uptake by grain was a function of the yield of grain where the application of biologically activated S and Stanes Microfood resulted in maximum uptake. All the treatments increased the B uptake by grain. The influence of Stanes Microfood in improving the uptake of nutrients by grain is further evidenced here.

Because of the high rate of dry matter production, S application recorded the maximum total B uptake followed by the B treated plants. Significant positive correlation was observed between total B uptake and available K in soil (r = 0.652*) (Table 21).

3.12 Molybdenum

Data on the effect of various treatments on the content and uptake of Mo by straw at different growth stages of the crop are given in Table 15.

Molybdenum per cent of straw did not show much variation among the treatments. Applications of Mn, B and Cu along with control were on par with Mo application with regard to its level in straw. A decline in the Mo level was noticed at the harvesting stage by the application of nutrients which can be due to the interference in the availability and uptake of Mo by these nutrients.

Results on the influence of various treatments on the content and uptake of Mo by grain and total Mo uptake are presented in Table 3.

Molybdenum content and uptake by grain followed a similar pattern as that of the grain but here the application of treatments did not have an adverse effect. Influence of a particular nutrient on the Mo per cent of grain could not be observed, eventhough S application resulted in a maximum uptake of 3.1 g ha^{-1}.

Table 15. Molybdenum content and uptake in straw as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Mo content, ppm			Mo uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	2.17	1.19	2.66	5.486	10.80	10.770
T_2	1.82	1.19	1.68	4.601	9.65	6.154
T_3	2.03	1.05	1.54	5.018	8.63	5.746
T_4	2.24	1.05	1.26	5.817	9.10	4.991
T_5	2.31	1.19	2.24	5.840	10.23	8.445
T_6	2.24	1.26	1.40	5.103	11.11	4.782
T_7	1.68	1.12	1.54	5.438	9.83	6.463
T_8	1.75	1.54	1.40	4.618	14.55	5.152
T_9	1.54	1.33	1.33	4.064	10.10	4.937
T_{10}	1.47	1.26	1.40	3.756	10.92	5.257

Total Mo uptake was found to decline with the application of various nutrients. The highest Mo uptake of 12.79 g ha^{-1} was recorded in the control plants. High levels of SO_4^{2-} in the rooting media depress the molybdenum uptake by plants and since most of the treatments are applied as the sulphate salts, this reduction in uptake by plants can be expected. Significant positive correlation was obtained between total Mo uptake and total N in soil (r = 0.672*) (Table 21).

4. Soil analysis

4.1 Total nitrogen

Data on the total N content of the soil as influenced by different treatments at different crop growth stages are presented in Table 16.

A gradual decline in the total N content of the soil was observed as the crop growth advanced which can be due to the uptake by the crop. Total N content of the soil was not found to be affected by any of the treatments considerably, in any of the stages, the values ranging from 0.119 per cent to 0.217 per cent. The minimum value of 0.119 per cent and maximum value of 0.217 per cent was recorded in the control plants at the harvesting and maximum tillering stages respectively.

Total N content of the soil was found to have significant positive correlations with total Mo uptake (r = 0.672*) and available Cu in soil (r = 0.781**) (Table 21).

Table 16. Total N, available P and available K of soil as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Total N, per cent			Available P, kg ha^{-1}			Available K, kg ha^{-1}		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	0.217	0.141	0.119	76.07	69.03	100.0	388.3	261.3	309.9
T_2	0.206	0.141	0.130	90.17	77.45	108.5	418.1	321.1	306.1
T_3	0.212	0.135	0.135	77.48	67.59	98.6	350.9	252.0	259.5
T_4	0.195	0.152	0.141	80.30	64.81	100.7	377.1	319.2	308.0
T_5	0.201	0.136	0.132	73.26	63.40	94.4	354.7	321.1	352.8
T_6	0.195	0.141	0.135	73.26	58.47	101.5	365.9	298.7	308.0
T_7	0.196	0.141	0.141	74.66	59.87	114.1	384.5	306.1	268.8
T_8	0.190	0.130	0.146	77.48	70.44	95.8	395.7	272.5	321.1
T_9	0.185	0.135	0.135	74.66	67.62	105.7	392.0	268.8	283.7
T_{10}	0.195	0.136	0.147	69.03	78.19	101.4	347.2	265.1	313.6

4.2 Available phosphorus

Data on the effect of various treatments on the available P content of soil are given in Table 16.

No significant difference in the available P content of soil was observed between the treatments applied in all the three stages studied. Available P content of the soil was found to decrease from the maximum tillering to flowering stage and then increased in all the treatments except T_{10}. Application of Stanes Microfood resulted in a gradual increase in the availability of P. Maximum availability of P at the tillering stage was recorded by the application of Zn, indicating an adverse interaction between these two nutrients with regard to the plant uptake. Application of biologically activated S resulted in a maximum available P of 114.1 kg ha^{-1} at the harvesting stage. The increased microbial activities at the rhizosphere by the introduction of the biologically activated S would have caused better solubilization and uptake of phosphate from the root zone of the crop.

Available P of the soil was significantly and positively correlated with total Cu uptake ($r = 0.846^{**}$), available K ($r = 0.728^{*}$), organic carbon ($r = 0.696^{*}$) and available Zn ($r = 0.789^{**}$) in soil (Table 21). The positive correlation between organic carbon and available P points out the possible role of organic matter in maintaining the available P reserve of the soil. *It is* also possible that this influence of organic matter on available P would have in turn caused an indirect correlation of available P with available Zn in soil and uptake of Cu by plants. Regression equations worked out are in Table 22.

4.3 Available potassium

Results on the effects of various treatments on the available K of soil at different stages of crop growth are presented in Table 16.

In general, the available K of soil decreased from the maximum tillering stage to the flowering stage, which can be due to the uptake by the crop as the growth advanced. Thereafter, no regular trend was observed at the harvesting stage. The application of treatments could not bring any consistent variation in the available K content of the soil.

Significant positive correlations of available K of soil was observed with total Cu uptake (r = 0.646*), total B uptake (r = 0.652*), organic carbon (r = 0.751*), pH (r = 0.635*), available Zn in soil (r = 0.659*) and available B in soil (r = 0.744*) (Table 21). This reveals the influence of these nutrients in the availability of K and a strong positive interaction with B. The significant correlation between organic carbon and available K suggests that release of K from organic sources as a result of mineralisation would have taken place. It is also possible that increased organic matter content may contribute towards increased availability of other nutrients like Zn and Cu. A balance between K and B seems to exist in plants. Tisdale et al. (1985) observed that B uptake by tomato and corn was enhanced by high K in combination with high B. Available K of soil was significantly negatively correlated with total Mg uptake ($r = -0.770^{**}$) (Table 21) which indicates the K-Mg antagonism. Regression equations are given in Table 22.

4.4 Exchangeable calcium

Data on the influence of the application of secondary and micronutrients on the exchangeable Ca of soil at different stages of crop growth are given in Table 17.

Exchangeable Ca content of soil was not found to be affected by any of the treatments in any of the stages of rice crop. Comparatively higher values of 5.129 cmol(+) kg^{-1} and 5.114 cmol(+) kg^{-1} were obtained by the application of Zn and Stanes Microfood respectively in the maximum tillering stage. Values of the other treatments at the different stages did not vary considerably. High cation exchange capacity of the soil indicates the high availability of Ca in the soil.

4.5 Exchangeable magnesium

Exchangeable Mg content of the soil as influenced by different treatments at different growth stages of the crop are presented in Tabel 17.

Table 17. Exchangeable Ca, exchangeable Mg and available S of soil as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Exchangeable Ca, cmol(+) kg^{-1}			Exchangeable Mg, cmol(+) kg^{-1}			Available S, ppm		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	4.864	4.753	4.545	0.721	0.621	0.586	70.31	70.31	65.63
T_2	5.129	4.909	4.054	0.880	0.641	0.589	70.31	75.00	70.31
T_3	4.177	4.317	4.328	0.671	0.607	0.579	65.63	60.94	56.25
T_4	4.833	4.903	4.755	0.720	0.678	0.637	70.31	65.63	65.63
T_5	4.847	4.677	3.782	0.686	0.641	0.535	65.63	65.63	65.63
T_6	4.570	4.773	4.185	0.642	0.630	0.570	60.94	56.25	65.63
T_7	4.931	5.572	4.204	0.755	0.649	0.574	70.31	60.94	79.69
T_8	4.716	4.619	4.500	0.738	0.599	0.610	70.31	51.56	65.63
T_9	4.844	4.683	4.347	0.680	0.644	0.557	79.69	70.31	70.31
T_{10}	5.114	4.290	4.390	0.657	0.600	0.612	75.00	70.31	65.63

A gradual decline in the exchangeable Mg of soil was observed from the initial to the final stages of crop growth. The contents did not differ significantly by any of the treatments in any of the stages. Application of Mg, eventhough resulted in a higher content of Mg in the tillering stage, was not found to influence the soil content of exchangeable Mg throughout crop growth, revealing the presence in adequate amounts in soil, as evidenced by the high CEC.

Exchangeable Mg in soil failed to establish significant correlation with the availability and uptake of other nutrients.

4.6 Available sulphur

Data on the effect of various treatments on the available S content of soil at different stages of crop growth are given in Table 17.

Available S content of soil was not found to be influenced by the application of secondary and micronutrients in this rice soils. This may be due to the fact that sufficient amount of this nutrient already existed in the soil. This confirms the earlier observations made by Jacob (1966) and Mathew (1989). The high values of available S in soil were usually associated with higher S uptake.

4.7 Available zinc

Data on available zinc content of soil as influenced by various treatments at different stages of crop growth are presented in Table 18.

Significant difference was obtained between the application of Zn and other nutrients in the available Zn content of the soil at the tillering stage. The highest Zn content of 5.9 ppm in soil was resulted by the Zn treatment while the other treatments were on par. An increase in the available Zn of soil at harvest was noted by the application of Zn, combination of nutrients and Stanes Microfood, the highest being resulted by the independent application of Zn. All the above three treatments involved Zn and thus confirms the advantage of Zn application in the availability of this nutrient in the soil.

Available Zn of soil was significantly positively correlated with total Cu uptake ($r = 0.783^{**}$) (Table 21) indicating a positive interaction between these two nutrients in the soil. Significant negative correlation was observed between available Zn in soil and total P uptake ($r = -0.645^{*}$) showing the adverse interaction in uptake of phosphorus.

4.8 Available copper

Data on the influence of various treatments on the content

Table 18. Available Zn, Cu and Mn of soil as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Available Zn, ppm			Available Cu, ppm			Available Mn, ppm		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	4.673	4.492	4.931	5.277	5.185	5.039	125.3	105.5	279.4
T_2	5.900	5.133	6.909	5.132	5.307	4.889	128.0	108.1	232.6
T_3	4.529	4.184	4.796	5.121	5.109	5.073	120.6	106.9	175.1
T_4	4.476	4.341	4.363	5.128	5.095	4.868	118.0	111.4	167.0
T_5	4.471	4.705	4.987	5.080	5.102	5.647	118.7	107.6	173.9
T_6	4.325	4.527	4.987	4.892	5.416	5.096	105.3	126.4	210.1
T_7	4.615	4.509	4.449	4.951	5.132	4.905	127.4	107.1	167.7
T_8	4.487	4.424	4.719	4.937	5.061	4.977	116.8	98.2	159.1
T_9	4.687	5.171	5.612	4.727	5.185	5.017	116.9	103.5	142.4
T_{10}	4.647	4.416	5.108	5.179	4.874	4.875	117.3	89.6	163.9

For available Zn of soil at tillering stage, CD (0.05) for comparison of treatment means is 0.7842 of available Cu in soil at different crop growth stages are given in Table 18.

Results revealed a uniform status of available Cu in soil irrespective of the treatments. Application of Cu did not result in an increase in the available Cu of soil except a slight increase at the harvesting stage. It is likely that the amount of Cu applied is not sufficient enough to raise the available Cu level of the soil appreciably. However, increased uptake of Cu was noticed due to the application of Cu. Relationship between total N and available Cu in soil is given in Fig. 7.

4.9 Available manganese

Effect of various treatments on the available Mn content of soil at different stages of the rice crop is presented in Table 18.

Considerable increase has been noted in the available Mn content of the soil from 72.73 ppm in the initial soil to 125.3 ppm at tillering stage. This can be attributed to the increased availability of the nutrient on submergence. Values of available Mn content of soils treated with different nutrients were on par except a high availability exhibited by the control plot at the harvesting stage. This may be due to the lower uptake by the crop.

Significant positive correlations of available Mn in soil were obtained with straw yield (r = 0.701*), total K uptake

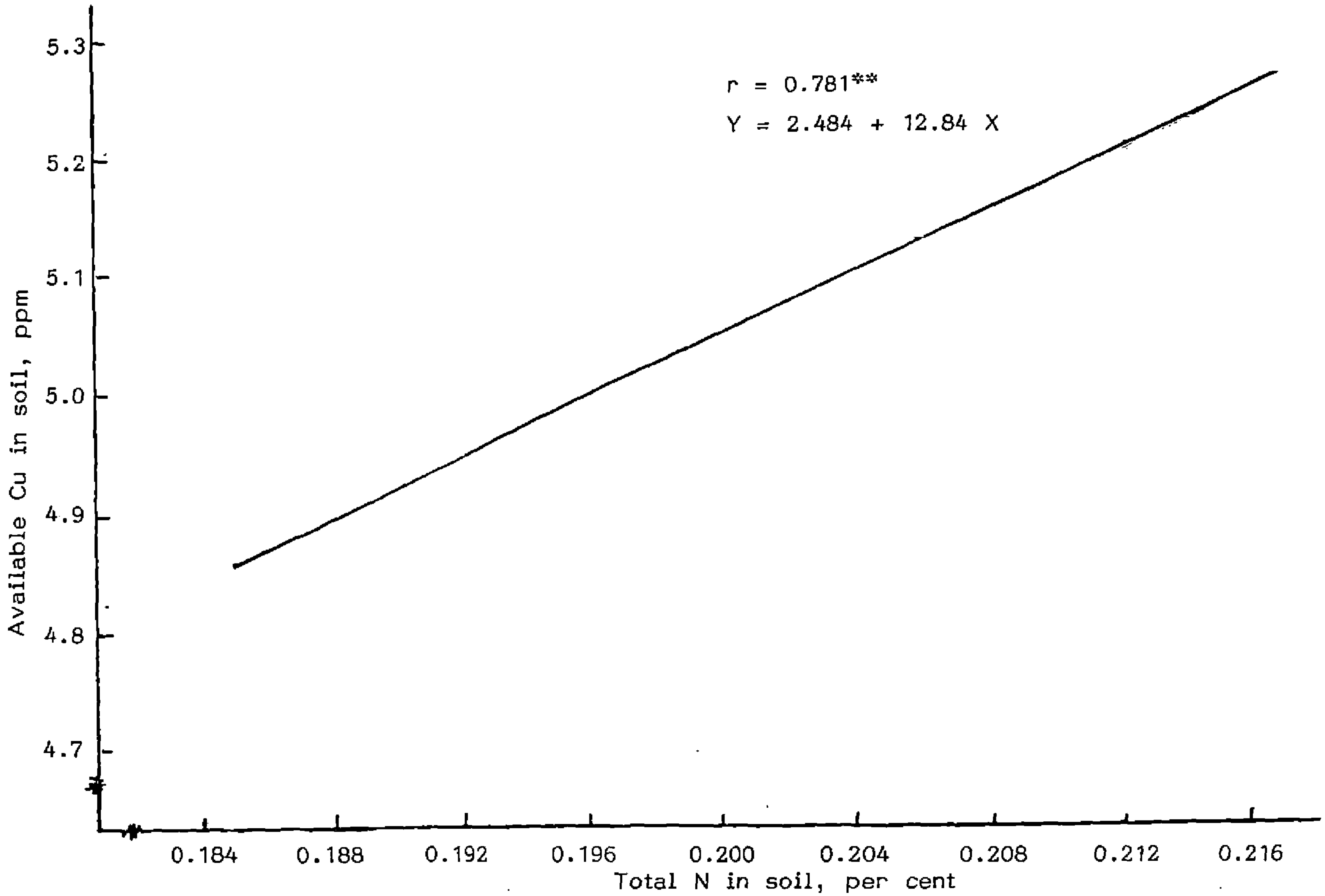

Fig. 7. Relationship between total N in soil and available Cu in soil (first crop)

(r = 0.687*), total Zn uptake (r = 0.705*) and available B in soil (r = 0.695*) (Table 21).

4.10 Available iron

Results on the influence of various treatments on the available Fe of soil at different stages of crop growth are given in Table 19.

Available Fe of soil was significantly increased from 120.6 ppm in the initial soil to 185.6 ppm at the tillering stage, invariably due to submergence. An increase in the available Fe content of soil from the tillering to flowering stages and a subsequent decrease in the harvesting stage was noticed, uniformly in all the treatments. Application of any particular nutrient was not found to influence the content of available Fe considerably but the highest contents of available Fe were recorded by the application of Mn in all the three stages. This expresses a negative interaction between Mn and Fe with regard to the plant uptake which resulted in an accumulation of Fe in the soil.

4.11 Available boron

Data on the effects of various treatments on the available B of soil at different growth stages of rice crop are furnished in Table 19.

of available Cu in soil at different crop growth stages are given in Table 18.

Results revealed a uniform status of available Cu in soil irrespective of the treatments. Application of Cu did not result in an increase in the available Cu of soil except a slight increase at the harvesting stage. It is likely that the amount of Cu applied is not sufficient enough to raise the available Cu level of the soil appreciably. However, increased uptake of Cu was noticed due to the application of Cu. Relationship between total N and available Cu in soil is given in Fig. 7.

4.9 Available manganese

Effect of various treatments on the available Mn content of soil at different stages of the rice crop is presented in Table 18.

Considerable increase has been noted in the available Mn content of the soil from 72.73 ppm in the initial soil to 125.3 ppm at tillering stage. This can be attributed to the increased availability of the nutrient on submergence. Values of available Mn content of soils treated with different nutrients were on par except a high availability exhibited by the control plot at the harvesting stage. This may be due to the lower uptake by the crop.

Significant positive correlations of available Mn in soil were obtained with straw yield (r = 0.701*), total K uptake

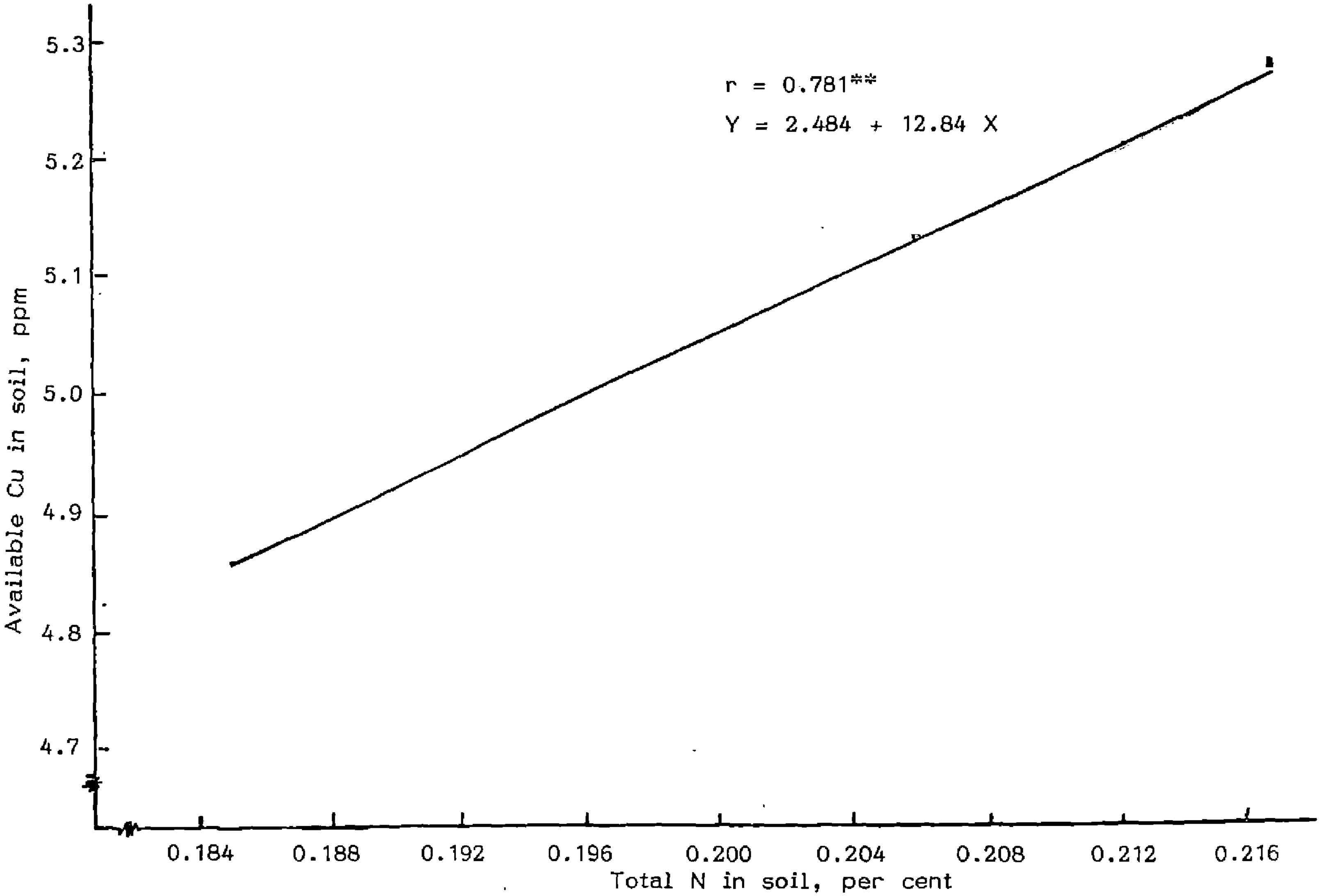

Fig. 7. Relationship between total N in soil and available Cu in soil (first crop)

(r = 0.687*), total Zn uptake (r = 0.705*) and available B in soil (r = 0.695*) (Table 21).

4.10 Available iron

Results on the influence of various treatments on the available Fe of soil at different stages of crop growth are given in Table 19.

Available Fe of soil was significantly increased from 120.6 ppm in the initial soil to 185.6 ppm at the tillering stage, invariably due to submergence. An increase in the available Fe content of soil from the tillering to flowering stages and a subsequent decrease in the harvesting stage was noticed, uniformly in all the treatments. Application of any particular nutrient was not found to influence the content of available Fe considerably but the highest contents of available Fe were recorded by the application of Mn in all the three stages. This expresses a negative interaction between Mn and Fe with regard to the plant uptake which resulted in an accumulation of Fe in the soil.

4.11 Available boron

Data on the effects of various treatments on the available B of soil at different growth stages of rice crop are furnished in Table 19.

Table 19. Available Fe, B and Mo of soil as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Available Fe, ppm			Available B, ppm			Available Mo, ppm		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	185.6	247.0	198.1	2.796	1.165	0.932	2.52	3.15	2.66
T_2	170.7	236.3	215.9	2.563	1.398	0.582	2.80	3.15	3.50
T_3	215.5	284.9	235.1	0.582	0.699	1.048	3.08	2.80	3.36
T_4	181.9	233.6	206.4	0.466	0.233	1.398	2.66	2.80	2.80
T_5	218.3	264.0	232.1	0.116	0.699	1.631	3.22	2.94	2.94
T_6	208.6	271.0	226.9	0.233	0.932	0.233	3.64	3.64	4.20
T_7	198.3	274.5	203.6	2.097	0.932	0.349	3.36	3.36	4.06
T_8	168.5	237.4	223.3	1.165	1.864	0.582	3.08	3.22	4.76
T_9	195.2	274.3	238.3	2.097	0.932	1.631	2.80	3.08	2.66
T_{10}	201.7	236.8	202.6	0.932	1.165	0.349	3.08	3.08	3.22

Results on the influence of various treatments on the available B of soil were inconsistent. Available B content of 2.796 ppm in the control plot at the tillering stage was reduced by various treatments. It may be probably due to the chemical interactions triggered by the application of nutrients which rendered the B unavailable. Application of B also did not result in an increase in the available B content in the soil.

Significant negative correlation was observed between available B of soil and total Mg uptake (r = -0.654*). Available B of soil was significantly and positively correlated with available K (r = 0.744*) and available Mn (r = 0.695*) in soil (Table 21).

4.12 Available molybdenum

Available Mo of soil as affected by various treatments at different stages of rice crop is presented in Table 19.

No significant difference in the available Mo of soil was observed as a result of the application of treatments. At harvest, Mg applied soil recorded maximum content followed by Mo applied soil. The favourable effects of Mg on the availability and uptake of Mo have been reported by Tisdale et al. (1985).

4.13 Organic carbon

Data on the influence of various treatments on the organic carbon content of soil at different stages of crop growth are presented in Table 20.

Organic carbon content of the initial soil, 0.68 per cent, was not influenced by any of the treatment at any stage. The range of organic carbon content was from 0.62 per cent to 0.75 per cent in all the stages. It can be concluded that the application of secondary and micronutrients has no influence on the organic carbon content of the soil.

Significant positive correlation of organic carbon was observed with available P (r = 0.696*) and available K (r = 0.751*) in soil probably because of the contribution of these elements to the available pool by the mineralisation of organic matter.

4.14 pH

Data on soil pH at different stages of crop growth as influenced by the treatments are presented in Table 20.

The initial soil had a pH of 5.65 which increased to the range of 5.84 - 5.91 at the tillering stage due to submergence of the soil. pH of the soil was not found to be affected by any

Table 20. Organic carbon, pH and specific conductance of soil as influenced by the treatments at different stages of crop growth (first crop)

Treatment	Organic carbon, per cent			pH			Specific conductance dS m^{-1}		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	0.68	0.68	0.67	5.86	5.86	5.68	0.083	0.069	0.087
T_2	0.75	0.70	0.71	5.94	5.93	5.71	0.084	0.088	0.097
T_3	0.65	0.68	0.69	5.84	5.89	5.56	0.083	0.078	0.094
T_4	0.67	0.69	0.66	5.88	5.90	5.77	0.084	0.072	0.079
T_5	0.67	0.67	0.73	5.89	5.91	5.74	0.084	0.075	0.096
T_6	0.71	0.72	0.74	5.87	5.79	5.64	0.079	0.072	0.088
T_7	0.69	0.63	0.66	5.87	5.97	5.69	0.098	0.086	0.091
T_8	0.71	0.68	0.70	5.89	5.85	5.71	0.081	0.066	0.082
T_9	0.66	0.65	0.67	5.91	5.90	5.60	0.088	0.074	0.096
T_{10}	0.64	0.62	0.66	5.89	5.89	5.76	0.085	0.080	0.081

of the treatments and uniform values obtained in all the three stages. A decline in pH at the harvesting stage was noted which can be due to the draining of the soil 15 days before harvest.

pH of the soil showed significant positive correlations with total Cu uptake (r = 0.689*), available K in soil (r = 0.635*), exchangeable Mg in soil (r = 0.683*) and available Zn in soil (r = 0.715*). Availability of Cu, K, Mg and Zn might have increased due to the increase in pH caused by submergence of the soil.

Specific conductance

Data on the influence of various treatments on the specific conductance of soil at different stages of crop growth are given in Table 20.

In general, the specific conductance of soil decreased from the maximum tillering stage to the flowering stage. This can be accounted for the uptake of salts by the crop. Then a subsequent increase was observed at the harvesting stage which can be because of the lower uptake at harvesting stage and also due to the drying of the field at this period. Various treatments did not show any influence on the specific conductance of soil in all the three stages. The highest value of 0.098 dS m^{-1} at the maximum tillering stage was recorded by soil applied with S. The initial soil had a specific conductance of 0.086 dS m^{-1} which was further reduced on submergence.

Table 21. Inter-relationships of soil and plant characteristics of the first crop (coefficient of simple linear correlation)

	Grain yield	Straw yield	Total dry matter	Total N uptake	Total P uptake	Total K uptake	Total Mg uptake	Total S uptake	Total Zn uptake	Total Cu uptake	Total Mn uptake	Total B uptake	Total Mo uptake
Grain yield	–	0.394	0.851**	0.354	0.436	0.339	0.605	0.213	0.157	-0.472	0.006	0.162	-0.076
Straw yield		–	0.818**	0.218	0.344	0.722*	0.205	0.397	0.592	-0.113	0.301	0.627	0.550
Total dry matter yield			–	0.346	0.469	0.624	0.496	0.360	0.436	-0.360	0.175	0.460	0.266
Total N uptake				–	0.643*	-0.142	0.370	-0.072	-0.423	-0.194	-0.217	0.228	0.122
Total P uptake					–	0.089	0.751*	-0.322	-0.366	-0.494	0.118	-0.132	0.200
Total K uptake						–	0.321	0.363	0.848**	0.139	0.764*	0.209	0.366
Total Mg uptake							–	-0.148	-0.138	-0.348	0.449	-0.294	-0.085
Total S uptake								–	0.589	0.215	0.174	0.581	-0.280
Total Zn uptake									–	0.178	0.493	0.332	0.300
Total Cu uptake										–	0.432	0.299	-0.303
Total Mn uptake											–	-0.139	0.002
Total B uptake												–	0.058
Total Mo uptake													–

Contd.

Table 21. Continued

	Total N in soil	Av. P in soil	Av. K in soil	Org. C in soil	pH	Exch. Mg in soil	Av. S in soil	Av. Zn in soil	Av. Cu in soil	Av. Mn in soil	Av. B in soil	Av. Mo in soil
Grain yield	-0.482	-0.674*	-0.540	-0.668*	-0.271	0.154	0.290	-0.613	-0.047	-0.172	-0.396	0.158
Straw yield	0.242	-0.039	0.104	-0.247	-0.295	0.274	0.291	-0.057	0.337	0.701*	0.421	-0.380
Total dry matter yield	-0.164	-0.444	-0.279	-0.559	-0.338	0.253	0.348	-0.417	0.163	0.292	-0.008	-0.118
Total N uptake	-0.109	-0.066	-0.179	-0.036	-0.289	-0.231	-0.410	-0.531	0.047	-0.169	-0.546	0.097
Total P uptake	0.310	-0.271	-0.577	-0.504	-0.813**	-0.563	-0.386	-0.645*	0.421	-0.070	-0.520	-0.011
Total K uptake	0.255	0.031	-0.112	-0.253	-0.062	0.407	0.233	0.264	0.407	0.687*	0.261	-0.139
Total Mg uptake	0.005	-0.385	-0.770**	-0.757*	-0.622	-0.474	-0.148	-0.574	0.144	-0.184	-0.654*	0.126
Total S uptake	-0.486	0.214	0.496	0.172	0.426	0.334	0.545	-0.469	0.469	0.423	-0.016	0.275
Total Zn uptake	0.063	0.048	0.203	0.017	0.247	0.614	0.416	0.455	0.108	0.705*	0.573	-0.045
Total Cu uptake	-0.006	0.846**	0.646*	0.612	0.689*	0.418	0.114	0.783**	0.052	0.276	0.310	-0.351
Total Mn uptake	0.357	0.387	-0.118	-0.162	0.005	0.063	0.058	0.446	0.417	0.529	0.045	-0.202
Total B uptake	-0.279	0.232	0.652*	0.285	0.224	0.460	0.395	0.087	-0.185	0.366	0.531	-0.356
Total Mo uptake	0.672*	-0.146	-0.099	-0.130	-0.337	0.166	-0.142	-0.015	0.566	0.491	0.292	-0.239

Contd.

Table 21. Continued

	Total N in soil	Av. P in soil	Av. K in soil	Org. C in soil	pH	Exch. Mg in soil	Av. S in soil	Av. Zn in soil	Av. Cu in soil	Av. Mn in soil	Av. B in soil	Av. Mo in soil
Total N in soil	–	0.287	-0.065	0.046	-0.416	-0.216	-0.396	0.260	0.781**	0.485	0.234	-0.304
Av. P in soil		–	0.728*	0.696*	0.501	0.131	-0.041	0.789**	0.183	0.482	0.388	-0.430
Av. K in soil			–	0.751*	0.635*	0.404	0.317	0.659*	-0.191	0.442	0.744*	-0.421
Org. C in soil				–	0.547	0.236	-0.297	0.594	-0.105	0.152	0.339	0.100
pH					–	0.683*	0.433	0.715*	-0.260	0.150	0.333	-0.176
Exch. Mg in soil						–	0.528	0.509	0.150	0.374	0.467	-0.285
Av. S in soil							–	0.240	-0.192	0.315	0.531	-0.561
Av. Zn in soil								–	0.221	0.598	0.609	-0.371
Av. Cu in soil									–	0.441	0.063	-0.422
Av. Mn in soil										–	0.695*	-0.506
Av. B in soil											–	-0.527
Av. Mo in soil												–

** Significant at 1% level   * Significant at 5% level   n = 10   df = n - 2 = 8

Table 22. Relationship between straw yield, grain yield, nutrient uptake and soil characteristics (first crop)

X	Y	Regression equation	R^2
Available P in soil	Grain yield	Y = 5520 - 17.45 X	0.531
Organic carbon in soil	,,	Y = 5520 - 2842 X	0.531
Available Mn in soil	Straw yield	Y = 989.9 + 23.47 X	0.491
Total N uptake	Total P uptake	Y = 179.4 + 0.080 X	0.860
pH	,,	Y = 179.4 - 29.32 X	0.860
Available Zn in soil	,,	Y = 179.4 + 0.499 X	0.860
Straw yield	Total K uptake	Y = -101.1 + 0.03 X	0.586
Available Mn in soil	,,	Y = -101.1 + 0.761 X	0.586
Total P uptake	Total Mg uptake	Y = 1.985 + 0.066 X	0.829
Available K in soil	,,	Y = 1.985 + 0.001 X	0.829
Organic carbon in soil	,,	Y = 1.985 - 3.204 X	0.829
Available B in soil	,,	Y = 1.985 - 0.074 X	0.829
Total K uptake	Total Zn uptake	Y = -0.954 + 0.008 X	0.747
Available Mn in soil	,,	Y = -0.954 + 0.006 X	0.747
Available P in soil	Total Cu uptake	Y = -6.84 + 0.01 X	0.820
Available K in soil	,,	Y = -6.84 - 0.001 X	0.820
pH	Total Cu uptake	Y = -6.84 + 1.085 X	0.820
Available Zn in soil	,,	Y = -0.516 + 0.1295 X	0.613

Contd.

Table 22. Continued

X	Y	Regression equation	R^2
Total K uptake	Total Mn uptake	Y = -0.769 + 0.046 X	0.584
Available K in soil	Total B uptake	Y = -0.787 + 0.003 X	0.425
Total N in soil	Total Mo uptake	Y = -17.85 + 133.3 X	0.452
Available P in soil	Available K in soil	Y = 153.3 + 2.925 X	0.529
Available P in soil	Organic carbon in soil	Y = 0.371 + 0.004 X	0.484
Available K in soil	,,	Y = 0.271 + 0.001 X	0.564
Available K in soil	pH	Y = 5.585 + 0.001 X	0.403
pH	Exchangeable Mg in soil	Y = -34.06 + 6.604 X	0.466
Available P in soil	Available Zn in soil	Y = -40.28 + 0.049 X	0.761
Available K in soil	,,	Y = -40.28 - 0.002 X	0.761
pH	,,	Y = -40.28 + 7.109 X	0.761
Total N in soil	Available Cu in soil	Y = 2.484 + 12.84 X	0.609
Available K in soil	Available B in soil	Y = -15.96 + 0.024 X	0.721
Available Mn in soil	,,	Y = -15.96 + 0.069 X	0.721

B. Second crop

The continued effects of the application of secondary and micronutrients were studied by repeating the field experiment in the second crop season with the same set of treatments applied to the same plots. Yield of straw and grain and nutrient uptake were recorded and the soil nutrient status was studied for the second crop also.

1. Biometric characters

Data on the influence of various treatments on biometric characters such as number of tillers and height of the plant at maximum tillering stage, number of spicklets per panicle and dry weight of 100 grains of the second crop are presented in Table 23.

Number of tillers at the active tillering was maximum by the application of biologically activated S (7.1). This reflects the influence of S on the vegetative growth of the crop. Application of Cu and Stanes Microfood resulted in the minimum number of tillers (5.7 and 5.6 respectively) in the second crop season. All the other treatments were on par with the control in the number of tillers. Height of the plant at maximum tillering stage was slightly reduced by the applications of Mn, Mo and the combination of all nutrients while the maximum height was recorded by the application of biologically activated S. This further

Table 23. Biometric observations of rice in the field experiment, second crop (mean of three replications)

Treatments	No. of tillers at maximum tillering	Height of plant at tillering stage, cm	No. of spikelets per panicle	Dry weight of 100 grains, g	Grain yield, kg ha^{-1}	Straw yield, kg ha^{-1}
T_1	6.1	58.03	8.87	2.803	2813	2808
T_2	6.1	56.37	7.33	2.777	2486	2628
T_3	6.0	52.97	8.37	2.810	2813	2551
T_4	6.2	56.73	9.47	2.830	2964	3100
T_5	5.7	57.73	8.60	2.800	2943	2757
T_6	6.9	52.13	8.87	2.810	3005	2907
T_7	7.1	62.47	9.07	2.863	2689	3221
T_8	6.0	55.87	8.27	2.810	2709	2662
T_9	6.2	52.97	8.70	2.807	3185	2955
T_{10}	5.6	57.57	8.90	2.807	2464	2620

indicates the influence of S on vegetative growth of the crop. Number of spikelets per panicle, a character which reflects the grain yield, was maximum in plants applied with B (9.47) followed by S (9.07). The importance of B in the carbohydrate metabolism and cell development might have influenced this yield character which subsequently resulted in a higher grain yield. Other treatments did not vary much in this regard. Dry weight of 100 grains ranged from 2.777 g for Zn treated plants to 2.863 g for the S treated plants. Thus the beneficial effects of the application of biologically activated S are confirmed.

In general the morphological characters are not found to be consistently influenced by treatments except an enhanced growth resulted by the application of biologically activated sulphur. In general, plot which received application of S as biologically activated elemental S showed maximum yield of straw. This could be attributed to the effect of inoculation of S with Thiobacillus and Aspergellus organisms on the oxidation of S. When elemental S is applied in soil, and its performance compared with that of soluble sulphate salts, the sulphate salts may give initially better responses but because of the high solubility of the sulphur salts there will be heavy leaching loss of sulphates from the root zone through percolating waters. On the other hand the elemental S must first be oxidised to sulphate which is not a rapid process. As a result application of biologically activated elemental S assures better availability of S during the entire growth period of the plant. This may be the probable reason for the better performance of the crop under elemental S application as compared to its performance in treatments which received various sulphate salts. It is also possible that the microorganisms viz. Thiobacillus sp. and Aspergillus avomerii would have increased the availability of plant nutrients through their activity at the rhizosphere. Similiar results were obtained during the first crop also.

2. Yield of straw and grain

2.1 Yield of straw

Data on the effects of various treatments on the yield of straw for the second crop are given in Table 23.

In the second crop also the maximum straw yield was recorded by the application of biologically activated S (3221 kg ha^{-1}). The influence of the application of biologically activated S on the vegetative growth was evident and this resulted in the highest straw yield, confirming the results of the first crop. Application of B, the combination of nutrients and Mo gave straw yields of 3100, 2955 and 2907 kg ha^{-1} respectively. In all the other treatments, the yield of straw was found to be less than that of the control.

Significant positive correlations of straw yield was observed with total dry matter yield (r = 0.685*), total P uptake (r = 0.722*) and total K uptake (r = 0.834**) (Table 41). Regression equations were also worked out (Table 42).

2.2. Yield of grain

Yield of grain as influenced by the different treatments in the second crop is presented in Table 23.

No significant difference was observed between the different treatments with regard to the grain yield in the second crop also. The highest grain yield (3185 kg ha^{-1}) was obtained by the application of the combination of nutrients. Application of Mo, B and Cu resulted in higher yields than that of the control. Boron is said to function in carbohydrate metabolism and is believed to influence cell development by its control over polysaccharide formation. Copper is one of the metals concerned with light reactions and therefore better availability of Cu would have enhanced the uptake and utilization of N. Because of the essentiality of Mo in many important enzymes such as nitrate reductase and nitrogenase, it also enhances the uptake and utilization of N and other nutrients. The beneficial effects of all these nutrients were exhibited in the second crop which resulted in an increased uptake and utilization of N and other nutrients and thus increased the grain yield. Grain yield of biologically activated S applied plants was comparatively lesser, may be due to the higher straw yield. In the second crop, Stanes Microfood was not as effective as in the first crop in increasing the grain yield.

Grain yield was significantly correlated with total dry matter yield (r = 0.795**), total N uptake (r = 0.802**) and total P uptake (r = 0.842**) (Table 41 and Fig. 8, 9).

It can be observed that the yields of grain and straw in both first and second crops were not significantly influenced by any of the secondary or micronutrients applied. This leads to the conclusion that these nutrients are present in the required forms and levels in the soil where the experiment was conducted. But the mean yield of grain and straw in the second crop was comparatively higher than that of the first crop which indicated that the application of these nutrients resulted in increased uptake of nutrients and thus increased in yields.

3. Content and uptake of nutrients

3.1 Nitrogen

Influence of various treatments on the content and uptake of N by the straw at different growth stages of the second crop is presented in Table 25.

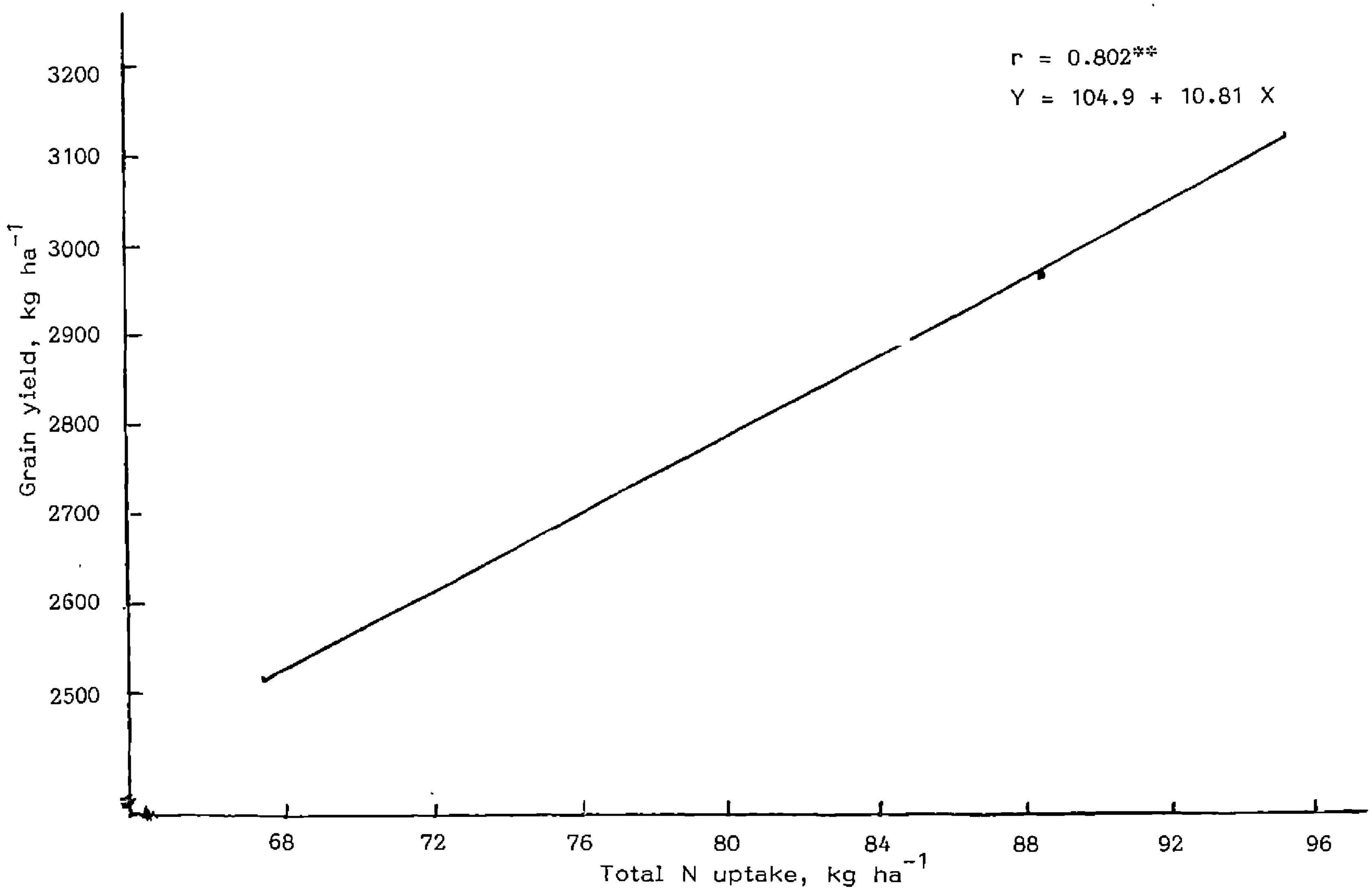

Fig. 8. Relationship between total N uptake and grain yield of rice (second crop)

(9)

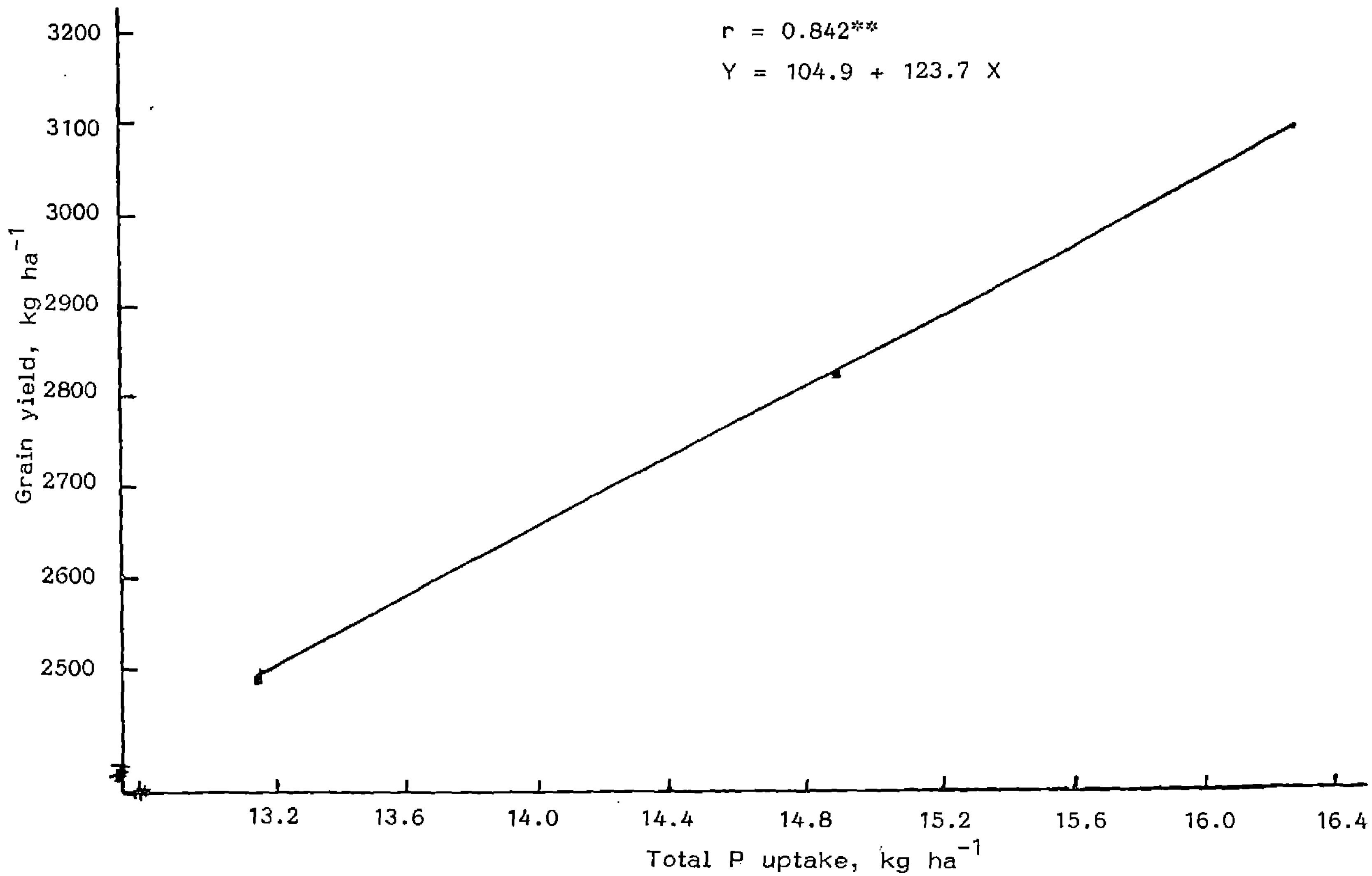

Fig. 9. Relationship between total P uptake and grain yield of rice (second crop)

Considerable decline in the N content of straw was observed from the tillering stage to the flowering stage and subsequently a slight decrease to the harvesting stage. This can be attributed to the dilution of the N content of straw resulted by the vigorous growth and increased dry matter production. At the harvesting stage, N removal by grain could account for the decrease in N content of straw. No significant difference was obtained in the N content of the straw by the application of treatments at any of the stages of crop growth. N uptake by straw followed similiar pattern as that of the first crop, where it was maximum at the flowering stage. Application of biologically activated S resulted in the highest uptake of N (122.66 kg ha^{-1}) at the flowering stage, expressing its influence on the vegetative growth of the crop.

Data on the effect of various treatments on the content and uptake of N by the grain and total N uptake are given in Table 24.

Nitrogen per cent of grain varied from 1.301 per cent to 1.627 per cent. Uptake of N by grain was very much dependent on the grain yield. Application of Mo and B recorded maximum uptake of 48.89 and 48.23 kg ha^{-1} respectively because of the relatively higher grain yield observed under these treatments. The low N content of grain in the use of the combination of nutrients may be due to a lower uptake of N by the plants.

Table 24. Mean values of nutrient per cent and nutrient uptake of straw and grain at harvest as influenced by different treatments (second crop)

Treatment	N % of straw	N uptake by straw, kg ha^{-1}	N % of grain	N uptake by grain, kg ha^{-1}	Total N uptake, kg ha^{-1}	P % of straw	P uptake by straw, kg ha^{-1}	P % of grain	P uptake by grain, kg ha^{-1}	Total P uptake, kg ha^{-1}
T_1	1.301	36.75	1.627	45.92	82.67	0.161	4.548	0.367	10.352	14.90
T_2	1.464	38.47	1.301	32.35	70.82	0.149	3.916	0.371	9.224	13.14
T_3	1.301	33.19	1.627	45.77	78.96	0.175	4.464	0.360	10.126	14.59
T_4	1.301	40.33	1.627	48.23	88.56	0.180	5.580	0.362	10.730	16.31
T_5	1.464	40.36	1.464	43.09	83.45	0.201	5.542	0.318	9.358	14.90
T_6	1.627	46.53	1.627	48.89	95.42	0.180	5.148	0.350	10.522	15.67
T_7	1.301	41.91	1.301	34.98	76.89	0.173	5.572	0.355	9.548	15.12
T_8	1.464	38.97	1.627	44.08	83.05	0.194	5.164	0.320	8.666	13.83
T_9	1.464	43.26	1.301	41.74	85.00	0.175	5.171	0.334	10.719	15.89
T_{10}	1.301	34.09	1.301	33.21	67.30	0.177	4.637	0.371	9.473	14.11

Contd.

Table 24. Continued

Treatment	K % of straw	K uptake by straw, kg ha^{-1}	K % of grain	K uptake by grain, kg ha^{-1}	Total K uptake, kg ha^{-1}	Ca content of straw, ppm	Ca uptake by straw, kg ha^{-1}	Ca content of grain, ppm	Ca uptake by grain, kg ha^{-1}	Total Ca uptake, kg ha^{-1}
T_1	1.20	33.90	0.50	14.11	48.01	178	0.503	59	0.166	0.669
T_2	1.50	39.42	0.50	12.43	51.85	161	0.423	70	0.174	0.597
T_3	1.40	35.71	0.45	12.66	48.37	218	0.556	55	0.155	0.711
T_4	1.40	43.40	0.55	16.30	59.70	209	0.648	38	0.113	0.761
T_5	1.40	38.60	0.55	16.18	54.78	249	0.686	62	0.182	0.868
T_6	1.40	40.04	0.55	16.53	56.57	180	0.515	54	0.162	0.677
T_7	1.40	45.09	0.55	14.79	59.88	220	0.709	41	0.110	0.819
T_8	1.30	34.61	0.50	13.54	48.15	32	0.085	82	0.222	0.307
T_9	1.35	39.89	0.45	14.44	54.33	33	0.098	41	0.132	0.230
T_{10}	1.40	36.68	0.55	14.04	50.72	200	0.524	64	0.163	0.687

Contd.

Table 24. Continued

Treatment	Mg content of straw, ppm	Mg uptake by straw, kg ha^{-1}	Mg content of grain, ppm	Mg uptake by grain, kg ha^{-1}	Total Mg uptake, kg ha^{-1}	S content of straw, ppm	S uptake by straw, kg ha^{-1}	S content of grain, ppm	S uptake by grain, kg ha^{-1}	Total S uptake, kg ha^{-1}
T_1	355	1.003	158	0.446	1.449	1000	2.825	767	2.162	4.987
T_2	472	1.240	296	0.736	1.976	1133	2.978	1066	2.650	5.628
T_3	418	1.066	189	0.532	1.598	1033	2.635	833	2.344	4.979
T_4	338	1.048	239	0.708	1.756	1099	3.407	667	1.975	5.382
T_5	267	0.736	188	0.553	1.289	1532	4.224	800	4.707	8.931
T_6	377	1.078	228	0.685	1.763	1599	4.573	700	2.103	6.676
T_7	414	1.333	171	0.460	1.793	1399	4.506	1133	3.047	7.553
T_8	377	1.004	233	0.631	1.635	1133	3.016	900	2.438	5.454
T_9	319	0.943	189	0.606	1.549	1333	3.939	933	2.993	6.932
T_{10}	444	1.163	247	0.631	1.794	1166	3.055	800	2.042	5.097

Contd.

Table 24. Continued

Treatment	Zn content of straw, ppm	Zn uptake by straw, kg ha^{-1}	Zn content of grain, ppm	Zn uptake by grain, kg ha^{-1}	Total Zn uptake, kg ha^{-1}	Cu content of straw, ppm	Cu uptake by straw, kg ha^{-1}	Cu content of grain, ppm	Cu uptake by grain, kg ha^{-1}	Total Cu uptake, kg ha^{-1}
T_1	40.1	0.113	32.4	0.092	0.205	7.2	0.020	10.5	0.030	0.050
T_2	96.1	0.253	38.6	0.096	0.349	6.8	0.018	14.2	0.035	0.053
T_3	50.8	0.130	30.6	0.086	0.216	7.1	0.018	12.2	0.034	0.052
T_4	44.4	0.138	28.8	0.085	0.223	7.1	0.022	14.9	0.044	0.066
T_5	43.3	0.119	53.8	0.158	0.278	5.0	0.014	15.7	0.046	0.060
T_6	40.4	0.116	32.1	0.096	0.212	4.2	0.012	15.1	0.045	0.057
T_7	43.2	0.139	34.4	0.093	0.232	5.7	0.018	13.9	0.038	0.056
T_8	35.6	0.095	29.9	0.081	0.176	4.8	0.013	11.1	0.030	0.043
T_9	75.2	0.222	33.2	0.107	0.329	6.3	0.019	11.9	0.038	0.057
T_{10}	60.7	0.159	35.8	0.091	0.250	6.9	0.018	14.4	0.037	0.055

Contd.

Table 24. Continued

Treatment	Mn content of straw, ppm	Mn uptake by straw, kg ha^{-1}	Mn content of grain, ppm	Mn uptake by grain, kg ha^{-1}	Total Mn uptake, kg ha^{-1}	Fe content of straw, ppm	Fe uptake by straw, kg ha^{-1}	Fe content of grain, ppm	Fe uptake by grain, kg ha^{-1}	Total Fe uptake, kg ha^{-1}
T_1	842	2.379	164	0.462	2.841	204	0.576	225	0.635	1.211
T_2	902	2.370	205	0.510	2.880	234	0.615	234	0.582	1.197
T_3	990	2.525	149	0.420	2.945	236	0.602	138	0.388	0.990
T_4	910	2.821	152	0.451	3.272	238	0.738	175	0.519	1.257
T_5	701	1.933	166	0.488	2.421	191	0.527	190	0.559	1.086
T_6	934	2.671	154	0.643	3.134	201	0.575	199	0.598	1.173
T_7	1164	3.749	131	0.352	4.101	239	0.770	149	0.401	1.171
T_8	1041	2.771	195	0.528	3.299	215	0.572	206	0.558	1.130
T_9	908	2.683	127	0.407	3.090	193	0.570	141	0.452	1.022
T_{10}	1270	3.327	205	0.523	3.850	235	0.616	175	0.447	1.063

Contd.

Table 24. Continued

Treatment	B content of straw, ppm	B uptake by straw, kg ha^{-1}	B content of grain, ppm	B uptake by grain, kg ha^{-1}	Total B uptake, kg ha^{-1}
T_1	139.8	0.395	34.95	0.099	0.494
T_2	69.9	0.184	81.54	0.202	0.386
T_3	139.8	0.357	46.59	0.131	0.488
T_4	128.1	0.397	46.59	0.138	0.535
T_5	128.1	0.353	69.89	0.206	0.559
T_6	69.9	0.200	58.24	0.175	0.375
T_7	139.8	0.450	69.89	0.188	0.638
T_8	139.8	0.372	40.77	0.111	0.483
T_3	104.8	0.310	52.42	0.168	0.478
T_{10}	122.3	0.320	52.42	0.134	0.454

Table 25. Nitrogen per cent and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	N content, per cent			N uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	3.091	1.139	1.301	43.15	77.08	36.75
T_2	3.091	1.627	1.464	48.28	111.91	38.47
T_3	2.928	1.627	1.301	40.87	105.22	33.19
T_4	3.091	1.301	1.301	43.15	71.92	40.33
T_5	3.091	1.627	1.464	47.66	101.77	40.36
T_6	2.766	1.139	1.627	37.59	80.55	46.53
T_7	3.091	1.627	1.301	45.50	122.66	41.91
T_8	3.254	1.464	1.464	41.36	77.27	38.97
T_9	2.603	1.464	1.464	36.83	107.28	43.26
T_{10}	2.928	1.789	1.301	39.03	115.39	34.09

The influence of Mo and B on the uptake and utilization of N has already been discussed.

The influence of Mo on total N uptake by the plant was significant. While maximum uptake of N was recorded by Mo applied plants (95.42 kg ha^{-1}), application of Stanes Microfood resulted in the lowest uptake of 67.30 kg ha^{-1}. This may be the reason for a comparatively poor performance of this product in the second crop season. Total N uptake was highly correlated with grain yield (r = 0.802**) and total P uptake (r = 0.724*) (Table 41).

3.2 Phosphorus

Results on the effects of various treatments on the content and uptake of P by the straw at different growth stages of the crop are given in Table 26.

Phosphorus percentage of straw continuously declined from the maximum tillering stage to the harvesting stage. The decrease at the flowering stage can be explained by the dilution caused by increased dry matter production and the subsequent decrease at harvest can be due to its translocation to grain. Application of Mg and S recorded the maximum P content of 0.322 and 0.318 per cent respectively at the flowering stage. A low P level of the straw was exhibited by plants which received Zn application, at harvest. There was no significant difference in P uptake also,

Table 26. Phosphorus per cent and uptake in straw as influenced by the treatments at different stage of crop growth (second crop)

Treatment	P content, per cent			P uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	0.402	0.276	0.161	5.612	18.68	4.548
T_2	0.399	0.283	0.149	6.232	19.46	3.916
T_3	0.399	0.287	0.175	5.570	18.56	4.464
T_4	0.404	0.287	0.180	5.640	15.87	5.580
T_5	0.402	0.301	0.201	6.199	18.83	5.542
T_6	0.390	0.248	0.180	5.281	17.54	5.148
T_7	0.397	0.318	0.173	5.804	23.97	5.572
T_8	0.383	0.322	0.194	4.868	17.00	5.164
T_9	0.381	0.304	0.175	5.391	22.28	5.171
T_{10}	0.413	0.304	0.177	5.505	19.61	4.637

by the straw. Sulphur and Mg treatments reflected the higher P content of straw at flowering stage, in P uptake also. The lowest P uptake of 3.916 kg ha^{-1} at harvest has resulted by the application of Zn, further indicating a negative interaction between these two on the nutrient uptake. Magnesium acts as a P carrier and helps in better utilization of P by the plant which resulted in an increased level and uptake of P in plants applied with Mg treatment.

Data on the influence of various treatments on the content and uptake of P by grain and total P uptake are presented in Table 24.

Except Cu and Mg, all the other treatments did not vary widely with regard to their P content in grain. Application of B, Cu and the combination of nutrients resulted in a slight increase in the P uptake by grain compared to the control, which can be attributed to the higher grain yield resulted by the application of these nutrients.

The highest P uptake of 16.31 kg ha^{-1} was recorded by B treated plants followed by the combined application of nutrients (15.89 kg ha^{-1}). This was reflected in the grain yield of the corresponding treatments. P-Zn antagonism was further evidenced by the lowest P uptake of 13.14 kg ha^{-1} by the Zn applied plants. There were significant positive correlations of total P uptake with grain yield (r = 0.842**), straw yield (r = 0.722*), total dry matter yield (r = 0.747*), total N uptake (r = 0.724*), total K uptake (r = 0.643*) and total Cu uptake (r = 0.680*) (Table 41). This revealed the influence of P uptake on the crop growth and yield.

3.3 Potassium

Results on the influence of various treatments on the content and uptake of K by the straw at the different stages of crop growth in the second season are given in Table 27.

Eventhough the K per cent of the straw was not significantly influenced by any of the treatments at any of the stages, considerable decline was observed in the K level from tillering to flowering stage. This can be accounted for the dilution caused by increased dry matter production. Further decrease in the K level observed at the harvesting stage can be assigned to the translocation to the grain. Uptake of K by straw increased considerably from the tillering to the flowering stage, obviously by the higher rate of dry matter production. The lowest uptake of K was obtained by the application of Mg in the tillering and flowering stages, further confirming the K-Mg antagonism. All the treatments resulted in a slight increase in the K uptake by straw at harvest, the least being showed by Mg applied plants.

Table 27. Potassium per cent and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	K content, per cent			K uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	3.3	1.8	1.2	46.07	121.8	33.90
T_2	3.2	2.0	1.5	49.98	137.6	39.42
T_3	3.3	2.1	1.4	46.07	135.8	35.71
T_4	3.5	1.9	1.4	48.86	105.0	43.40
T_5	3.4	1.9	1.4	52.43	118.8	38.60
T_6	3.1	1.8	1.4	41.97	127.3	40.04
T_7	3.3	2.0	1.4	48.25	150.8	45.09
T_8	3.2	1.9	1.3	40.67	100.3	34.61
T_9	3.3	2.0	1.4	46.70	146.6	39.89
T_{10}	3.3	2.0	1.4	43.99	129.0	36.68

Data on the K content and uptake by grain and total K uptake as influenced by different treatments in the second crop, as given in Table 24, did not show significant difference among the treatments. Uptake of K by grain did not show a consistent influence of any of the treatments on K uptake by grain. Application of Zn, Mn and Mg resulted in a lower K uptake by grain compared to the control, probably due to the interaction of cations for exchange sites in the soil which resulted in a comparatively lower availability and uptake of K.

The highest total uptake of K was obtained by the application of biologically activated S (59.88 kg ha^{-1}) followed by B (59.70 kg ha^{-1}). It was noted that the straw yield was maximum by the application of these two nutrients. The lowest uptake was recorded by the control plants (48.01 kg ha^{-1}) which was on par with that of Mg (48.15 kg ha^{-1}). Total K uptake by the crop was significantly and positively correlated with straw yield (r = 0.834**), total P uptake (r = 0.643*) and total Cu uptake (r = 0.795**) while it was negatively correlated with pH of the soil (r = -0.722*) (Table 41).

3.4 Calcium

Results on the effect of various treatments on the content and uptake of Ca at different stages of crop growth in the second season (Table 28) were highly inconsistent and reliable

Table 28. Calcium content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Ca content, ppm			Ca uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	224	224	178	0.313	1.516	0.503
T_2	224	219	161	0.350	1.506	0.423
T_3	212	170	218	0.296	1.099	0.556
T_4	197	278	209	0.275	1.537	0.648
T_5	202	178	249	0.311	1.113	0.686
T_6	224	119	180	0.303	0.842	0.515
T_7	267	208	220	0.390	1.568	0.709
T_8	237	250	32	0.301	1.320	0.085
T_9	167	205	33	0.236	1.502	0.098
T_{10}	183	188	200	0.244	1.213	0.524

conclusions could not be drawn based on these figures. Further, no treatment under this study contained calcium.

Data as shown in Table 24 revealed that per cent of Ca in the grain ranged from 38 to 82 ppm and consistent influence of any particular treatment on Ca level was not observed. Similiar trend followed in Ca uptake by grain also.

Application of Cu resulted in the maximum uptake of 0.868 kg ha^{-1} which can be due to the beneficial effect of Cu on the total P and K uptake which have been favourably influenced by Cu application. The same results were obtained in the first crop also. The lowest Ca uptake was observed by the combined application of nutrients followed by Mg. This may be due to a competitive interaction between Ca and Mg in the soil.

3.5 Magnesium

Data on the influence of various treatments on the content and uptake of Mg by the straw at different crop growth stages in the second season are presented in Table 29.

Magnesium per cent of straw at different stages was inconsistent except that a gradual increase was observed from the initial to the harvesting stages in many of the treatments. Application of Mg did not result in an increased level of Mg in the maximum tillering and harvesting stages but at flowering

Table 29. Magnesium content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Mg content, ppm			Mg uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	235	279	355	0.328	1.888	1.003
T_2	153	181	472	0.239	1.245	1.240
T_3	219	571	418	0.306	3.693	1.066
T_4	225	219	338	0.314	1.211	1.048
T_5	225	214	267	0.347	1.339	0.736
T_6	233	224	377	0.315	1.584	1.078
T_7	253	352	414	0.370	2.654	1.333
T_8	185	569	377	0.235	3.003	1.004
T_9	139	427	319	0.200	3.129	0.943
T_{10}	181	587	444	0.241	3.786	1.163

very high level was observed which was on par with that of Mn and Stanes Microfood treated plants. Uptake of Mg also showed a similiar trend in all the three stages indicating a lack of significant influence in the soil studied.

Results of the influence of the different treatments on the content and uptake of Mg by grain in the second crop, as shown in Table 24, did not show a significant influence of the application of Mg on the Mg content of grain. Influence of Mg addition on the uptake of Mg also revealed the same trend, despite an increase compared to the control. Application of Zn, B and Mo resulted in higher uptake of Mg by the grain than that of Mg application.

Data on the total Mg uptake of the crop as influenced by various treatments showed a range from 1.289 kg ha^{-1} to 1.976 kg ha^{-1}. Lack of significant influence of the application of Mg on crop growth and yield was confirmed in the second crop. Varughese (1992) observed that there was no positive response of rice for Mg application in laterite soil.

3.6 Sulphur

Results on the influence of various treatments on the S content of straw and uptake at different growth stages of the second crop are presented in Table 30.

Table 30. Sulphur content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	S content, ppm			S uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	1333	1066	1000	1.861	7.214	2.825
T_2	1266	867	1133	1.977	5.963	2.978
T_3	966	733	1033	1.349	4.740	2.635
T_4	867	933	1099	1.210	5.158	3.407
T_5	966	1233	1532	1.490	7.712	4.224
T_6	833	1133	1599	1.128	8.013	4.573
T_7	966	1400	1399	1.412	10.555	4.506
T_8	833	1133	1133	1.059	5.980	3.016
T_9	733	1333	1333	1.037	9.768	3.939
T_{10}	833	1100	1166	1.110	7.095	3.055

Application of all the treatments reduced the S per cent of straw in the maximum tillering stage. At the flowering stage, the highest level of 1400 ppm was resulted by the application of biologically activated S itself. This influence was not repeated at the harvesting stage. Uptake of S by straw followed a similiar pattern except that the highest uptake at maximum tillering stage was recorded by Zn application. No significant difference was observed in the uptake of S between treatments at any stage.

Data given in Table 24 reveals a significant influence of application of biologically activated S on the grain S level. But the highest S uptake was recorded by Cu application, obviously due to the higher grain yield.

Total S uptake was improved by the application of various treatments, the highest being by Mo followed by S. Higher total dry matter yield resulted by the application of Mo caused the higher uptake of S than that of S application.

3.7 Zinc

Data on the influence of various treatments on the content and uptake of Zn by the straw at different stages of crop growth are presented in Table 31 (second crop).

In general, the mean Zn level of straw and the uptake were found to be lower compared to the first crop. Significantly

Table 31. Zinc content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Zn content, ppm			Zn uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	33.9	53.7	40.1	0.047	0.363	0.113
T_2	37.0	103.1	96.1	0.058	0.709	0.253
T_3	32.7	58.5	50.8	0.046	0.378	0.130
T_4	32.5	37.5	44.4	0.045	0.207	0.138
T_5	32.6	66.4	43.3	0.050	0.415	0.119
T_6	49.6	67.3	40.4	0.067	0.476	0.116
T_7	32.5	67.0	43.2	0.048	0.505	0.139
T_8	33.0	67.1	35.6	0.042	0.354	0.095
T_9	36.2	116.4	75.2	0.051	0.853	0.222
T_{10}	34.3	75.7	60.7	0.046	0.488	0.159

higher per cent of Zn in straw was obtained by the combined application of nutrients and Zn at the flowering and harvesting stages. This is in line with the results of the first crop which confirms the influence of applied Zn on content and uptake by straw. Zinc level of the straw gradually increased upto the flowering stage and then decreased at harvest, due to the possible Zn removal by the grain. Uptake of Zn showed the same trend in all the stages of crop growth.

Results on the influence of various treatments on the content and uptake of Zn by the grain and total Zn uptake are presented in Table 24.

The highest Zn per cent and thus the highest uptake was recorded by the application of Cu. Other treatments did not vary much except a comparatively low Zn uptake by grain observed in the Mg applied plants.

A significant increase in the total Zn uptake from 0.205 kg ha^{-1} to 0.349 and 0.329 kg ha^{-1} was obtained by Zn application and combined application of nutrients respectively. This further confirms the beneficial effect of Zn. Relationship between available Zn in soil and total Zn uptake by rice is shown in Fig. 10. The lowest uptake of 0.176 kg ha^{-1} was recorded by Mg treatment which indicates a possible negative interaction

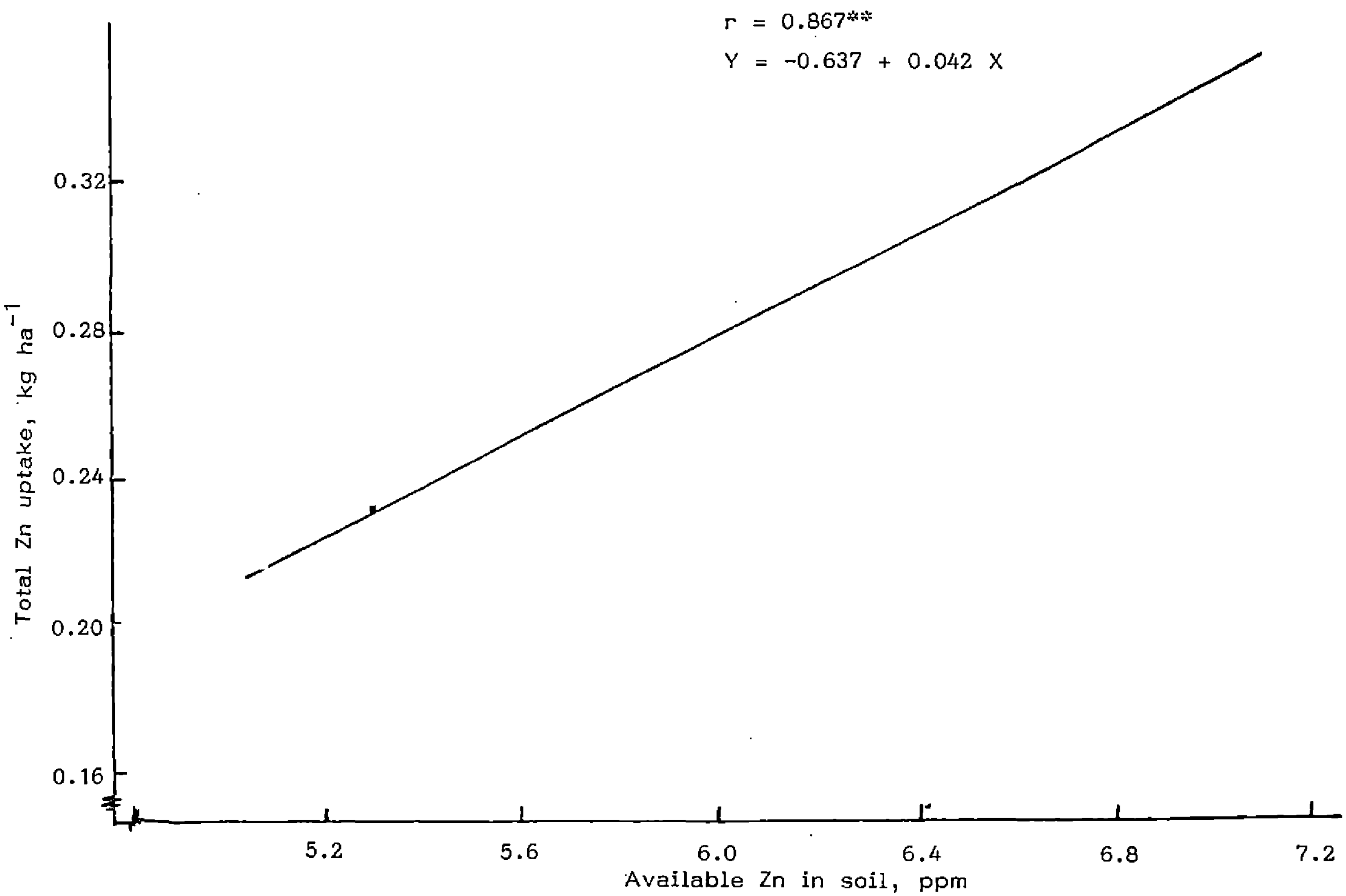

Fig. 10. Relationship between available Zn in soil and total Zn uptake by rice (second crop)

between Zn and Mg in the soil. The possible competition of Zn^{2+} ions with Mg ions for exchangeable sites which leads to the release of Zn ions to the soil solution and loss through leaching might have resulted in the low uptake of Zn by Mg treated plants. Similiar type of interaction which was also observed in the case of Mg uptake by plants, was noticed in the first crop also. Significant positive correlation was observed between available Cu in soil and total Zn uptake by rice crop (Table 41 and Fig. 11).

3.8 Copper

Data on the influence of various treatments on the content and uptake of Cu by the straw in the second crop season at different growth stages are given in Table 32.

Results showed a high per cent of Cu in straw at the tillering stage in plants which received Cu treatment, but at flowering and harvesting stages, the Cu content of straw was lower compared to other treatments. The rate of dry matter production might have exceeded the rate of nutrient uptake by the crop which resulted in dilution of the nutrient in the straw. Application of Zn showed a higher per cent of Cu in straw at the flowering stage which may be due to a positive interaction between these two nutrients.

(11)

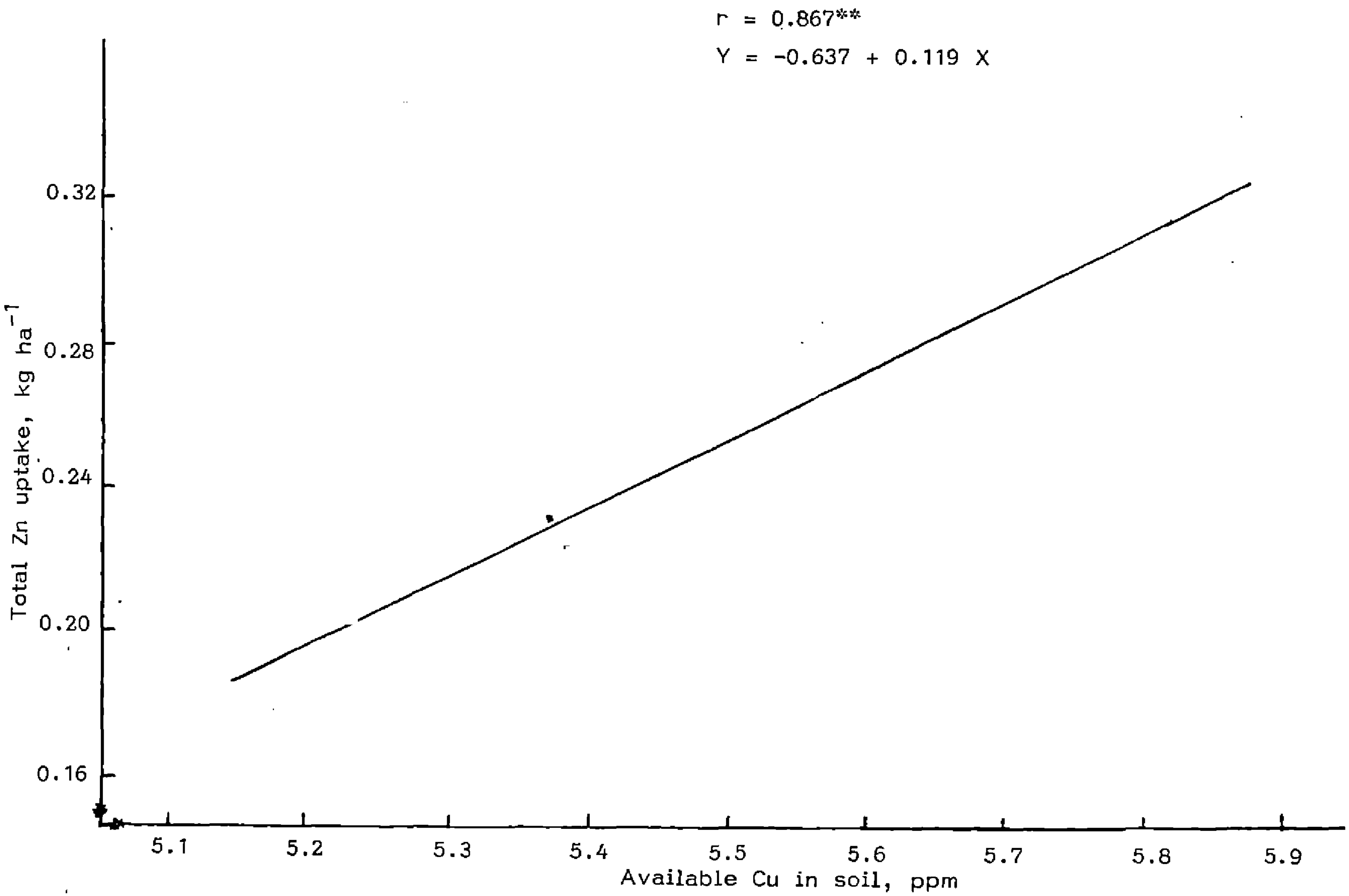

Fig. 11. Relationship between available Cu in soil and total Zn uptake by rice (second crop)

Table 32. Copper content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Cu content, ppm			Cu uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	9.9	6.9	7.2	0.014	0.047	0.020
T_2	9.4	9.6	6.8	0.015	0.066	0.018
T_3	8.9	7.9	7.1	0.012	0.051	0.018
T_4	9.2	7.1	7.1	0.013	0.039	0.022
T_5	10.3	5.9	5.0	0.016	0.037	0.014
T_6	9.5	6.9	4.2	0.013	0.049	0.012
T_7	9.9	7.5	5.7	0.014	0.057	0.018
T_8	9.9	9.1	4.8	0.013	0.048	0.013
T_9	9.9	8.2	6.3	0.014	0.060	0.019
T_{10}	9.7	9.0	6.9	0.013	0.058	0.018

Results on the Cu content and uptake of grain and total Cu uptake as influenced by various treatments are presented in Table 24.

It was found that all the treatments improved the Cu per cent of grain, the least being resulted by Mg application. Application of Cu revealed the highest Cu content of 15.7 ppm in the grain. Uptake of Cu by grain also followed the same pattern where control and Mg application were on par.

Molybdenum application resulted in a higher total Cu uptake by the crop than that by Cu application. This is due to the difference in the total dry matter yield between these two treatments. Rest of the treatments were on par except Mg which showed a reduced Cu uptake by the crop. Interaction of Mg with Cu appear to be in a similar pattern as that of Zn and it was further noted that Zn and Cu interact positively in the soil.

Significant positive correlations of total Cu uptake with total P uptake ($r = 0.680^{*}$) and total K uptake ($r = 0.795^{**}$) were observed (Table 41 and Fig. 12). Total Cu uptake was negatively correlated with pH of the soil ($r = -0.654^{*}$). The relationship of total Cu uptake with total P and K uptake was in line with the results of the first crop.

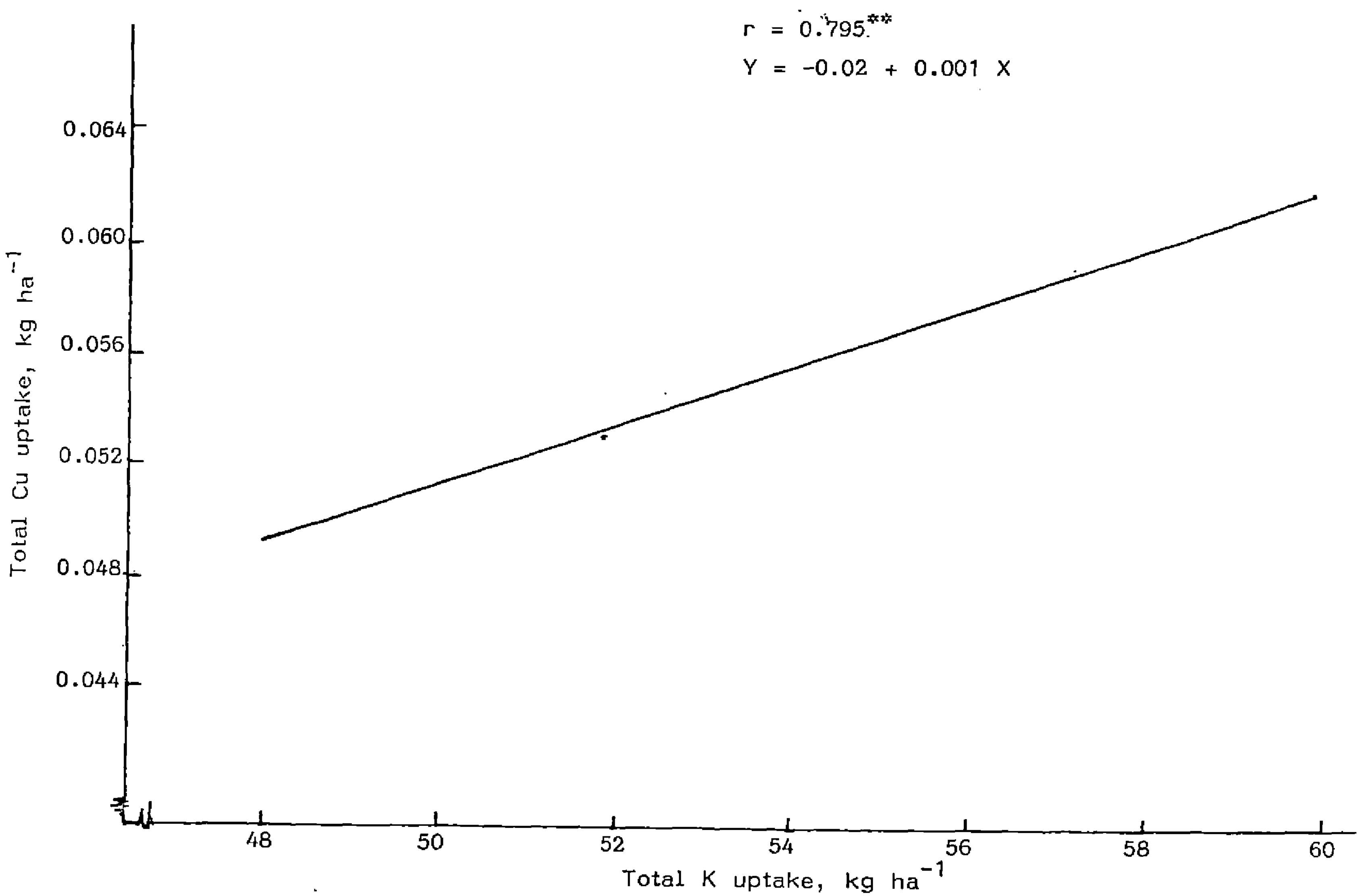

Fig. 12. Relationship between total K uptake and total Cu uptake by rice (second crop)

3.9 Manganese

Data on the effects of various treatments on the content and uptake of Mn by the straw at different stages of crop growth in the second crop season are presented in Table 33.

All the treatments except Mg depressed the Mn level of straw at the tillering stage. Significantly lower Mn level of straw was exhibited by Mo application. Similiar to that of the first crop, application of Stanes Microfood resulted in the highest per cent of Mn in the straw at the flowering and harvesting stages. Zinc application significantly reduced the Mn level of straw at the flowering stage. Uptake of Mn by straw at the tillering stage was the highest in the control plants. Sulphur, because of its positive influence in dry matter production, caused the highest Mn uptake at the flowering and harvesting stages.

Data presented in Table 24 reveal that Mn application did not influence the Mn content of the grain in the second crop also. Uptake of Mn by grain also showed similiar trend where Mo application resulted in maximum uptake (0.643 kg ha^{-1}).

Influence of various treatments on the total Mn uptake is presented in Table 24 which reveals the lack of influence of Mn application on the total Mn uptake by the crop. Maximum uptake of 4.101 kg ha^{-1} was recorded by S application which

Table 33. Manganese content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Mn content, ppm			Mn uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	1346	1187	842	1.879	8.032	2.379
T_2	1195	354	902	1.867	2.435	2.370
T_3	1286	1340	990	1.795	8.666	2.525
T_4	1283	1315	910	1.791	7.269	2.821
T_5	1057	1067	701	1.630	6.674	1.933
T_6	401	885	934	0.543	6.259	2.671
T_7	1250	1380	1164	1.828	10.404	3.749
T_8	1417	1145	1041	1.801	6.043	2.771
T_9	1261	844	908	1.784	6.185	2.683
T_{10}	1110	1388	1270	1.480	8.953	3.327

is due to the higher total dry matter yield by this treatment. Lack of significant influence of the treatments on the Mn content and uptake by the plant indicates the required status and availability of Mn in the soil as explained in the case of the first crop. Manganese availability of the soil increases under submergence especially in acidic conditions.

3.10 Iron

Data on the content and uptake of Fe by the straw as influenced by different treatments were found to be inconsistent in the second crop (Table 34). It was observed that application of any of the treatment did not considerably influence the Fe content of straw or the uptake, probably because the treatments under this study did not contain iron.

Results showed that application of Mn and combination of nutrients had a inverse relationship with the content and uptake of Fe by the grain in the second crop (Table 24). This points to a competitive interaction between Mn and Fe in the soil. Zinc application resulted in the highest Fe content of grain (234 ppm) followed by the control. Similiar results were obtained during the first crop also which indicates a positive interaction between Zn and Fe in the plant. Presence of sufficient level of Zn in straw enhances the movement of iron within the plants and thus results in an increased translocation of the nutrient to the grain (Tisdale *et al*., 1985).

Table 34. Iron content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Fe content, ppm			Fe uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	345	194	204	0.482	1.313	0.576
T_2	287	181	234	0.448	1.245	0.615
T_3	338	224	236	0.472	1.449	0.602
T_4	344	249	238	0.480	1.376	0.738
T_5	403	208	191	0.621	1.301	0.527
T_6	385	203	201	0.521	1.436	0.575
T_7	260	270	239	0.380	2.036	0.770
T_8	279	249	215	0.355	1.314	0.572
T_9	283	253	193	0.400	1.854	0.570
T_{10}	238	210	235	0.317	1.355	0.616

Application of Mn recorded the lowest total uptake of Fe, which further confirms the negative interaction between these two in the soil. All the other treatments were on par with the control in the total Fe uptake.

3.11 Boron

Results on the effects of the different treatments on the content and uptake of B by the straw at different stages of crop growth in the second season are presented in Table 35.

Results did not reveal a significant influence of B application on the B per cent and uptake in the straw, except a higher B per cent at flowering stage. Zinc application resulted in the lowest per cent of B at the flowering and harvesting stages but the lower level at harvest can be accounted for the increased translocation to the grain which resulted in a higher content in the grain.

Eventhough the application of various treatments increased the content and uptake of B by the grain, lack of significant influence of any of the treatments except Zn was noted (Table 24). The reason for a higher value for Zn application has already been discussed.

Total B uptake as influenced by various treatments in the second crop season was corresponding to the total dry matter yield with respect to each treatment (Table 24).

Table 35. Boron content and uptake in straw as influenced by the treatments at different stages of crop growth (second crop)

Treatment	B content, ppm			B uptake, kg ha^{-1}		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	116.5	151.4	139.8	0.163	1.025	0.395
T_2	116.5	81.5	69.9	0.182	0.561	0.184
T_3	116.5	151.4	139.8	0.163	0.979	0.357
T_4	122.3	163.1	128.1	0.171	0.902	0.397
T_5	104.8	116.5	128.1	0.162	0.729	0.353
T_6	203.9	157.3	69.9	0.276	1.112	0.200
T_7	122.3	151.4	139.8	0.179	1.141	0.450
T_8	151.4	93.2	139.8	0.192	0.492	0.372
T_9	186.4	81.5	104.8	0.264	0.597	0.310
T_{10}	128.1	151.4	122.3	0.171	0.977	0.320

4. Soil analysis

4.1 Total nitrogen

Total N content of the soil as influenced by different treatments at different stages of crop growth are presented in Table 36.

Unlike in the first crop, a gradual increase in the total N content of the soil was observed from the tillering to the harvesting stage. This might have resulted either by a decreased uptake and removal by the crop or by increased availability caused by the application of other nutrients. There was no significant difference between the various treatments with regard to the total N content of the soil.

4.2 Available phosphorus

Data on the influence of various treatments on the available P of the soil at different growth stages of the crop in the second season are presented in Table 36.

The general trend in the available P of the soil was a gradual increase observed from the maximum tillering to the harvesting stage. This may be because of fall in rate of P uptake at the better stages of crop growth. No significant difference between the treatments was obtained with regard to the available P of the soil.

Table 36. Total N, available P, available K of soil as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Total N, per cent			Available P, kg ha^{-1}			Available K, kg ha^{-1}		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	0.135	0.120	0.146	69.03	69.74	85.94	324.8	240.8	238.9
T_2	0.103	0.141	0.174	83.38	78.89	78.89	352.8	255.7	218.4
T_3	0.125	0.136	0.157	73.26	77.48	80.30	283.7	214.7	196.0
T_4	0.114	0.136	0.163	70.44	78.89	87.34	345.3	293.1	205.3
T_5	0.125	0.130	0.168	71.14	69.03	71.85	324.8	274.4	242.7
T_6	0.135	0.119	0.168	73.26	78.89	83.12	324.5	252.0	222.1
T_7	0.130	0.141	0.146	76.07	84.51	88.74	330.4	220.3	197.9
T_8	0.119	0.130	0.179	71.85	83.12	83.12	354.7	233.3	197.9
T_9	0.119	0.146	0.157	70.44	77.48	84.53	289.3	222.1	203.5
T_{10}	0.109	0.146	0.141	67.62	87.33	84.53	300.5	237.1	201.6

4.3 Available potassium

Results on the influence of various treatments on the available K of soil at different stages of growth in the second crop are given in Table 36.

Available K of soil decreased gradually by all the treatments from the initial to the final stages, obviously due to the increased removal by the crop. The lowest availability of K in all the three stages of growth was recorded by the application of Mn. This can be interpreted as the decreased availability of K, probably due to a negative interaction in the soil. The treatments did not differ significantly in the available K of soil at any of the stages.

4.4 Exchangeable calcium

Effects of the different treatments on the exchangeable Ca content of the soil at different crop growth stages in the second season are presented in Table 37.

It was found that at the tillering stage, application of all the treatments reduced the exchangeable Ca of the soil. Application of Mg resulted in a slight increase in exchangeable Ca at flowering stage which may be due to a decreased uptake by the crop. At harvest, exchangeable Ca of the soil applied with biologically activated S was the lowest indicating a possible

Table 37. Exchangeable Ca, exchangeable Mg and available S of soil as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Exchangeable Ca, cmol(+) kg^{-1}			Exchangeable Mg, cmol(+) kg^{-1}			Available S, ppm		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	4.741	4.109	3.753	0.698	0.622	0.670	74.98	66.65	74.98
T_2	3.519	4.019	4.684	0.694	0.678	0.772	79.15	83.31	70.82
T_3	4.384	4.178	4.175	0.638	0.680	0.615	79.15	79.15	74.98
T_4	4.334	1.991	3.959	0.649	0.368	0.649	74.98	79.15	74.98
T_5	4.603	4.097	4.025	0.669	0.718	0.692	79.15	79.15	70.82
T_6	3.922	3.769	3.713	0.681	0.646	0.722	79.15	87.48	74.98
T_7	4.519	3.831	2.356	0.637	0.577	0.743	79.15	83.31	66.65
T_8	3.891	4.278	4.091	0.686	0.641	0.758	70.82	74.98	74.98
T_9	3.106	3.528	4.225	0.656	0.651	0.654	62.48	70.82	83.31
T_{10}	4.278	3.944	2.978	0.643	0.587	0.644	66.65	74.98	83.31

utilization of Ca by the inoculated organisms and vigorous uptake of Ca by the crop for the increased dry matter production.

4.5 Exchangeable magnesium

Exchangeable Mg of soil as influenced by various treatments, as given in Table 37, reveal a lack of uniform trend at different stages of crop growth in the second season. A positive response to the applied Mg also was not observed which is line with the observations of the first crop. This lack of response in the exchangeable Ca in soil can be assigned to the adequate status of the nutrient in the soil.

4.6 Available sulphur

Results on the effect of various treatments on the available S of soil, show a uniform increase from the tillering to the flowering stage and a subsequent decline at harvest (Table 37). But the application of combination of nutrients and Stanes Microfood responded differently by a continuous increase in the available S of soil. The decline in the available S content at harvest in plots applied with biologically activated S might have resulted by increased removal by the crop for higher rate of dry matter production (straw + grain).

Available S in soil was found to be significantly negatively correlated with available Mn in soil ($r = -0.704^{*}$) (Table 41).

4.7 Available zinc

Data on the effect of various treatments on the available Zn of the soil at different stages of crop growth in the second crop season are given in Table 38.

The superiority of the application of Zn on the available Zn content of soil was proved during the second crop season also. Application of Zn and the combination of nutrients resulted in a significant increase in the available Zn content of soil in all the three stages. But this increased availability of Zn was not reflected in any of the morphological characters or yield of grain and straw.

Highly significant positive correlation was observed between available Zn of soil and total Zn uptake ($r = 0.867^{**}$). Positive but insignificant correlation between available Zn and available Cu in soil ($r = 0.608^{*}$) was also observed (Table 41) which indicates a positive interaction. Similiar results were obtained in the first crop also.

4.8 Available copper

Results on the influence of various treatments on the available Cu of the soil (Table 38) did not show a significant difference between treatments at any of the stages of growth in the second crop season. A slight increase in the available

Table 38. Available Zn, u and Mn of soil as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Available Zn, ppm			Available Cu, ppm			Available Mn, ppm		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	5.300	5.220	4.588	5.144	5.396	5.172	234.9	171.4	92.56
T_2	7.132	9.476	8.908	5.668	5.236	5.208	198.7	143.8	87.88
T_3	5.068	5.136	4.888	5.200	5.152	5.080	178.0	136.0	95.60
T_4	5.044	4.932	4.856	5.384	5.416	5.076	199.4	139.4	104.00
T_5	5.148	5.384	5.284	5.776	6.228	5.784	165.9	138.5	81.68
T_6	5.264	4.948	5.168	5.344	5.224	5.444	190.0	130.4	94.40
T_7	5.296	4.848	5.164	5.372	5.416	5.264	194.8	181.3	95.50
T_8	5.200	4.612	5.056	5.232	5.120	5.264	188.8	112.3	132.80
T_9	6.548	6.952	8.916	5.872	5.936	5.156	239.7	114.5	85.88
T_{10}	5.448	5.076	5.028	5.588	5.180	5.160	219.0	132.2	88.52

Cu was noticed in soils applied with Cu and the combination of nutrients. Similiar results, which may be due to an increased uptake and removal indicating higher requirement of Cu by the crop were observed in the first crop also.

Available Cu in the soil was highly significantly correlated with total Zn uptake by the crop (r = 0.867**).

4.9. Available mangenese

Available Mn of soil as influenced by various treatments in the second crop season are presented in Table 38.

Availability in the soil was continuously decreased from the tillering to the harvesting stage. This can be attributed to the removal of the nutrient from the soil by the crop. The drainage of the soil before harvesting would have led to a further decline in the Mn content of the soil at harvest. Manganese application did not significantly influence the availability of Mn in the soil. This is in conformity with the results of the first crop.

There was a significant positive correlation between available Mn and organic carbon in the soil (r = 0.676*).

4.10 Available iron

Results on the available Fe of the soil, as presented in Table 39, revealed a lack of uniform trend and a consistent influence of a particular treatment on the available Fe content of the soil. This may be due to the fact that no treatment under this study contained iron.

4.11 Available boron

Data on the influence of the different treatments on the available B of the soil at different stages of crop growth are given in Table 39.

Similiar to the observations made in the first crop, inconsistent results were obtained in the second crop also. Application of B was not found to influence the available B of the soil except a slight increase at the flowering stage.

4.12 Organic carbon

Data on organic carbon content of the soil as influenced by various treatments at different stages of crop growth are presented in Table 40.

Eventhough the organic matter content of the soil was generally lower than that in the first crop, it was not influenced by any of the treatments in the second crop also. The relatively lower level of organic carbon observed during the second crop may be because no addition of organic manure was effected during

Table 39. Available Fe and B of soil as influenced by the treatments at different stages of crop growth (second year)

Treatment	Available Fe, ppm			Available B, ppm		
	Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	227.1	218.7	241.2	0.233	1.514	0.466
T_2	208.9	243.3	230.8	0.233	0.582	0.466
T_3	240.6	229.0	257.8	0.233	0.233	0.466
T_4	240.0	220.3	208.0	0.233	1.165	0.466
T_5	274.9	274.0	250.0	0.932	0.466	0.466
T_6	262.8	210.3	240.8	1.048	0.932	0.582
T_7	261.5	222.6	238.9	1.281	0.233	1.980
T_8	234.6	173.4	222.6	1.631	0.699	2.213
T_9	233.0	204.4	251.3	0.233	1.165	1.631
T_{10}	253.9	192.3	263.2	0.233	0.466	0.699

Table 40. Organic carbon, pH and specific conductance of soil as influenced by the treatments at different stages of crop growth (second crop)

Treatment	Organic carbon, per cent			pH			Specific conductance, dS m^{-1}		
	Stages			Stages			Stages		
	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting	Tillering	Flowering	Harvesting
T_1	0.44	0.41	0.45	5.84	5.72	6.00	0.056	0.059	0.070
T_2	0.42	0.39	0.49	5.84	5.79	6.09	0.065	0.059	0.053
T_3	0.43	0.44	0.41	5.78	5.76	6.00	0.058	0.057	0.067
T_4	0.42	0.42	0.46	5.72	5.82	5.99	0.057	0.060	0.063
T_5	0.41	0.45	0.42	5.79	5.83	6.03	0.060	0.065	0.082
T_6	0.43	0.45	0.41	5.69	5.81	6.05	0.057	0.058	0.078
T_7	0.43	0.40	0.53	5.74	5.68	5.93	0.065	0.067	0.096
T_8	0.40	0.42	0.48	5.83	5.72	6.01	0.057	0.058	0.076
T_9	0.44	0.42	0.42	5.73	5.71	5.90	0.066	0.064	0.078
T_{10}	0.43	0.38	0.44	5.75	5.68	5.92	0.060	0.062	0.074

the second crop. Organic carbon in the soil was found to have significant positive correlation with available Mn in soil (r = 0.676*).

4.13 pH

Influences of the different treatments on the pH of the soil at different stages of crop growth has been presented in Table 40.

Significant difference in pH of the soil was not observed between the treatment in any of the growth stages.

4.14 Specific conductance

Results on the effect of various treatments on the specific conductance of soil at different stages of crop growth in the second season are presented in Table 40.

There was no significant difference between the treatments with regard to the specific conductance of the soil. An increase in the specific conductance of the soil was observed at the harvesting stage probably due to the effect of drying the field 15 days prior to harvest.

The results obtained and the observations made during the two seasons of rice crop may be related to the objectives of the study as follows.

In general, the yields of grain and straw were not significantly increased by the application of individual micronutrients or the combination of nutrients in the first crop and second crop. While application of biologically activated sulphur recorded the second highest yield of grain in the first crop, application of combination of nutrients, B and Mo gave higher grain yield in the second crop. The highest yield of straw in both the crops was resulted by the application of biologically activated sulphur. The general level of the nutrients in the soil, tried under this study, was comfortably above the reported critical limits for these nutrients in Kerala soil and hence the results obtained were in line with most of the earlier studies in Kerala.

The pattern of uptake of the macro and micronutrients by the crop, unless affected by interactions, corresponded to the different growth stages and the rate of dry matter production. Positive interactions of N-P, P-K, P-Mg, P-Cu, K-Cu and Zn-Cu were observed and total K uptake was found to enhance the straw yield generally. Negative interactions of K-Mg, Mg-Zn, P-Zn and Fe-Mn were observed which hindered the uptake of each other by the crop.

Application of Stanes Microfood, a micronutrient formulation resulted in the highest grain yield in the first crop. The uptake and utilization of many nutrients such as K, Ca, Zn and Mn by plants were enhanced by the application of this treatment. In the second crop season, the product was not as effective as in the first crop in increasing the grain yield of rice.

Table 41. Inter-relationships of soil and plant characteristics of the second crop (coefficients of simple linear correlation)

	Grain yield	Straw yield	Total dry matter yield	Total N uptake	Total P uptake	Total K uptake	Total Mg uptake	Total S uptake	Total Zn uptake	Total Cu uptake	Total Mn uptake	Total B uptake
Grain yield	–	0.406	0.795**	0.802**	0.842**	0.336	-0.541	-0.378	0.007	0.433	-0.346	0.096
Straw yield		–	0.685*	0.391	0.722*	0.834**	0.063	0.392	-0.053	0.542	0.406	0.586
Total dry matter yield			–	0.615	0.747*	0.506	-0.397	0.608	0.048	0.307	0.008	0.338
Total N uptake				–	0.724*	0.349	-0.343	0.253	-0.353	0.270	-0.330	-0.044
Total P uptake					–	0.643*	-0.277	0.282	-0.162	0.680*	0.036	0.315
Total K uptake						–	0.235	0.553	0.153	0.795**	0.316	0.392
Total Mg uptake							–	-0.390	0.168	0.021	0.567	-0.363
Total S uptake								–	0.313	0.387	-0.162	0.422
Total Zn uptake									–	0.300	-0.248	-0.217
Total Cu uptake										–	-0.021	0.237
Total Mn uptake											–	0.291
Total B uptake												–

Contd.

Table 41. Continued

	Total N in soil	Av. P in soil	Av. K in soil	Org. C in soil	pH	Exch. Mg in soil	Av. S in soil	Av. Zn in soil	Av. Cu in soil	Av. Mn in soil	Av. B in soil
Grain yield	0.453	-0.439	-0.355	0.265	-0.530	-0.098	-0.249	-0.154	0.202	0.145	-0.049
Straw yield	0.324	-0.061	0.180	0.255	-0.551	0.291	0.005	-0.139	0.027	0.196	0.183
Total dry matter yield	0.631	-0.235	-0.273	0.409	-0.539	-0.130	-0.150	-0.062	0.201	0.234	0.219
Total N uptake	0.597	-0.255	0.099	-0.018	-0.431	0.206	0.119	-0.359	-0.203	-0.126	0.280
Total P uptake	0.461	-0.469	-0.253	0.385	-0.749*	-0.354	-0.137	-0.353	0.022	0.174	-0.089
Total K uptake	0.087	0.129	0.196	0.057	-0.722*	-0.387	0.183	-0.067	0.285	-0.150	0.165
Total Mg uptake	-0.510	0.575	0.314	0.037	-0.191	-0.088	0.074	0.400	-0.050	0.068	-0.074
Total S uptake	0.293	0.087	0.009	-0.166	-0.279	-0.099	0.211	-0.009	0.552	-0.363	0.438
Total Zn uptake	-0.549	0.458	-0.123	0.178	0.036	0.041	-0.171	0.867*	0.867**	0.217	-0.449
Total Cu uptake	-0.077	-0.111	-0.097	0.193	-0.654*	-0.435	0.085	-0.069	0.426	-0.072	-0.342
Total Mn uptake	-0.094	-0.068	-0.010	0.171	-0.411	-0.539	-0.253	-0.141	-0.175	0.220	0.230
Total B uptake	0.278	-0.220	0.002	-0.080	-0.076	-0.518	0.100	-0.457	-0.066	-0.166	0.274

Contd.

Table 41. Continued

	Total N in soil	Av. P in soil	Av. K in soil	Org. C in soil	pH	Exch. Mg in soil	Av. S in soil	Av.Zn in soil	Av.Cu in soil	Av.Mn in soil	Av. B in soil
Total N in soil	–	-0.295	-0.189	0.303	-0.192	0.076	0.336	-0.564	-0.482	-0.081	0.370
Av. P in soil		–	0.424	-0.176	0.249	0.246	0.547	0.595	0.115	-0.315	0.088
Av. K in soil			–	-0.637*	0.347	0.550	0.341	0.056	-0.177	-0.255	0.445
Org. C in soil				–	-0.343	-0.221	-0.206	0.186	0.002	0.676*	-0.584
pH					–	0.594	0.154	0.207	-0.180	-0.026	-0.019
Exch. Mg in soil						–	0.154	0.305	-0.105	0.111	0.135
Av. S in soil							–	-0.238	-0.361	-0.704*	0.232
Av. Zn in soil								–	0.608	0.396	-0.363
Av. Cu in soil									–	0.124	-0.225
Av. Mn in soil										–	-0.492
Av. B in soil											

** Significant at 1% level * Significant at 5% level n = 10

Table 42. Relationship between straw yield, grain yield, nutrient uptake and soil characteristics (second crop)

X	Y	Regression equation	R^2
Total N uptake	Grain yield	Y = 104.9 + 10.81 X	0.787
Total P uptake	,,	Y = 104.9 + 123.7 X	0.787
Total P uptake	Straw yield	Y = 126.8 + 71.59 X	0.754
Total K uptake	,,	Y = 126.8 + 30.59 X	0.754
Grain yield	Total dry matter yield	Y = 1022 + 0.953 X	0.790
Straw yield	,,	Y = 1022 + 0.665 X	0.790
Total P uptake	Total dry matter yield	Y = 1739 + 258.8 X	0.558
Total N uptake	Total P uptake	Y = 29.42 + 0.001 X	0.952
pH	,,	Y = 29.42 - 4.339 X	0.952
Total P uptake	Total K uptake	Y = 8.742 + 2.997 X	0.413
pH	,,	Y = 289.6 - 44.97 X	0.822
Available Zn in soil	Total Zn uptake	Y = -0.637 + 0.042 X	0.935
Available Cu in soil	,,	Y = -0.637 + 0.119 X	0.935
Total P uptake	Total Cu uptake	Y = -0.02 + 0.002 X	0.681
Total K uptake	,,	Y = -0.02 + 0.001 X	0.681
pH	,,	Y = -0.02 + 0.001 X	0.681
Organic carbon in soil	Available K in soil	Y = 857.4 - 1257 X	0.406
Available Mn in soil	Organic carbon in soil	Y = 0.352 + 0.0004 X	0.457
Available Mn in soil	Available S in soil	Y = 110.5 - 0.179 X	0.495

Summary

SUMMARY

A field experiment was conducted to study the response of rice to application of secondary and micronutrients in a typical laterite soil of Kerala, using rice variety Jyothi. The treatments consisted of individual application of magnesium, sulphur, zinc, copper, manganese, boron and molybdenum, a combination of all these nutrients and Stanes Microfood which is a micronutrient formulation both through soil and foliage. The continued effect of treatments was studied by repeating the experiment for the second season with the same set of treatments applied to the same plots.

1. The experimental soil was sandy clay loam in texture, acidic and nonsaline. The content of organic carbon was medium, while available P and K ratings were high based on the soil fertility classification followed in Kerala.

2. Micronutrient application in general did not influence the major biometric characters of the plant in the first crop season but application of biologically activated sulphur influenced them during the second crop season.

3. The highest straw yield was recorded by the application of biologically activated sulphur in both crops indicating its influence on the vegetative growth of the crop. Other treatments did not show a positive response uniformly in both seasons of crop growth.

4. Application of Stanes Microfood increased the grain yield from 2065 kg ha^{-1} to 2606 kg ha^{-1} in the first crop season, but it was not as effective in the second crop. The second highest yield was recorded by the application of biologically activated sulphur in the first crop but in the second crop, this gave only lower yield. Eventhough the mean grain yield increased from the first crop to the second crop, no treatment influenced the grain yield significantly in both seasons of crop studied.

5. Nutrient per cent of the straw decreased with the advancement of crop growth. Nitrogen, P, K, Mn and Fe per cent of the straw were maximum at the maximum tillering stage of the crop.

6. The straw nutrient uptake increased till the flowering stage and then decreased at the time of harvest due to the translocation of nutrients to the grains.

7. During the first crop season, total N uptake was enhanced by the application of B and Cu whereas application of Mo produced the same effect in the second crop.

8. Total P uptake was found to be uniform in both seasons of crop by the application of all the treatments except that of zinc and combination of nutrients. An adverse effect of these two treatments on the total P uptake was observed indicating the P-Zn antogonism in soil.

9. The highest total K uptake was recorded by the application of biologically activated sulphur in both the crops followed by application of Stanes microfood in the first crop and that of boron in the second crop. Total uptake of K was positively correlated with the straw yield. A negative interaction between K and Mg was observed which was evident in both seasons of the crop.

10. Data on the level and uptake of Ca in grain and straw were inconsistent and revealed a lack of influence of any treatment on the level and uptake of Ca. However, application of Cu appeared to be beneficial on the total uptake of Ca in both seasons.

11. Lack of significant influence of any of the treatments on the Mg level and uptake by the rice plants was revealed in both seasons of study. Application of Mg in particular had no effect on the Mg level and uptake by the crop in the soil studied.

12. Application of S biologically activated by inoculation with *Thiobacillus* and *Aspergillus avomerii* was very effective in increasing the straw yield and thus the total dry matter yield in both seasons.

13. Application of zinc resulted in significant increase of the Zn level and uptake in the straw and grain and thus total Zn uptake. A positive interaction of Zn with Cu was observed while application of Zn and Mg was found to interact negatively.

14. Slight increase in the level and uptake of Cu by plants as a result of Cu application was observed in both seasons of crop growth. A positive interaction between Zn and Cu was expressed with regard to the level and uptake of Cu by plants.

15. Application of Mn did not influence the level or uptake of Mn by the plants. Stanes Microfood treatment recorded a higher Mn level in the crop in both seasons of the crop.

16. Iron level and uptake by the rice plants were not influenced considerably by the different treatments, though a positive interaction with zinc and a negative interaction with Mn were noticed.

17. A significant influence on the B level and uptake by the plants was not observed by the application of any of the treatments. Lack of a consistent influence of B application on the per cent and uptake of B in plants was noticed.

18. Molybdenum content and uptake by plants were not found to be influenced by any of the treatments, significantly.

19. A gradual decline in the total nitrogen content of the soil was observed from the initial to the harvesting stages of the first crop, due to the removal of N by the crop. The level of available P of the soil was inconsistent during the period of crop growth. Continuous removal of K due to absorption by the plants resulted in a gradual decrease in the available

K of soil uniformly in both seasons of crop growth, though the rate of uptake at the later stages was rather slow.

20. Exchangeable Ca content of soil was not significantly influenced by any of the treatments tried and a uniform trend was observed to be lacking in both seasons of the crop.

21. Lack of influence of Mg application on the content of exchangeable Mg in soil was revealed in both the seasons.

22. A uniform trend with regard to the available S content of soil could not be observed in the first crop while a gradual increase in available S of soil was noticed in the second crop. Application of biologically active S was found to ensure continued availability of S throughout crop growth.

23. Significant increase in the available Zn content of soil was recorded both by the independent application of Zn and the combination of nutrients uniformly in both the crops. But the increased availability of Zn and higher uptake by the crop was not reflected either in the morphological characters or in the yields of straw and grain. A negative interaction with P and a positive interaction with Cu were also observed.

24. Application of copper could not sufficiently raise the available Cu content of the soil.

25. An increase in the available Mn content of the soil was caused by submergence of the soil and further decrease was noticed as a result of crop uptake and removal.

26. The available Fe content of the soil was not affected by any of the treatments in both the crops.

27. Application of boron and molybdenum both in the first and second crop seasons, could not influence the available B and Mo contents of soil significantly and values obtained under various treatments were inconsistent in both the cases.

28. Organic carbon content, pH and specific conductance of the soil at various stages of crop growth were not affected by the different treatments tried in this study.

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* Originals not seen

Appendix

Appendix-1

Weather data (weekly average) during the cropping period
(from 25.6.1991 to 28.1.1992)

Standard week No.	Month and date	Total rainfall, mm	No. of rainy days	Temperature		Relative humidity (%)		Sunshine hours
				Maximum °C	Minimum °C	Forenoon	Afternoon	
1	2	3	4	5	6	7	8	9
26	June 25-Jul. 1	216.0	6	28.4	23.1	93	83	0.6
27	Jul. 2-8	161.4	7	29.3	22.8	93	78	2.8
28	Jul. 9-15	179.4	7	28.4	23.2	94	79	2.1
29	Jul. 16-22	140.9	7	29.5	22.7	94	77	2.4
30	Jul. 23-29	361.6	7	29.3	22.6	92	79	3.2
31	Jul. 30-Aug. 5	160.8	7	29.0	23.3	95	84	1.9
32	Aug. 6-12	65.2	6	29.5	23.1	95	79	2.3
33	Aug. 3-19	313.9	7	27.8	22.0	95	84	1.8
34	Aug. 20-26	53.0	6	29.1	22.3	96	79	3.5
35	Aug. 27-Sept. 2	12.5	3	30.4	23.3	94	66	6.5
36	Sept. 3-9	0.0	0	31.4	23.2	90	59	9.1
37	Sept. 10-16	6.4	2	31.6	24.6	90	65	6.1
38	Sept. 17-23	18.3	4	31.5	22.4	92	59	6.8
39	Sept. 24-30	36.8	5	31.7	24.0	90	70	6.5
40	Octo. 1-7	11.4	3	31.2	23.5	92	77	4.1
41	Octo. 8-14	97.3	4	30.6	23.2	91	75	4.3

Contd.

Appendix-1. Continued

1	2	3	4	5	6	7	8	9
42	Octo. 15-21	57.6	4	32.1	23.0	87	66	6.4
43	Octo. 22-28	40.0	5	30.8	23.1	87	72	3.9
44	Octo. 29-Nov. 4	75.4	3	29.8	23.0	96	76	3.0
45	Nov. 5-11	105.0	6	32.1	22.5	89	62	7.4
46	Nov. 12-18	53.4	3	31.4	22.8	94	69	5.0
47	Nov. 19-25	0.5	1	31.0	24.4	76	58	7.7
48	Nov. 26-Dec. 2	0.0	0	31.9	20.9	79	58	8.6
49	Dec. 3-9	0.0	0	31.3	21.4	78	45	9.7
50	Dec. 10-16	0.0	0	30.9	23.5	69	56	8.0
51	Dec. 17-23	0.0	0	31.9	23.2	75	49	7.9
52	Dec. 24-30	0.0	0	33.2	19.9	91	45	8.6
1	Jan. 1-7	0.0	0	32.4	21.8	80	39	7.0
2	Jan. 8-14	0.0	0	32.1	20.6	66	35	9.3
3	Jan. 15-21	0.0	0	32.4	22.1	72	40	9.4
4	Jan. 22-28	0.0	0	33.2	19.8	60	28	9.7

Source: Meteorological Observatory, Vellanikkara

Plates

Plate 1. A general view of the field experiment (first crop)

Plate 2. Comparison of treatment plots receiving application of Stanes Microfood (T_{10}) with that of control (T_1)

Plate 3. A general view of the field experiment (second crop)

RESPONSE OF RICE TO APPLICATION OF MICRONUTRIENTS

By

P. MURALIDHARAN

ABSTRACT OF A THESIS

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Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry
COLLEGE OF HORTICULTURE
Vellanikkara 680654
THRISSUR

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ABSTRACT

A field experiment was conducted to study the response of rice to application of secondary and micronutrients during the first and second crop seasons of 1991. The experiment was conducted at the Agricultural Research Station, Mannuthy using rice variety Jyothi and the soil was sandy clay loam in texture. The treatments consisted of the different micronutrients (Zn, Cu, Mn, B and Mo), magnesium, sulphur, a combination of the above said nutrients and Stanes Microfood, a micronutrient formulation, in addition to the control with no micronutrients. Application of N, P and K was done uniformly in all the treatments. Soil and plant samples were collected at the maximum tillering, flowering and harvesting stages of the crop for the determination of uptake and availability of nutrients, pH and specific conductance. The continued effect of the application of micronutrients was studied by repeating the experiment in the second crop season with the same set of treatments applied to the same plots. Observations on the morphological and yield characters and yields of grain and straw were recorded in both the seasons of crop growth.

The experimental soil was a typical laterite soil of Kerala, sandy clay loam in texture, acidic and nonsaline. The organic carbon content of the soil was medium and available P and K ratings were high.

The morphological characters as well as the yield of straw was little influenced by the application of various treatments except a slight increase caused by the application of biologically activated sulphur. The highest straw yield was recorded by the application of biologically activated sulphur in both seasons of the crop. This may be due to the continued availability of the nutrient throughout crop growth made possible by the inoculation with mocroorganisms. Application of Stanes Microfood resulted in the highest grain yield of 2606 kg ha^{-1} during the first crop season while the combination of nutrients produced this effect in the second crop (3185 kg ha^{-1}), eventhough the increase in yield resulted in both cases was not to the extent of statistical significance.

The pattern of uptake of macro and micronutrients was corresponding to the rate of absorption at different growth stages of the crop and the dry matter production resulted, unless affected by nutrient interactions. Uptake and utilization of N were found to be enhanced by the application of B and Cu in the first crop and Mo in the second crop. Positive N-P interaction was also observed. Phosphorus uptake by the crop was uniform in all the treatments except an adverse effect caused by the Zn treatment. This reveals a possible antagonism between P and Zn in soil. The highest total K uptake was recorded by the application of biologically activated sulphur in both the seasons and total K uptake was positively correlated with the straw yield. An evident K-Mg antagonism was observed in both the seasons of crop studied.

Level and uptake of Ca, Mg, Mn, Fe, B and Mo by the crop were not significantly influenced by the application of treatments. Calcium and iron were not included in the treatments under this study. Lack of a positive response for the application of Mg, Mn, B and Mo, in the crop may be attributed to the presence of these nutrients in the soil in required amounts and forms, which was revealed by the analysis of the soil and comparison with the critical limits for these nutrients reported in Kerala soils. A negative interaction of Mn with Fe was also observed.

The uptake of S by the crop was found to be improved by the application of biologically activated sulphur, probably due to the continued availability of the nutrient resulted by the oxidation of sulphur caused by the inoculation with microorganisms like Thiobacillus and Aspergillus avomerii. Application of zinc significantly increased the Zn level and uptake in the plant but this was not found to influence the morphological characters or yields of straw and grain. A positive interaction of Zn with Cu and a negative interaction with Mg were observed. Copper application slightly increased the uptake of Cu by the crop, probably due to the increased availability caused by the application. A better performance in grain yield was recorded by the application of Cu in the second crop season, which was on par with the yield of grain recorded by individual applications of B and Mo.

The content and availability of the macro and micronutrients in the soil were related to the rate of uptake of the nutrients by the crop along with the advancement of crop growth. While the positive interactions such as P-Cu, P-Mg, K-Cu and Zn-Cu increased the availability of each other in the soil and thus increased uptake by the crop, adverse effects were caused by P-Zn, K-Mg, Mg-Zn and Fe-Mn interactions. Organic carbon content, pH and specific conductance of the soil were not influenced by any of the treatments tried under this study.