THE EFFECT OF CALCIUM, MAGNESIUM AND SILICON ON PRODUCTIVE FACTORS AND QUALITY OF RICE

A THESIS SUBMITTED TO THE UNIVERSITY OF KERALA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURE) IN AGRICULTURAL CHEMISTRY

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C E R T I F I C A T E

This is to certify that the thesis herewith submitted contains the results of bonafide research work carried out by Smt. P.Padmaja under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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INTRODUCTION

INTRODUCTION.

The soils of Kerala are generally of low productivity. The fertility surveys and soil test data on nearly 50,000 samples of soils in the State carried out since 1956 reveal that about 20 per cent of our soils are deficient in nitrogen, and over 80 per cent low in phosphorus and potassium. The tropical climate and the heavy rainfall have depleted the soils of the important base calcium and rendered them acidic (Ray Chaudhuri 1953). The limited data available at present on the level of magnesium in our soils indicate that it falls below the critical minimum required for satisfactory plant growth.

The use of nitrogenous, phosphatic and potassic fertilisers enabled us to obtain bumper yields of paddy in the early years of their widespread use. However, the response to these fertilisers, in some areas has not been very encouraging in recent years. This may partly be due to the progressive removal of the secondary elements Ca and Mg by continuous cropping resulting in a low level of these elements in our soils so that crops grown on them have started showing hunger signs for these plant food elements. Thus a situation has arisen where NPK fertilisation alone can no longer maximise the yields of paddy obtained from these soils.

This problem can partly be solved by neutralising the acidity in our soils by the application of liming materials. The inclusion of dolomitic lime stone in our manurial programmes will supply both Ca and Mg to our soils.

Recent work in Japan and other rice growing countries emphasises the importance of silicon in the nutrition of the rice crop. The application of silicon prevents lodging of the rice plants, (Winifred et al 1927), so characteristic under high nitrogen fertilisation and confers resistance to the plants against the incidence of the yield-decreasing blast disease (Volk et al 1957). Besides, the use of soluble silicon in the form of sodium silicate or easily available silicon in the form of calcium magnesium silicate releases soil phosphorus and minimises the fixation of fertiliser phosphorus, especially in acid soils. In a recent report of the International Rice Research Institute, Phillippines, it is observed that increased yields of rice to the extent of 500 kg. per hectare are obtained by the application of 100 kg. per hectare of silica in the form of calcium magnesium silicate.

Rice is the major food crop in Kerala occupying an area of approximately 7.5 lakh hectares. Intensive cultivation is probably the only feasible method by which production can be substantially increased in the State. We have gone a long way in our research programmes on manuring of the rice crop with respect to the major plant food elements, nitrogen,phosphorus and potassium. But secondary elements, such as, calcium, magnesium and silicon which is reported to have beneficial effects on the rice crop, have received very little attention so far.

It was, therefore, felt that it would be worthwhile to undertake investigations to study the influence of calcium, magnesium and silicon on the productive factors and quality of rice.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

CALCIUM

1. Calcium as a nutrient

Much work has been done on the role of calcium as a nutrient especially in acid soils. Gedroiz (1931) reported that crop growth was maximum only in soils saturated with this element. Moser (1933) found that the nutrient uptake of plants increased with increasing amounts of available calcium. It was shown by Kipps (1947) and Brady and Colwel (1945) that calcium sulphate application increased yield and calcium content of crops. Black (1957) concluded that the beneficial effects observed on liming were mainly due to the nutrient effect of calcium.

Calcium as an ameliorant

The results of investigations by Kipps (1947), Schmehl *et al* (1950), Heslep (1951) and others indicated that the beneficial influence on crop production obtained by liming was not due to the nutrient affect of calcium but was associated with changes in soil reaction. Juska (1959) obtained the greatest response to the major nutrients at pH 7.0. Nambiar (1960) and Varghese (1963) observed a significant increase in pH in laterite soils consequent on the addition of lime.

Effect of calcium on growth and yield

True (1922) and Tiedjens (1948) reported an increase in the development of roots due to liming. Bavappa and Rao (1956) and Rothwell (1957) also observed the beneficial influence of calcium on root distribution.

Contrary to the above findings Pohlman (1946) and Bhat (1964) did not obtain any response to liming, as regards root development.

Nambiar (1960), Varghese (1963) and Bhat (1964) obtained an increase in the number of tillers per plant in rice as a result of the application of lime. Thousand grain weight was found to be increased due to liming by Kido et al (1958). Bhat (1964) recorded delayed flowering due to calcium application.

Novikov (1934) observed a reduction in tillering and heading due to liming in rice.

The influence of calcium on the yield of all crops especially rice was reported by several workers. Welch and Nelson (1950) found that calcium sulphate application increased yields on unlimed soils. Sethi et al (1952) have reported that the rice crop in the slightly acid soil of Pattambi responded to liming. Bavappa and Rao (1956) obtained substantial yield increases due to liming in South Kanara. Reviewing the results of experiments on liming conducted all over India, Chakraborthy et al (1961) reported

reported that liming increased rice yields in Mysore, Assam, Madras, Bihar and Kerala.

Effect of calcium on the availability and uptake of nutrients

(1) Nitrogen:

Calcium has been reported to be intimately associated with nitrogen assimilation. Parker and Truog (1927), Paden and Garman (1946) Coleman (1955) and Deguchii (1960) clearly pointed out the importance of calcium in protein metabolism. According to Blue and Eno (1957) liming resulted in better and efficient utilisation of nitrogenous fertilizers.

Varghese (1963) and Bhat (1964) recorded increased nitrogen content in grain and straw in rice by liming. Contrary to the above observations, Kobayashi *et al* (1956) reported that the nitrogen content of rice was not increased by the application of calcium carbonate.

Dhar and Ghosh (1955) observed a rapid oxidation of carbonaceous materials by the application of calcium carbonate, thereby decreasing the C/N ratio.

Palfalvi (1958), studying the effect of different doses of lime of a soil, poor in calcium found that the application of lime progressively decreased organic matter and total nitrogen and increased the levels of mineral nitrogen.

(2) Phosphorus:

As early as 1907, Hilgard stressed the importance of lime on phosphorus availability. Cook and Miller (1935), Davis and Brewer (1940), Dunn (1943) and Truog (1948) claimed that liming helped in increasing the availability of phosphorus. They also indicated that increasing doses of lime consistantly lowered the power of soils to fix acid-soluble phosphates.

Dhar and Singh (1955) observed an increase in the availability of soil phosphate by the addition of calcium carbonate. They attributed this to the better mineralisation of organic phosphorus. Mariakulandai (1955) showed that liming the acid soils of Nanjanad increased the availability and uptake of phosphorus by potato.

Contrary to the above observations Ressiter (1952) noticed a reduced phosphorus concentration in oats by lime application. This he attributed to increased microbial fixation due to increased nitrification. Thorp and Hobbs (1956) and Basak _et al_ (1961) also obtained similar results.

(3) Potassium:

Ehrenberg (1919) pointed out the antagonistic effect between calcium and potassium. Studies on the potash-lime problem by Jenny and Shade (1934) have shown that calcium induced microbial activity and tended to reduce the supply of potassium in the soil by microbial fixation. The investigations of Harris (1937) and Albrecht (1942) showed that liming increased the fixation of potassium rather than favouring its release. Koshy (1960) also obtained a decreased uptake of potassium by application of high levels of calcium.

York and Rogers (1947), and Barber and Marshal (1952) and York et al (1953) obtained quite contrasting results, wherein the addition of calcium resulted in an increased release of potassium from the soils.

(4) Calcium:

Shed (1922) and Moser (1933) found that the addition of calcium compounds increased the calcium content of the various crops. Truog (1948), Wahab and Shah (1952) and Deguchii (1960) also obtained similar results. Contrary results were reported by Eisenmenger et al (1939) and Basak et al (1961) where in they did not get any increase in the uptake of calcium due to liming. Kinzerskii (1938) found that liming improved appreciably the quality of barley. Kobayashi et al (1956) opined that the uptake of silicic acid was reduced by liming since silica was fixed by calcium as calcium silicate

MAGNESIUM

Effect of magnesium on growth and yield

The experiment conducted by Volker (1915) indicated that magnesium-treated plants tillered better and produced healthier tillers. Ishizukay and Hayakava (1951) observed that magnesium-treated plants were juicy and ripened very late. Ishaburo Nagai (1959) obtained significant improvement in plant growth, yield and magnesium content by the application of magnesium sulphate or carbonate. It was reported by

Sadapal and Das (1961) that vegetative growth, especially in the early stages, number of grains per ear and thousand grain weight were all increased by magnesium application.

Contrary results have also been reported by some workers. Coupin (1918) studying the effects of magnesium carbonate reported a decrease in the length of the main shoot and size of the rootlets and also a decrease in the number of rootlets and root hairs.

The effect of magnesium on the yield of crops has been studied extensively. The experiments conducted by Pisciotta (1913), Volker (1915), Shed (1922), Hashimoto and Kavaguchii (1955), Stenut and Piot (1958) all go to show the efficiency of magnesium in increasing the yield of various crops. Schreiber (1949) obtained high yields in oats by applying magnesium in combination with nitrogen, phosphorus and calcium. Narayanan and Vasudevan (1957) obtained three per cent increase in yield of rice by foliar application of magnesium sulphate.

The experiment conducted by Sadapal and Das (1961) in a sandy loam of pH 7.0 and medium fertility showed an appreciable increase in the number of grains per ear and thousand grain weight in rice.

According to Kobayashi _et al_ (1956) magnesium application had little effect on the yield or silicon or nitrogen content of the rice crop.

Effect of magnesium on the availability and uptake of nutrients.

(1) Nitrogen:

Dix (1930) stressed the need of magnesium for the formation of protein in plants. Sadapal and Das (1961) obtained increased protein content in rice grain due to magnesium application.

Contrary to the above, Sehropp (1949) and Kobayashi et al (1956) obtained a negative response to magnesium in relation to protein content.

(2) Phosphorus:

Leew (1901) was of the opinion that magnesium helped to improve the phosphorus economy in plants.

Truog et al (1947) obtained an increase in phosphorus content, especially of seeds, by magnesium application rather than by phosphorus application. The authors also suggested that the failure to obtain a crop of higher phosphorus content through the addition of phosphatic fertilizers was due to the lack of magnesium. Zimmerman (1947), Hashimoto et al (1955) and Sadapal and Das (1961) also obtained an increased phosphorus content following magnesium application.

An absence of response to magnesium application was reported by Mazaeva (1948) and Schropp (1949).

(3) Potassium:

Divergent results were reported by various workers as regards the influence of magnesium on potash availability. Griffith (1959), in his investigations, on the influence of magnesium on the availability of potash, obtained a decrease in the uptake of potassium. Koshy (1960) also obtained a similar result.

The study by Chambers (1953) indicated that magnesium increased crop yields by increasing the potassium supply. Graham (1956) observed that the addition of magnesium neither affected the magnesium nor the potash content of crops.

(4) Calcium:

Contrary views have been expressed by previous workers on the effect of magnesium on calcium uptake and availability.

Addition of magnesium compounds resulted in a decrease in calcium content, (Blair *et al*, 1939). It was observed by Eisenmenger *et al* (1939) that when calcium and magnesium salts were added the majority of the plants they tried recorded a decrease in calcium and magnesium uptake. Griffith (1959) obtained a decreased uptake of calcium due to magnesium application. Albrecht (1937), on the other hand found that the application of magnesium released calcium from the soil.

(5) Magnesium:

Increased uptake of magnesium has been generally observed as a result of magnesium application. Hashimoto et al (1955), Mazaeva (1957) and Ishaburo Nagai (1959) while studying the influence of magnesium in increasing the magnesium content of the various plant parts, reported an increase in all the parts, especially seeds.

Certain workers like Graham (1956) did not get any increase in magnesium content in soyabeans, clover, wheat and carrots due to magnesium application.

(6) Silicon:

Published work relating to the influence of magnesium on the silicon content of plants is meagre. Kobayashi et al (1956) did not get any increase in silicon content in rice due to magnesium application.

SILICON

Effect of silicon on growth and yield

The importance of silicon in plant nutrition has been studied extensively in Japan. Ishibashi and Hajima (1937), Srinivasan (1936), Okamoto (1957) and Azuma et al (1961) all reported an increase in the dry matter production, height of plants and the length of earheads and roots by the addition of silicon to rice. A different result was obtained by Yoshida (1959) who showed that silicon was not essential for growth in rice.

From the experiments conducted at Rothamsted, Hall and Morison (1906), observed, earliness and increased grain formation by the application of silicon. Hartong (1940), Mitsui (1956) and Okamoto (1959), from their studies on various cereals like rice, wheat and barley observed the importance of silicon in hastening panicle growth and ear weight. Mitsui and Taktohu (1960) also observed early flowering as induced by silicon.

Winifred et al (1927), Takyimia et al (1959), Miyoshi and Ishii (1960) and Azuma et al (1961), all obtained an increase in the number of tillers by silicon application. Yoshida (1959) however, was of the opinion that silicon was not essential for increased tiller formation in rice.

Divergent findings have been reported in literature regarding the role of silicon in increasing crop yields. Lemmermann and Weiesmann (1922) Okava and Kinsaku (1936), Srinivasan (1936), Ishibashi and Hajima (1937), Yoshida (1959) and Dutta et al (1962) reported the beneficial effect of silicon in increasing rice yields. Hosoda and Takata (1957) obtained fourteen per cent increase in grain yield from a soil having a low SiO_2/R_2O_3 ratio by adding calcium silicate. But Ganssman (1962) could not get any response in the yield of rice by silicon application in light soils.

Effect of silicon on the availability and uptake of nutrients

(1) Nitrogen:

Various workers have studied the influence of silicon on the availability and uptake of nitrogen. Lawes (1951) was of the opinion that silicon increased the dry weight and protein content of rice. Okamoto (1959) and Miyoshi and Ishi (1960), observed that translocation of nitrogen to the earhead and the protein content of the grain were increased in silicon-treated plants.

A different result was reported by the following workers regarding the role of silicon. Kobayashi et al (1956) obtained an increased percentage of nitrogen in rice due to slag application. Ishaburo Nagai (1959) claimed that the absence of silicon increased the nitrogen content of rice plant. Wagava and Ken-Ichi-Kashima (1963) observed that when silicon was applied though the percentage of nitrogen in every part of the rice plant was made to fall the movement of nitrogen to ears was accelerated.

(2) Phosphorus:

There are various schools of thought regarding the influence of silicon on the availability and uptake of phosphorus by plants. Lemmermann and Weiessman (1922) argued that silicon could perform in the plant some functions of phosphorus while another group led by Hall and Morison (1906) were of opinion that silicon increased phosphorus assimilation by plants, either directly by its ability to replace phosphate in the plant or indirectly by rendering it more easily available by solvent action on soil phosphorus.

Akhramako (1934) reported that silicon deposited on plant roots increased its ability to absorb phosphorus. Votkevich (1936) observed that soil application of silicon increased nitrification and the solubility of phosphorus. Fritz (1940) indicated from studies on rice, oats, barley and maize that silicon favoured the accumulation and better utilisation of phosphorus in plants. In a soil with a low SiO_2/Al_2O_3 ratio, Hosodo and Takata (1957) found that the available phosphorus in the soil and phosphorus in the plant were higher in the calcium silicate plot than in the calcium carbonate plot.

Altogether different results were reported by several other workers. Lawes (1951) observed that the solubility of phosphorus and the amount of phosphorus absorbed from the soil solution, decreased with increasing amounts of silicon. Azuma et al (1961) reported that the phosphorus uptake of rice plant was slightly decreased with increasing supply of silicon. In a recent work, Wagava and Ken-Ichi-Kashima (1963) also observed that when silicon was applied the percentage of phosphorus in every part of the rice plant was decreased but the movement of phosphorus to ears was accelerated.

(3) Potassium:

Silicon was found to favour the accumulation and utilization of potassium in plants by Okava and Kinsaku (1937) and Fritz (1940). Takyima et al (1959) noticed an increased absorption of potash by the application of silicon in rice. From their extensive studies on nutrient uptake as affected by silicon application Wagava and Ken-Ichi-Kashima sheaths and stalk and a decrease in the ear, leaf blade and roots.

(4) Calcium:

According to Fritz (1940) silicon application increased the accumulation and better utilisation of calcium. Contrary to the above result, Lawes (1951) indicated that the calcium percentage was decreased by silicon application. A detailed study on silicon nutrition of rice plants by Wagava and Ken-ichi-Kashima (1963) pointed out an increase of calcium in leaf sheath and roots and a decrease in the earhead, leaf blade and stalk.

(5) Magnesium:

Okava and Kinsaku (1937) obtained an increased level of MgO in rice and barley plants treated with silicic acid. Takyima et al (1959) also obtained similar results by silicon application. Recently Wagava and Ken-ichi-Kashima (1963) obtained a different result wherein the magnesium content was found to increase only in roots, whereas in earhead, leaf blade, leafsheath and stalk there was a decrease due to the application of silicon.

(6) Silicon:

Several workers have reported on the efficiency of available silicon in increasing the SiO_2 content of plants. Schollenburger (1922) observed that silicon added as calcium silicate or sodium silicate was assimilated as shown by an increased percentage of silicon in the plants. Bastisse (1951) reported that the SiO_2 content of wheat straw was increased by 129 percent of the original amount by repeated addition of silicate solution to the soil. Okamoto (1957), Volk et al (1957) and Kobayashi et al (1956) obtained increased percentage of SiO_2 in leaves and shoot due to silicon application.

A different result was reported by Mitsui et al (1961) from their radioautograph studies. They noticed that the addition of silicon in culture solution caused a significant depression of Si^{31} uptake by rice. It was also observed that the absorbed Si^{31} was mostly translocated to shoots particularly to well developed leaves.

MATERIALS AND METHODS

MATERIALS AND METHODS

A. Pot culture experiments

The effect of calcium, magnesium and silicon singly and in combinations, on the productive factors and quality of rice was studied in a pot culture experiment.

Design:

2^3 x 4 factorial randomised block design with the following treatments was used.

Treatments:

Treatment 1 Si_0 Mg_0 Ca_0

" 2 Si_1 Mg_0 Ca_0

" 3 Si_0 Mg_1 Ca_0

" 4 Si_1 Mg_1 Ca_0

" 5 Si_0 Mg_0 Ca_1

" 6 Si_1 Mg_0 Ca_1

" 7 Si_0 Mg_1 Ca_1

" 8 Si_1 Mg_1 Ca_1

Si_0=0 lb. silica per acre

Si_1=25 lb. silica per acre

Mg_0=0 lb. Mg per acre

Mg_1=100 lb.Mg per acre

Ca_0=0 lb. CaO per acre

Ca_1=1 ton CaO per acre

Soil:

The soil used was Vellayani red loam from the unmanured fields of the College Farm. The chemical characteristics of the soil is given in table 1.

Table 1

CHEMICAL COMPOSITION OF SOIL TAKEN FOR POT CULTURE STUDIES

		Percentage on oven dry basis
Moisture	..	1.50
Loss on ignition	..	8.30
Total nitrogen	..	0.08
Available nitrogen	..	0.04
Total P_2O_5	..	0.16
Available phosphorus	..	very low
Total potash (K_2O)	..	0.10
Calcium (CaO)	..	0.28
Magnesia (MgO)	..	0.09
Soluble silica	..	2.01

Strain

The short duration (90-100 days) period bound strain Ptb.10 was used for the study.

Fertilizers

Cattle manure at the rate of 5 tons per acre and NPK at the rate of 30:30:30 lbs. per acre as ammonium sulphate (20.5 per cent N) superphosphate (16.0 per cent P_2O_5) and muriate of potash (60 per cent K_2O), were applied uniformly in all the pots.

The nutrients calcium, magnesium and silicon were applied as calcium oxide, magnesium carbonate and sodium

The soil well mixed with powdered cattle manure was applied in equal amounts to 40 pots including eight dummy pots. The fertilizers calcium oxide, magnesium carbonate and sodium silicate were applied in calculated quantities to supply the required dose of nutrients at the time of filling the pots, a week prior to planting. The entire dose of superphosphate and muriate of potash and half the dose of ammonium sulphate were applied to each pot prior to planting. The other half of ammonium sulphate was applied just before flowering.

The seedlings were raised in a nursery and four seedlings (25 days old) were planted in each pot on 30-11-1963. The uncropped series of pots with the same treatments under exactly identical conditions were maintained for drawing periodical soil samples for chemical study. All the pots were arranged in the pot culture yard in a randomised manner. The pots were watered daily with measured quantity of well water. The crop was harvested 90 days after sowing on 11--2--1964.

The harvested plants from each pot were placed in separate paper bags and dried in an air oven at 70°C. The yield of straw and grain were recorded separately. The dried plant material was then powdered well in an electric grinding mill and stored in air-tight glass containers for chemical analysis.

B. Plant performance studies

The following observations were made to determine the effects of different treatments on plant performance.

1. **Total number of vegetative tillers:**

   This observation was made on the shot blade stage.

2. **Total number of productive tillers:**

   This was observed at the time of harvesting.

3. **Plant height:**

   This was recorded two weeks after flowering. Measurement of plant height was made from the soil surface to the tip of the last leaf.

4. **Leaf width:**

   The maximum width of the third leaf from the bottom was measured for all plants, at the shot blade stage (Hutchinson and Ramiah, 1938).

5. **Flowering duration:**

   A flowering chart was prepared and flowering of individual plants in each pot was marked from which the flowering duration for each treatment was calculated.

6. **Cumulative earhead emergence counts:**

   To assess the variation in flowering due to treatments the total number of emerged earheads per pot was counted on alternate days from the date of first flowering to the date of completion of flowering.

7. **Total earheads and immature earheads:**

   This was recorded at the time of harvest.

8. Grein and straw yield per pot:

Grain and straw yield were recorded on oven-dry basis.

9. Earhead length:

The length of earhead from the neck to the tip was recorded for five earheads per pot.

10. Thousand grain weight:

Weight of thousand grains selected at random from each sample was recorded.

11. Root measurements:

The soil in the pot was removed by directing a jet of water and the roots removed without damage, washed free of adhering soil particles and the weight of roots recorded after drying in an oven at 70°C. The length measured from the last node to the tip of the longest root was recorded as the length of the root system.

All the observations were statistically examined to find out the effect of various treatments on plant performance.

C. Laboratory investigations.

1. Number of silicated cells in the leaves:

Samples of the middle one third portion of the third leaf were drawn from various treatments and preserved in Formalin--Acetic acid--Alcohol mixture (5:5:90).

Small bits of the leaf samples were scratched with a blade to destroy the lower epidermis and immersed in concentrated nitric acid with a few crystals of potassium chlorate.

The mixture was warmed gently to get white epidermal peelings. The peelings were stained with saffranin (5 per cent), mounted in glycerine and examined under the high power objective of a microscope (Anon 1957). Dumbell shaped silicated cells in rows were counted from a uniform length of 75 μ. For this purpose an occular micrometer was used.

Observations were taken for each sample and four samples were studied for each treatment.

2. Soil studies:

Samples of soil from each treatment in the uncropped series of pots were drawn just before planting and thereafter at intervals of one month from the date of planting. The samples were analysed for total nitrogen and available nitrogen and P_2O_5 and pH by standard methods (Piper 1950; Jackson, 1958).

Total nitrogen:

This was estimated by Kjeldahl's method using sulphuric-salicylic acid mixture.

Total phosphorus

Total phosphorus was determined volumetrically in the hydrochloric acid extract of the soil.

Available nitrogen:

Available nitrogen of the soil samples was determined by the alkaline permanganate method.

Available phosphorus:

The soil samples were analysed for available phosphorus by Dickman and Bray's method using 0.03 N ammonium fluoride in 0.025 N.Hcl.

pH:

The pH measurements were made on the Photovolt pH meter with glass electrodes using a 1:2.5 soil:water suspension.

3. Chemical analysis of plant material.

The unhusked grain and straw from each pot were separately analysed for nitrogen, phosphorus, potassium, calcium, magnesium and silicon by standard methods(Piper 1950; Jackson, 1958.)

Phosphorus, Potassium, Calcium, Magnesium and Silicon.

A weighed quantity of the oven-dry material was dry ashed at 300°C. and digested with 1:1 hydrochloric acid. 0.1 ml. of nitric acid was added to oxidise the ferrous salt and the solution evaporated to dryness and then ignited to dehydrate the silica. The residue was extracted with 1:1 hydrochloric acid, filtered through Whatman No.42 filter paper and the filtrate made upto 250 ml. The residue on the filter paper was reserved for silica estimation.

In aliquots of the extract, P_2O_5 was determined volumetrically after precipitation as ammonium phosphomolybdate and K_2O was determined gravimetrically as sodium potassium cobaltinitrate. Calcium and magnesium were determined by the Versenate titration method.

The residue on the filter paper was ignited in a platinum crucible and weighed. The silica was converted to volatile silicon fluoride by heating with hydrofluoric acid and the reduction in weight was recorded as silica.

R E S U L T S

RESULTS

1. Soil reaction

The soil reaction recorded during the course of the cropping period at monthly intervals for the various treatments is given in table II.

It may be seen that a week after application of the various treatments, the soil pH recorded for the treatments Ca, Ca+Si, Ca+Mg, Ca+Mg+Si were 1.0 to 1.5 units higher than that of the control. Combinations of Ca and Mg had a greater ability to neutralise soil acidity than Ca alone. However, Mg alone or combined with silicon was not able to raise the pH to any appreciable extent above that of the control. During the cropping period, the pH of the soils in the various treatments showed a slight tendency to decrease.

2. Available nitrogen and phosphorus status of the soils

Data on the available nitrogen and phosphorus status of the soils in the various treatments from the uncropped soils at different intervals during the cropping period are presented in table III.

It may be seen from the above table that in general the available nitrogen decreased progressively in all the treatments during the cropping period. However, in the case of the treatments that included Ca, the decrease was not as well marked as in the other cases. The slight increase (Fig.1) in the available nitrogen recorded at the second sampling period coincides with the top dressing of the

Table II

pH OF THE SOILS IN THE VARIOUS TREATMENTS AT DIFFERENT PERIODS OF SAMPLING

Treatments	Control	Si	Mg	Mg+Si	Ca	Ca+Si	Ca+Mg	Ca+Mg+Si
First sample (at the time of planting)	6.0	6.1	6.2	6.2	7.1	7.3	7.5	7.7
Second sample	5.9	5.9	6.1	6.2	6.6	7.0	6.7	7.2
Third sample	5.8	5.9	6.0	6.2	6.3	6.4	6.8	7.0
Fourth sample (at the time of harvest)	5.8	6.0	6.0	6.1	6.5	6.9	7.0	7.0

Table III

AVAILABLE NITROGEN AND PHOSPHORUS STATUS OF THE SOILS IN THE VARIOUS TREATMENTS AT DIFFERENT STAGES DURING THE CROPPING PERIOD (IN MILLIGRAMS PER HUNDRED GRAMS ON OVEN DRY BASIS)

Treatments	First sample				Second sample				Third sample				Fourth sample			
	N	Percentage on total	P_2O_5	Percentage on total	N	Percentage on total	P_2O_5	Percentage on total	N	Percentage on total	P_2O_5	Percentage on total	N	Percentage on total	P_2O_5	Percentage on total
Control	77.9	15.2	.00216	2.35	50.1	9.8	.00354	3.90	40.0	7.8	.00083	0.89	45.0	8.7	.00092	0.99
Si	73.2	14.3	.00290	2.76	52.3	10.9	.00350	3.31	45.8	8.9	.00230	2.16	34.8	6.8	.00294	2.76
Mg	84.8	21.5	.00244	2.07	58.6	14.8	.00368	3.17	29.5	7.5	.00039	0.08	23.2	5.8	.00028	0.30
Mg+Si	73.3	20.6	.00340	4.87	62.3	17.4	.00294	4.23	43.5	12.2	.00151	1.64	31.0	8.7	.00183	1.90
Ca	64.0	21.6	.00322	3.73	70.1	23.6	.00156	1.79	68.0	22.8	.00046	0.52	63.2	14.3	.00041	0.47
Ca+Si	64.0	21.9	.00345	5.93	84.9	28.1	.00258	4.32	64.8	21.9	.00101	1.75	53.1	18.0	.00138	2.39
Ca+Mg	64.0	22.2	.00281	4.37	68.6	23.8	.00166	2.57	64.3	22.3	.00124	0.22	58.0	20.1	.00129	0.18
Ca+Mg+Si	94.1	30.8	.00300	4.51	97.2	28.2	.00175	2.02	74.8	24.2	.00092	1.06	65.3	21.1	.00104	1.27

Table IV

NUMBER OF SILICATED CELLS IN THE UPPER EPIDERMIS

Treatments	Control	Si	Mg	Mg+Si	Ca	Ca+Si	Ca+Mg	Ca+Mg+Si	Significance	Standard error	C.D.
Average number of silicated cells per unit length.	12.3	12.0	12.3	13.5	12.0	13.0	11.3	13.0	*	0.54	1.12

Conclusion: 4,(6,8),(1,3)2,5,7

* Significant at 5 percent level.

second half of the ammonium sulphate given uniformly to all the treatments.

It is also evident from the table that the levels of available P_2O_5 for the treatments Si, Mg+Si, Ca+Si and Ca+Mg+Si was fairly uniform, with a slight increase in the third month of planting ie. at the time of harvest. The treatments with silicon and magnesium alone recorded a slight increase in available P_2O_5 at the fourth stage of sampling ie. 2 months' after transplanting.

3. Number of silicated cells in the upper epidermis

It is seen from the data presented in table IV that application of silicon in combination with Ca or Mg or both resulted in a significant increase in the number of silicated cells per unit length of 75 μ in the upper epidermis of the leaf.

4. Productive factors

Table V A presents data relating to the total number of tillers, average height of plants, duration of flowering, average leaf width and length of earhead, as affected by the various treatments.

It may be seen from the table that the treatments Mg+Si and calcium alone significantly increased the total number of tillers per plant.

It may also be observed that the duration of flowering was significantly reduced to the extent of 10 days

Table V A

PRODUCTIVE FACTORS

Treatments	Total tillers per pot	Average height of plants	Flowering duration	Average leaf width	Average earhead length
1.Control	12.7	92.0	69.3	6.1	15.4
2.Si	14.0	98.4	59.9	6.6	17.9
3.Mg	15.2	97.6	60.4	7.1	17.0
4.Mg+Si	20.0	107.0	60.0	6.6	18.7
5.Ca	17.0	104.2	62.2	6.8	17.5
6.Ca+Si	14.5	104.6	61.1	7.1	18.0
7.Ca+Mg	14.8	104.4	63.2	6.5	18.7
8.Ca+Mg+Si	15.0	98.2	62.7	6.5	17.1
Significance	**	N.S.	**	N.S.	*
S.E.M.	1.58	-	0.67	-	0.93
C.D.	3.29	-	2.08	-	2.08
Conclusion	4,5,3,8,7,6,2,1		1,7,8,5,6,3,4,2		(4,7)6,2,5,8,3,1

* Significant at 5 percent level
** Significant at 1 percent level

N.S. Not significant

Table V B

PRODUCTIVE FACTORS

Treatments	1000 grain weight in grams.	Root measurements		Percentage of immature to total earheads.	Ratio of grain to straw
		Weight in grams.	Depth in cms.		
1. Control	21.6	2.1	19.0	20.5	0.70
2. Si	22.8	5.9	30.8	4.0	0.72
3. Mg	22.5	10.7	39.5	5.4	0.69
4. Mg+Si	24.2	12.7	65.5	4.2	0.86
5. Ca	22.3	9.6	44.5	5.9	0.68
6. Ca+Si	22.5	6.3	34.0	3.5	0.68
7. Ca+Mg	22.7	4.9	38.0	3.6	0.64
8. Ca+Mg+Si	22.5	4.4	56.0	5.1	0.66

by the treatment silicon alone. The treatment Mg+Si reduced the duration by nine days which was also significantly different from the control.

It will be observed from the table that earhead length is significantly increased by the treatments Mg+Si and Ca+Mg.

The data also show that the height of plants and the width of leaf have not been effected by treatments as they are not significantly different from the control. However, Mg+Si recorded the maximum height of 107 cm.

Data relating to thousand grain weight, root measurements, percentage of immature to total earheads, and ratio of grain to straw are recorded in Table V B.

It is clear from the results that the treatment Mg+Si gave the maximum weight for 1000 grains viz. 24.2 grams which was 12 per cent over that for the control and 7.5 percent over that for the treatment Mg alone.

The data indicate that the treatments Mg alone and Mg+Si considerably increased the root weight, the increase being five and six times respectively, the weight of the roots in the control. Mg+Si and Mg+Ca+Si increased the depth of penetration of the root system by 244.7 percent and 194.7 percent respectively over control. From the Plate No.4, it is clear that the root system is more spreading in the case of the treatments Mg and Mg+Si. It may also be noted that the proportion of thicker to thinner roots was higher in

Table VI

EARHEAD EMERGENCE COUNTS

Date \ Treatments	Control 1	Si 2	Mg 3	Mg+Si 4	Ca 5	Ca+Si 6	Ca+Mg 7	Ca+Mg+Si 8
5-1-64	0	2	4	5	1	4	2	3
7 " "	0	4	10	8	6	5	4	5
9 " "	3	5	10	12	8	6	5	11
11 " "	5	11	10	12	10	5	9	6
13 " "	4	8	8	12	10	5	9	6
15 " "	5	6	6	12	10	11	5	9
17 " "	4	7	3	10	8	9	5	4
19 " "	1	7	2	4	4	10	6	8
21 " "	3	1	2	3	5	2	7	2
23 " "	4	1	1	1	1	0	1	1
25 " "	4	0	1	0	1	0	1	2
27 " "	4	0	1	0	1	0	1	1
29 " "	5	0	0	0	1	0	1	1
31 " "	5	0	0	0	0	0	0	0
Total	47	52	58	79	66	57	56	59

Table VII

YIELD OF GRAIN AND STRAW

	Treatments	Weight of filled grains per pot in grams.	Weight of straw per pot in grams.
1.	Control	8.3	11.8
2.	Si	12.4	17.2
3.	Mg	13.5	19.5
4.	Mg+Si	20.4	23.8
5.	Ca	14.9	21.8
6.	Ca+Si	14.9	22.0
7.	Ca+Mg	13.2	20.5
8.	Ca+Mg+Si	13.6	20.5
	Significance	**	**
	S.E.M.	1.66	1.1
	C.D.	3.45	2.30
	Conclusion	4,(6,5),8,3,7,2,1	4,6,5,8,7,3,2,1

treatments which included silicon.

The results show that the treatment Ca+Si has reduced the proportion of immature to mature earheads. Mg+Si treatment was found to have a slightly lesser effect when compared to Ca+Si.

Calcium either alone or in combination with silicon or magnesium reduced the grain/straw ratio. The ratio was a maximum in the treatment Mg+Si followed by silicon alone.

5. Earhead emergence counts

In table VI are presented data relating to earhead emergence. Earhead emergence counts recorded on alternate days from the date of first flowering indicate clearly that soil application of calcium delayed and protracted flowering. On the other hand 83 percent of the total earheads completed flowering within the first ten days of commencement of flowering in the treatment Mg alone. Though silicon induced earliness in flowering it protracted the period of earhead emergence.

6. Effect on yield of grain and straw.

The average yields of grain and straw in the various treatments in the pot culture experiment are given in Table VII.

From the data it may be seen that the treatment Mg+Si recorded the maximum yield of grain (20.4 grams) which was significantly greater than the other treatments. It may also be noted that all the other treatments were better than the control.

Table VIII

PERCENTAGE COMPOSITION OF GRAIN
(Percentage on oven dry basis)

	Treatments	Nitrogen N	Phosphorus P_2O_5	Potash K_2O	Calcium CaO	Magnesium MgO	Silicon SiO_2
1.	Control	1.75	0.657	0.28	0.072	0.281	3.00
2.	Si	1.65	0.664	0.34	0.143	0.230	5.51
3.	Mg	2.30	0.791	0.38	0.125	0.355	4.00
4.	Mg+Si	1.80	0.839	0.41	0.143	0.226	2.74
5.	Ca	1.96	0.662	0.29	0.272	0.135	3.20
6.	Ca+Si	1.93	0.802	0.31	0.179	0.214	3.80
7.	Ca+Mg	1.88	0.694	0.33	0.250	0.386	3.22
8.	Ca+Mg+Si	1.58	0.630	0.40	0.288	0.294	3.40

With regard to straw yield it may be observed that the treatments Mg+Si and Ca+Si are the best.

In general, grain and straw yields for all treatment combinations that contained amendment materials like CaO, MgO and SiO_2 were significantly greater than the control, which had received only the normal schedule of N,P,K manuring.

7. Chemical analysis of grain and straw

Table VIII presents data relating to the content of N, P_2O_5, K_2O, CaO, MgO and SiO_2 in the grain.

Treatments Mg alone, Ca alone and Ca+Si increased the percentage of nitrogen in grain as compared to the control. Silicon is found to have a tendency to reduce the uptake of nitrogen. When it is combined with calcium or magnesium or both the capacity of those nutrients for increasing the nitrogen uptake is reduced. This is true both in the case of straw and grain. These observations confirm the findings of several previous workers. Silicon in combination with Mg and Ca increased the percentage of P_2O_5 in grain to a greater extent than Si alone.

The treatments Mg+Si and Ca+Mg+Si increased the percentage of K_2O in the grain. The Ca+Mg treatment recorded the higher MgO content in the grain which was 8.8 percent more than that for the Mg treatment alone.

Application of silicon alone to the soil increased the SiO_2 content of the grain. But when silicon was applied

Table IX

PERCENTAGE COMPOSITION OF STRAW
(Percentage on oven dry basis)

	Treatments	Nitrogen N	Phosphorus P_2O_5	Potash K_2O	Calcium CaO	Magnesium MgO	Silicon SiO_2
1.	Control	0.664	0.126	1.69	0.250	0.245	7.7
2.	Si	0.588	0.135	2.06	0.200	0.221	11.4
3.	Mg	0.692	0.170	1.84	0.357	0.396	8.4
4.	Mg+Si	0.682	0.207	1.95	0.350	0.321	10.3
5.	Ca	0.798	0.190	1.75	1.250	0.345	7.9
6.	Ca+Si	0.617	0.260	1.89	1.180	0.357	12.2
7.	Ca+Mg	0.680	0.302	1.42	0.750	0.427	10.5
8.	Ca+Mg+Si	0.518	0.260	1.87	0.357	0.328	11.9

in combination with Ca or Mg or both, the SiO_2 content was less than when silicate was applied alone.

The data on the percentage composition of straw are presented in Table IX.

It may be seen from the table that the percentage of nitrogen was high in the straw from pots that received Ca or Mg treatment.

Percentage of P_2O_5 in the straw was maximum in the treatments Ca+Mg, followed by Ca+Si and Ca+Mg+Si.

Percentage of potash in the straw was higher in treatments that contained silicon. Silicon has a tendency to increase the K_2O uptake by plants. Silicon alone increased the K_2O content of straw by 21 percent. This effect is also noticeable in all the treatments containing silicon. The increase in potash content of the straw obtained by Ca and Mg is further increased by the addition of silicon.

CaO content of the straw was maximum in the treatment where calcium alone was given. The treatments Ca+Si and Ca and Mg also increased the CaO content of the straw though not to the same extent as the treatment Ca alone. The percentage of CaO was higher in the magnesium treatment than the control by 42.8 percent. In all the treatments which included Mg, the CaO content was increased.

Percentage of MgO in the straw was a maximum in Ca+Mg treatment and this was 7.8 percent more than that in the treatment Mg alone.

Table X

NUTRIENT RECOVERY (MILLIGRAMS PER POT)

	Treatments	N	P_2O_5	K_2O	CaO	MgO	SiO_2
1.	Control	175.0	56.8	142.8	23.4	38.1	775.8
2.	Si	231.6	82.7	248.4	35.5	46.7	1750.2
3.	Mg	344.1	110.5	255.3	55.4	86.9	1426.0
4.	Mg+Si	424.4	178.9	403.6	84.3	93.5	2221.3
5.	Ca	368.2	113.7	272.3	203.2	64.1	1481.9
6.	Ca+Si	342.6	142.8	295.9	182.8	76.8	2152.0
7.	Ca+Mg	303.4	113.0	207.4	118.5	95.6	1625.8
8.	Ca+Mg+Si	252.8	107.3	273.5	77.7	75.0	1843.9

Table XI

CRUDE PROTEIN CONTENT OF GRAIN AND STRAW
(Percentage on oven dry basis)

	Treatments	Grain	Straw
1.	Control	8.90	3.90
2.	Si	9.89	2.51
3.	Mg	11.47	4.47
4.	Mg+Si	9.04	3.25
5.	Ca	11.62	4.22
6.	Ca+Si	9.42	3.205
7.	Ca+Mg	11.10	3.96
8.	Ca+Mg+Si	9.4	3.43
	Significance	*	N.S.
	S.E.M.	1.66	-
	C.D.	1.893	-
	Conclusion	5,3,7,2,6,8,4,1	

SiO_2 content was found to be increased by the soil application of soluble silicon either singly or in combination with Ca or Mg.

Table X presents data on the total recovery of the various nutrients through grain and straw from each pot.

Recovery of nitrogen was a maximum in the treatment Mg+Si. In general, total nitrogen uptake was found to be more with Ca or Mg alone or in combination, or in combination with silicon.

The uptake of P_2O_5 and K_2O was maximum in the treatment Mg+Si and was nearly 3 times more than that of the control.

Recovery of CaO was higher in all the treatments that included calcium. Pots receiving Ca in combination with Mg showed only about half the recovery of CaO as compared to Ca alone.

MgO recovery was also maximum in the treatments Mg alone and Mg+Ca. Plants receiving silicon in combination with Ca or Mg removed maximum amount of SiO_2 from the soil.

8. <u>Quality of grain and straw</u>

Crude protein content of the straw and grain was taken as an index of their quality. The data on the crude protein content of grain and straw are recorded in table XI.

The protein content of the grain was significantly higher in treatments Ca and Mg alone and Ca+Mg. In general, the protein content was found to be increased by calcium either alone or in combination with other nutrients, especially Mg.

D I S C U S S I O N

DISCUSSION

The laterite and lateritic soils of Kerala are generally of low productivity. This has been attributed mainly to their low base and available nutrient status as well as their acidic nature. For increasing the productivity of these soils previous workers have recommended the application of amendments like lime and magnesium in conjunction with the normal doses of N,P,K. The importance of silicon in the nutrition of the rice crop has been fairly well established by Japanese workers. But the indispensibility of silicon in rice nutrition especially in combination with calcium and magnesium on the availability and uptake of nutrients has not been assessed so far.

The present investigation has revealed the beneficial influence of calcium and magnesium in combination with silicon in improving the productivity of Kerala soils.

1. Soil reaction

Soil reaction is one of the important factors which influence its productivity. The results of investigation of Kipps (1947) Scheml et al (1950) and Heslep (1951) have indicated that the beneficial influence of liming on crop production was not entirely due to the calcium it contained, but also to the associated changes in the soil reaction. In the present investigation it is found that pH of the soil is shifted towards the alkaline side by 1 to 1.5 units by treatments which included calcium. (Table II) The low buffering capacity of these soils may be one of the reasons for this appreciable increase in pH consequent on the application of lime at 1 ton per acre. The results of the work carried out by Nambiar (1960) and Varghese (1963) on similar soils also confirm these findings.

The present finding that a combination of Ca and Mg is better than Ca alone in raising the pH, (Table II) is in agreement with the results of Schmutt (1960) who found that the neutralisation was better achieved when liming was carried out with dolomitic limestone rather than with calcium oxide, magnesium oxide or calcium carbonate.

2. <u>Available nitrogen and phosphorus status of the soil</u>

In the present study it is observed that there is a progressive decrease in the available nitrogen status in all the treatments. This decrease, however, is less marked in the treatments which included lime.

It is well known that in soils immobilisation and mineralisation of nitrogen takes place simultaneously, (Russel 1961). The applied inorganic nitrogen is being continuously immobilised either to organic nitrogen (Waksman 1952) or is getting denitrified under the water-logged conditions (Abichandani and Patnaik, 1961).

One of the consequences of liming is the increase in the rate of mineralisation of organic nitrogen and the concomitant increase in the available nitrogen status of the soils (Dhar and Ghosh 1955). Abichandani and Patnaik (1961) in their studies on soil nitrogen obtained double the rate of mineralisation by liming with 2000 lbs. of lime within fifteen days after application.

The results in the present study show that the rate of decrease in the available nitrogen is less in those treatments which received lime.(Table III, Fig.2). This may be due to the increased mineralisation of organic nitrogen, which to a large extent, offsets the immobilisation and denitrification losses. The losses of ammonical nitrogen might also be decreased by liming. (Gerretson and DcHopp, 1957).

Silicon, either alone or in combination with calcium or magnesium, or both, considerably increased the available phosphorus status of the soils (Table III,Fig.2). Silicon application is known to increase the availability of phosphorus in the soil either by releasing the soil phosphorus or by decreasing the fixation of applied fertilizer phosphorus. Votkevich (1936) observed an increase in available phosphorus with increasing rates of silicon. Hosoda and Takata (1957) obtained a much higher increase in available soil phosphorus and P_2O_5 content of the plant with calcium silicate than with calcium carbonate. The increase in the availability of phosphorus in treatments with silicon (Table III) observed in the present investigation can be attributed to either of these two factors.

In the present experiment Mg, Ca and Si either alone or in combination increased the soil pH by 1.5 units (Table II). Increasing the pH of the soil and applying soluble phosphates like superphosphate reduce the chances of the phosphates getting fixed by soluble iron and aluminium. Cook and Miller (1935) and Truog (1948) claimed that liming increases the availability of the added phosphates by a similar mechanism.

A combination of all these factors, are probably operative in the increased availability of phosphates observed in the treatments with Ca, Mg or silicon. In general, a progressive decrease in the available P_2O_5 status in the case of all the treatments is noticed during the cropping period.(Fig.2) This may be attributed to the microbial fixation of available phosphorus.

3. Productive factors

The present study has shown that the combination Mg+Si, is highly beneficial for tillering (Table V A). This character is one of the more important productive factors that contribute to higher yield. Even though, it is mainly a genetically controlled factor, it is also subject to wide variations as a result of soil conditions or manuring. (Ghose et al 1956).

Volker (1915) observed that magnesium-treated plants were stronger and better tillered than untreated plants. Winifred et al (1927) opined that the rate of tillering was closely related to the amount of silicon applied. But the combined effect of both these nutrients has not been worked out so far. Liming is also found to have a favourable influence on tillering. Similar observations were made by Nambiar (1960) Varghese (1963) and Bhat (1964).

Flowering duration and the number of days required for completion of flowering ie. the number of days taken for the completion of flowering after the appearance of the first flower, are both subject to wide variations depending on soil conditions and manuring (Ghose et al 1956). It is observed that application of silicon reduces flowering duration but not the time taken for the completion of flowering, whereas magnesium considerably reduces the time taken for the completion of flowering (Fig.3).

Application of Mg+Si over and above the normal schedule of manuring reduces both the flowering duration as well as the time taken for the completion of flowering. This effect is slightly less than that of Si (Table VI). These characters viz. early flowering and early completion of flowering, have significant practical utility. Early flowering saves time and early completion of flowering leads to uniform grain setting thus ultimately increasing the grain weight. This increased grain weight is observed in the 1000 grain weight of the treatment Mg+Si.(Table V B).

Okamoto (1959), Mitsui and Takohu (1960) obtained early heading with silicon-treated plants. This character as influenced by silicon can be attributed to increased availability of phosphorus to plants. The effect of silicon in inducing earliness is decreased when it is combined with magnesium. Ishaburo Nagai (1959) and Sadapal and Das (1961) recorded delayed maturity in rice due to magnesium application.

In the present study application of calcium extends the flowering duration and also protracts the time taken for the completion of flowering. This is in agreement with the findings of Bhat (1964).

The present study shows that the thousand grain weight for the treatment Mg+Si is 12 per cent more than that of the control and 7.5 percent more than the treatment Mg alone. Ishaburo Nagai (1959) and Sadapal and Das (1961) recorded an increased thousand grain weight by the application of magnesium. Mitsui (1956) and Okamoto (1959) emphasized the importance of silicon in increasing the thousand grain weight in their studies on cereals. Thus it appears that Si and Mg have an additive effect in enhancing the 1000 grain weight.

An extensive and healthy root system gives the plant, the necessary pre-requisites for maximum productivity under the limitations imposed by soil conditions and other factors. Though the treatments Mg, Ca and Si are found to increase the root weight more than the control treatment, magnesium is found to be the most effective, when the individual nutrients are compared.(Table V B) The length of the [illegible] by Ca and Si whereas the treatment

Mg alone gives more extensive root system. (Plate No.4).

Several authors have reported that silicon and calcium tend to increase the length and weight of the root system. The increase in the length of the root system by the application of silicon was observed by Lipman (1938). Tiedjins (1948) and Rothwell (1957) reported the influence of lime in increasing root development. Not much work has been done in this line with magnesium. Coupin (1918) obtained a reduction in size and number of root lets in rice by the application of magnesium. The level of Mg in the soil being below the critical minimum, application of magnesium might have contributed towards better photosynthesis as is indicated by increased leaf width in Mg-treated plants (Table V A). The increased photosynthetic activity might have indirectly increased the weight of the root system.

The best treatment which had an overall effect on the root system is the treatment Mg+Si which incidentally also recorded the maximum grain and straw yield (Table VII).

The present study has shown that silicon is important in reducing the ratio of immature to mature ear-heads at the time of harvest. This property of silicon, is increased when it is combined with calcium.(Table V B). Okamoto (1959), Mitsui and Taktohu (1960), and Azuma <u>et al</u> (1961), obtained increased percentage of ripened grain by applying silicon. The results of the present study are thus found to be in agreement with the findings of above authors.

A higher grain straw/ratio is an indication of the greater capacity of the plants to utilise its metabolic activities towards greater grain production. Silicon is well known to influence favourably the production of grain in comparison to straw. Shed (1922) and Srinivasan (1936) obtained appreciable increase in grain yield when compared to straw yield in oats and rice respectively. This is in agreement with the results of the present study. Combination of silicon with magnesium is found to be more efficient in increasing the grain/straw ratio. (Table V B). The ability of Mg to increase the grain yield has been recorded by Schreiber (1949) and Hashimoto and Kavaguchii (1955). Application of calcium however reduces the ratio significantly by increasing the straw weight.

4. Grain and straw yield

In the present study Mg+Si treatment is found to increase the grain yield by 146 percent more than that of the control. (Table VII) Hashimoto and Kavaguchii (1955), Stenut and Piot (1958), and Kido (1958) obtained similiar increase in grain yield by magnesium application while Srinivasan (1936), Ishibashi and Hajima (1937) Dutta *et al* (1962), achieved the same result by the application of silicon.

Shed (1922) observed appreciable increase in yields in soyabeans and oats by the application of magnesium silicate. In the present investigation magnesium and silicon were applied as magnesium carbonate and sodium silicate. In I.R.R.I.

increased yields of about 500 kg. per hectare were obtained. (Anon 1963).

The treatment Mg+Si produced the maximum number of productive tillers, length of earhead and thousand grain weight (Table V A and V B). More number of productive tillers means, more number of earheads per plant and increase in the length of earhead means more number of grains per earhead. Incidentally the same treatment records a shorter flowering duration than the control treatment by about nine days and also an early completion of flowering.(Table VI). Thus a uniform ripening of grain is obtained which is reflected in the increased thousand grain weight (Table V B). The same treatment Mg+Si is found to induce a very well developed root system, which enables the plant to utilise nutrients available in the soil to the maximum extent. This has been reflected in the total uptake of nutrients viz. nitrogen, phosphorus, potassium, magnesium and silicon (Table VIII).

The treatment Mg+Si is also found to record the maximum yield of straw. The total number of tillers, plant height, and leaf width are characters which contribute to a higher yield of straw.

Schreiber (1952) and Narayanan and Vasudevan (1957) noted increased straw yield by magnesium application. Ishibashi and Hajima (1937) obtained increased straw yield by silicon.

The treatment Ca+Si is found to give the next highest yield both in the case of grain and straw. In this treatment both earhead emergence and flowering are earlier. The percentage of immature to total earhead is also less. All these characters contribute to uniform ripening and thereby to an increased thousand grain weight and increased grain yield.

The present investigation thus clearly indicates the need for amendments like Ca and Mg. These ameliorants not only correct soil acidity but considerably increase the yield of rice when applied together with soluble silicon in the red loam soils of Kerala.

5. Quality of grain and straw

Higher percentage of nitrogen (Table VIII) and protein content are noticed in treatments Mg and Ca alone and in combination. Sadapal and Das (1961) obtained an increased protein content of grain due to magnesium application. The favourable influence of calcium in increasing the nitrogen uptake was reported by Colemann (1955) Deguchii (1960) and Bhat (1964). This may be attributed to the increased mineralisation of organic nitrogen in the presence of calcium and subsequent increase in the available nitrogen. Magnesium may release calcium for the mineralisation of organic matter or it may by itself favourably increase the pH for the microbial release of organic nitrogen.

The beneficial effect of calcium in increasing the nitrogen content of grain and straw was slightly decreased when it is combined with silicon. Kobayashi et al (1956) reported a decreased percentage of nitrogen in plants by slag application. Wagava and Ken-ichi-Kashima (1963) observed that when silicon was applied, the percentage of nitrogen in every part of the rice plant viz. leaves, stem and earhead was decreased. Ishaburo Nagai (1959) also noted that in silica deficient soil, the nitrogen content of the rice plants was unusually high.

In the present study silicon either alone or in combination with calcium or magnesium or both is found to increase the P_2O_5 content of grain as well as straw (Tables VIII and IX). Okava and Kinsaku (1937) and Ganssman (1962) obtained increased P_2O_5 content in various cereals by the application of silicon. A contrary result was obtained by Miyoshi and Ishi (1960) who found that the P_2O_5 content of the grain and straw was decreased by silicon. The increased uptake of P_2O_5 may either be due to the increased release of soil phosphorus or decreased fixation of fertilizer phosphorus by silicon. Akhramako (1934) attributed this to the formation of SiO_2-P_2O_5 absorption complex which was more easily absorbed by the plants than the phosphate ion. Cook and Miller (1935), Davis and Brewer (1940), Dunn (1943), Truog (1948) and Nagabhushana (1961) claimed an increase in P_2O_5 content of both grain and straw by liming. This beneficial function of calcium may be due to its effect on the availability of soil phosphorus. Phosphorus uptake increases in the treatment Ca+Si. This may be attributed to the role of both Si and Ca in increasing the availability of phosphorus. (Table III). This is corroborated by the findings of Schollenburger (1922) who obtained increased P_2O_5 content in rice by the application of lime in combination with silicon than by lime alone.

Mg either alone or in combination with Si or Ca increased the P_2O_5 content of the grain and straw. Truog et al (1947), Sadapal and Das (1961) and Varghese (1963), obtained increased P_2O_5 content in various crops by magnesium fertilization. This beneficial influence of magnesium on phosphorus uptake may be due to its effect in raising the soil pH. (Table II) The present study reveals the effect of silicon in increasing the P_2O_5 content of grain and straw when applied in combination with calcium, magnesium or both.

The potassium content of the grain is high in the treatments that included silicon (Table VIII). Okava and Kinsaku (1937), Fritz (1940) and Takyima et al (1959) noticed an increased uptake of potassium by the application of silicon.

Chemical analysis of grain and straw in the various treatments shows that the treatments which included magnesium increased the percentage of MgO in both grain and straw. The treatment Mg+Ca records 8.8 percent increase in MgO content over the treatment Mg alone (Table VIII).

Blair et al (1939), Eisenmenger et al (1939), Ishaburo Nagai (1959), and Varghese (1963) reported increase in the MgO content in various plants following magnesium application. Varghese (1963) has further reported greater absorption of magnesium with Ca+Mg treatment than with Mg alone. This result is in agreement with the present finding.

The results show higher CaO content in all treatments which included calcium. This is in agreement with the findings of many workers, such as, Shedd (1922), Moser (1933), Deguchii (1960) and Varghese (1963) who obtained similiar results with various crops.

In the present study when calcium is applied in combination with magnesium, the calcium content of the plants are lower than that in the plants grown in soils treated with calcium alone. Similiar observations have been recorded by Eisenmenger et al (1939).

The CaO content in both the grain and straw in the treatment Ca+Si is less than that in the treatment Ca alone (Table VIII). Lawes (1951) found that CaO percentage in plants was decreased by silicon application. Wagava and Ken-ichi-Kashima (1963), in a detailed study on silicon nutrition, observed that the CaO content was decreased in the earheads, leaf blades and stalks by silicon.

In the present study it is seen that the percentage of CaO in the grain is increased by treating the soil with magnesium (Table VIII) similiar observations were made by Graham (1956) and Sco (1957).

Application of soluble silicon is found to increase the silicon content of both grain and straw (Tables VIII and IX) similar results have been obtained by several other workers (Srinivasan, 1936; Kobayashi et al, 1956; Mitsui, 1956 and Okamoto, 1957).

The uptake of silicon is found to be depressed when it is combined with calcium or magnesium or both. This is in agreement with the findings of Kobayashi et al (1956) who observed that the absorption of silicic acid was reduced by liming. This may be attributed to the fact that soluble silica is rendered insoluble by lime.

The level of silicon in the plant is found to be more when it is applied alone than when it is applied in combination with magnesium. Kobayashi et al (1956) found that the application of magnesium carbonate had no effect on silicon. Application of sodium silicate in combination with Ca or Mg or with both Ca and Mg increases significantly the number of silicated cells.

Taking into consideration all the above points it appears that the treatment Mg+Si influences all the productive factors and yield beneficially but the quality of grain and straw was improved by calcium and magnesium respectively.

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

A pot culture experiment was conducted to study the effect of calcium, magnesium and silicon, singly and in combination on the productive factors and quality of rice in the red loam rice soils of Kerala State.

The results are summarised below:

1. Liming the soil at the rate of one ton of CaO per acre raised the soil pH by 1 to 1.5 units.

2. Availability of nitrogen in the soil is increased by the application of calcium or magnesium or both, as revealed by the available nitrogen status of the soil during the cropping period and also by the uptake of nitrogen by the plants.

3. Availability of phosphorus is increased by the application of silicon either alone or in combination with calcium or magnesium or both, as indicated by the increased availability of P_2O_5 during the cropping period.

4. Application of Mg+Si over and above the normal schedule of N,P,K manuring considerably increased all the productive factors, such as, tillering, height of plants, earhead length, thousand grain weight and root development.

5. Grain and straw yields are significantly increased by applying Mg+Si over and above the normal schedule of manuring.

6. The quality of grain and straw as indicated by their protein content is markedly increased by the application of soil amendments like calcium oxide or magnesium carbonate.

7. The P_2O_5 and K_2O contents of the grain and straw are increased by applying silicon either alone or in combination with calcium or magnesium.

8. Application of soluble silicon not only increases the total SiO_2 content of the plant, but also increases significantly the number of silicated cells in the upper epidermis.

Thus the present study reveals that applications of Mg and Si at the rate of 100 lbs. of magnesium and 25 lbs. of silicon in the form of magnesium carbonate and sodium silicate respectively can considerably increase the grain and straw yield of paddy.

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FIG 1

AVAILABLE N AT MONTHLY INTERVALS

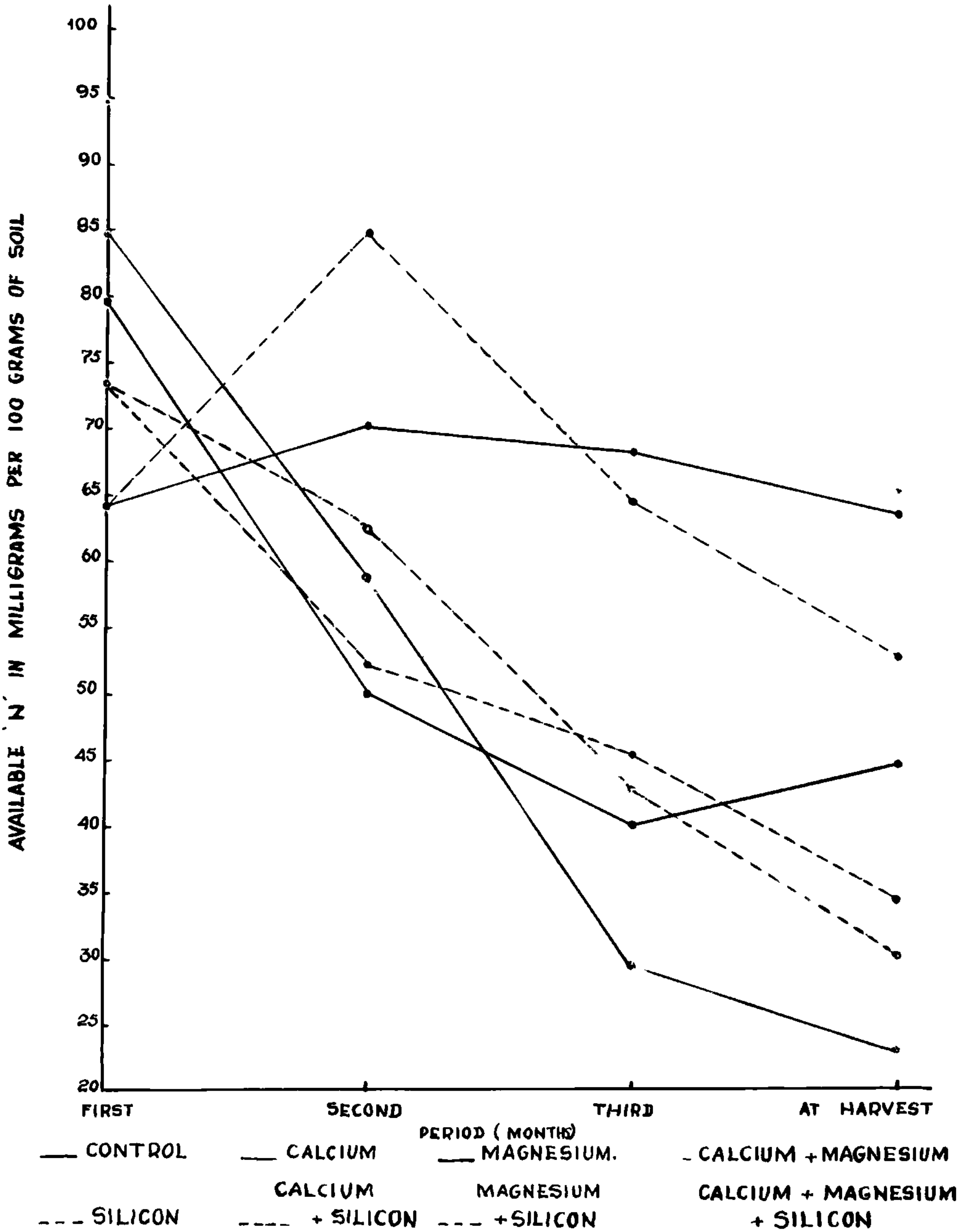


FIG 2

AVAILABLE P_2O_5 AT MONTHLY INTERVALS

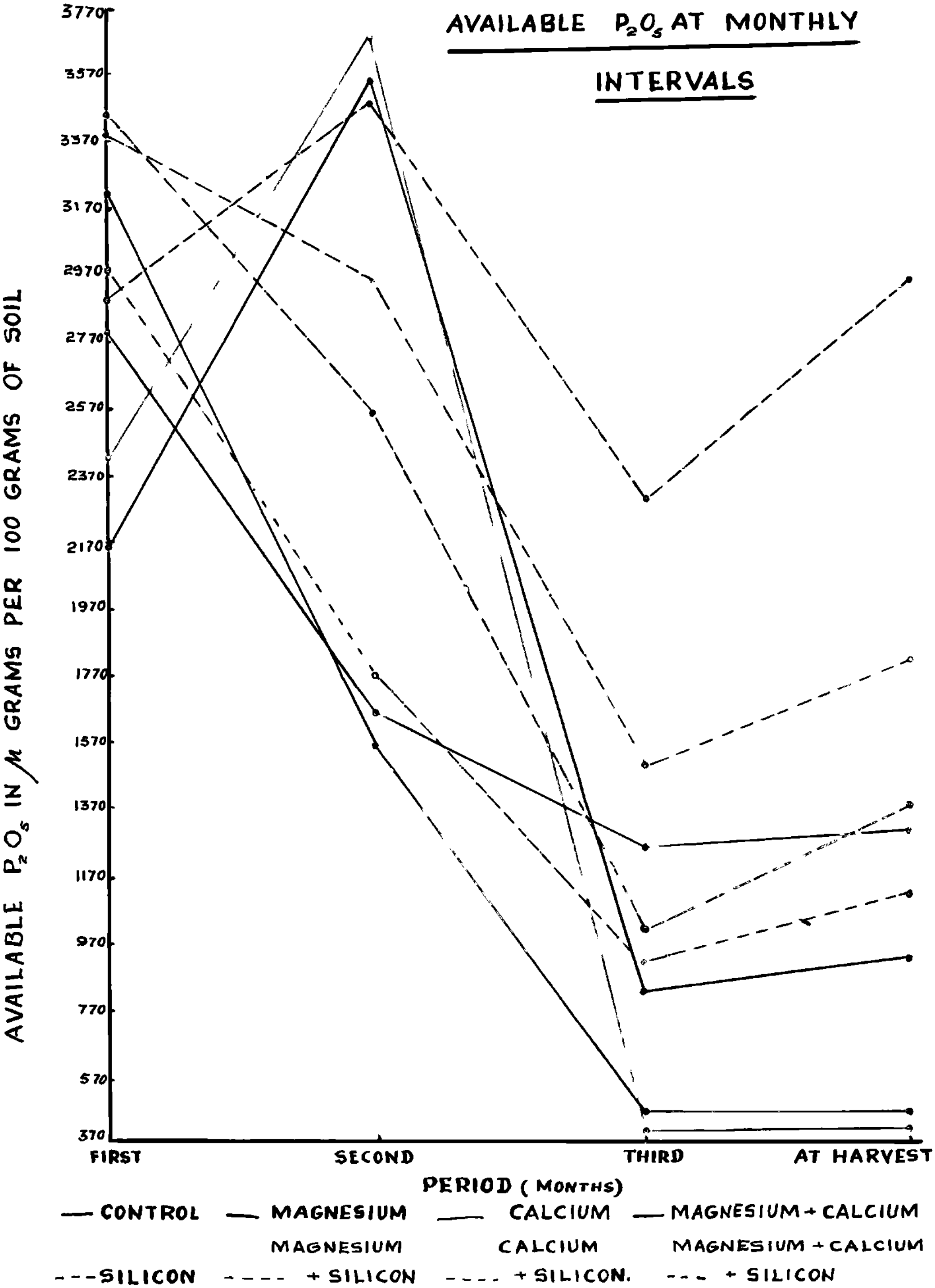


FIG 3

CUMULATIVE EARHEAD EMERGENCE COUNTS

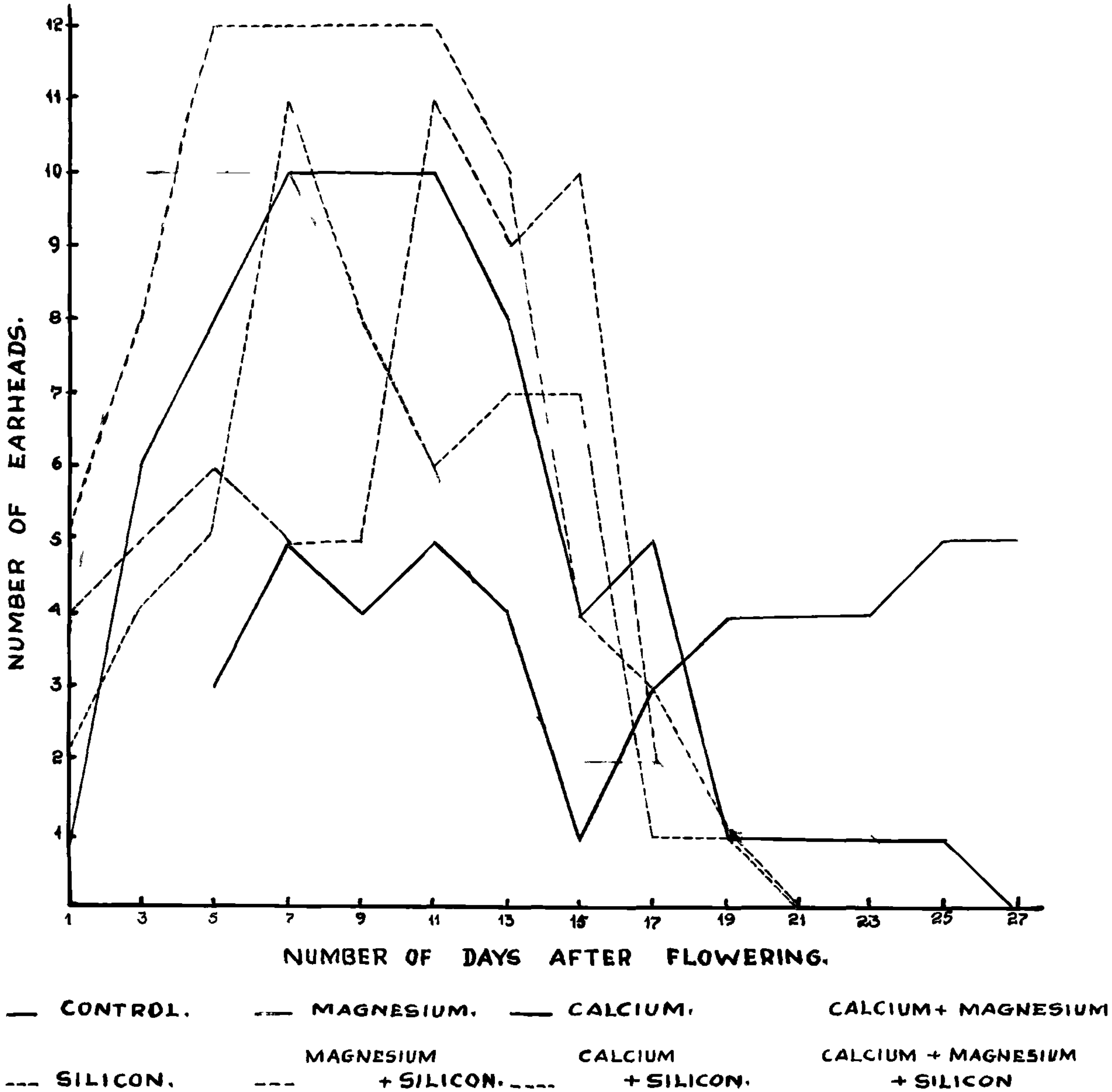


FIG 4A

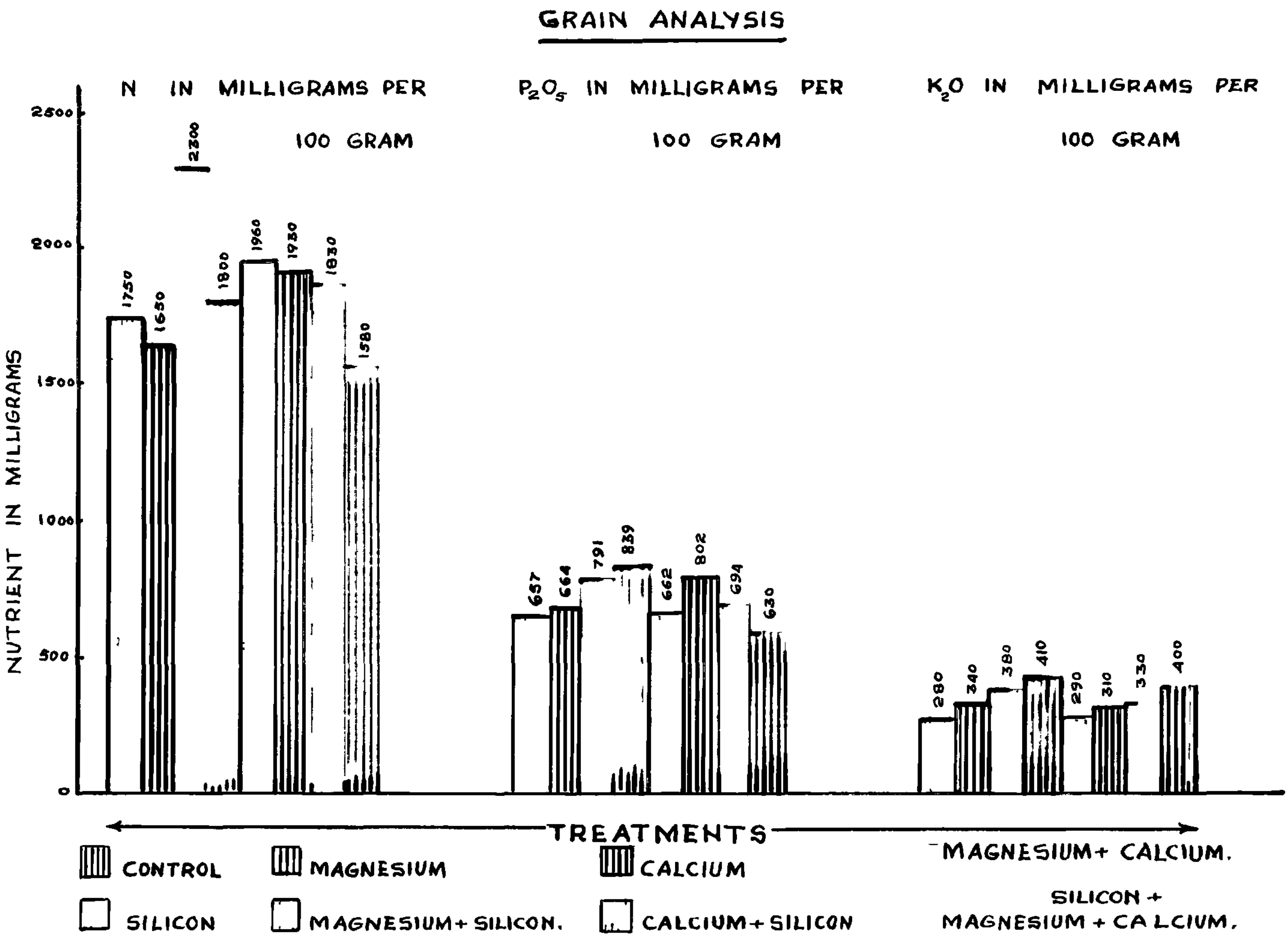

GRAIN ANALYSIS
N IN MILLIGRAMS PER 100 GRAM
P2O5 IN MILLIGRAMS PER 100 GRAM
K2O IN MILLIGRAMS PER 100 GRAM
NUTRIENT IN MILLIGRAMS
2500
2000
1500
1000
500
0
2300
1750
1650
1800
1960
1930
1830
1580
657
664
791
839
662
802
694
630
280
340
380
410
290
310
330
400
TREATMENTS
CONTROL
MAGNESIUM
CALCIUM
MAGNESIUM + CALCIUM.
SILICON
MAGNESIUM + SILICON.
CALCIUM + SILICON
SILICON + MAGNESIUM + CALCIUM.

FIG 4B

GRAIN ANALYSIS

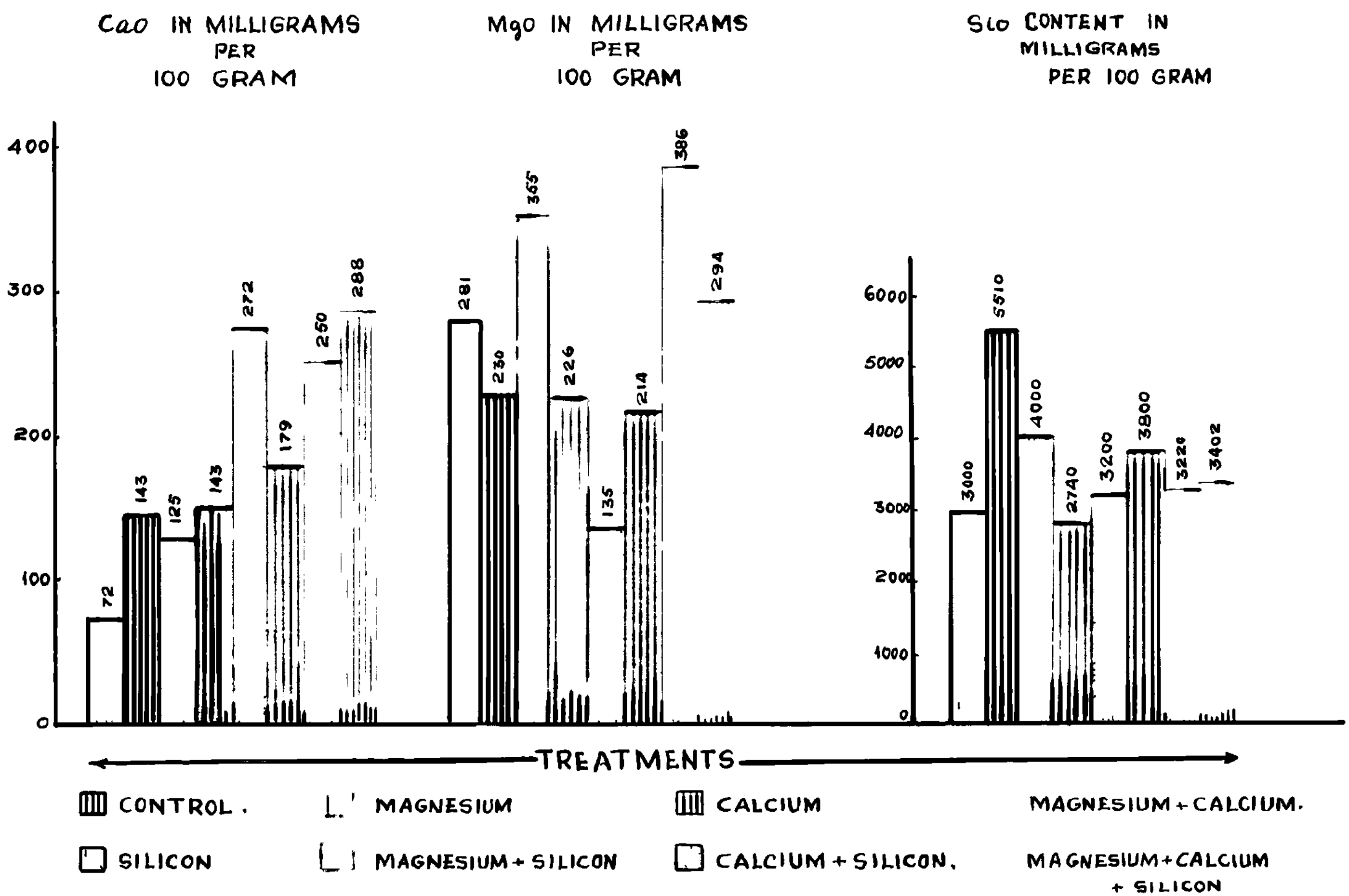


FIG 5A

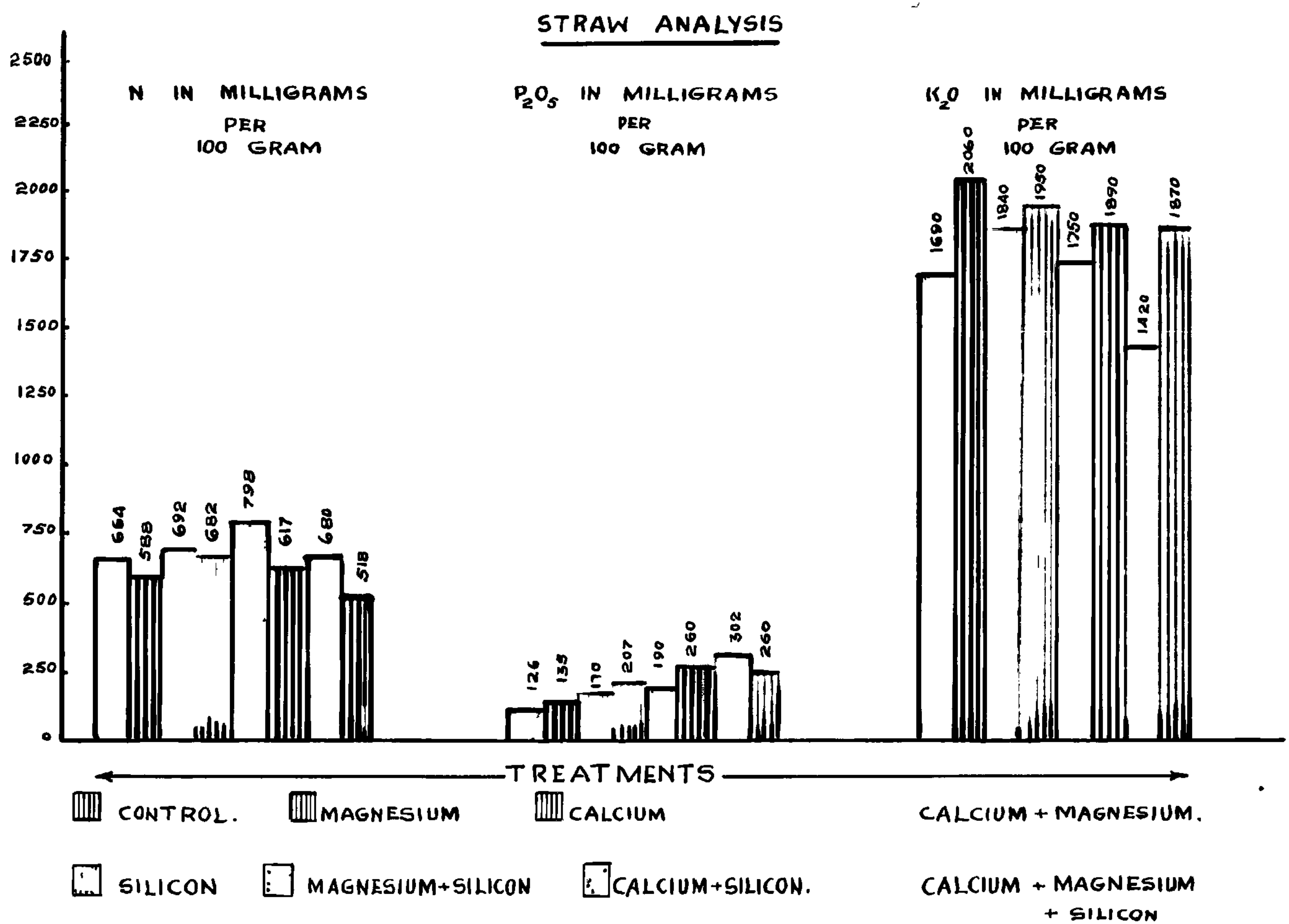
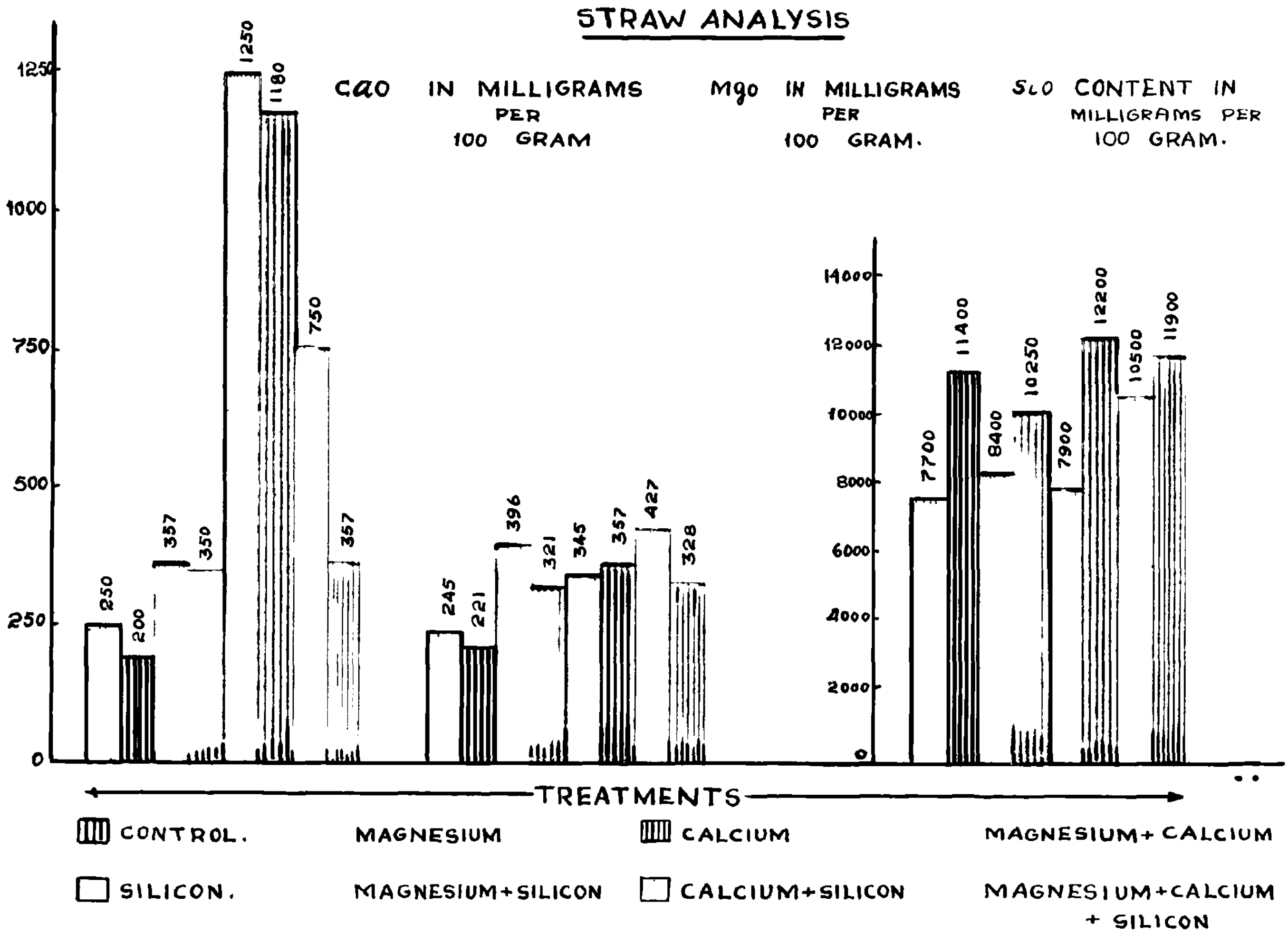

STRAW ANALYSIS
N IN MILLIGRAMS PER 100 GRAM
P2O5 IN MILLIGRAMS PER 100 GRAM
K2O IN MILLIGRAMS PER 100 GRAM
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
664
588
692
682
798
617
680
518
126
135
170
207
190
260
302
260
1690
2060
1840
1950
1750
1890
1420
1870
TREATMENTS
CONTROL.
MAGNESIUM
CALCIUM
CALCIUM + MAGNESIUM.
SILICON
MAGNESIUM+SILICON
CALCIUM+SILICON.
CALCIUM + MAGNESIUM + SILICON

FIG 5 B


STRAW ANALYSIS
CaO IN MILLIGRAMS PER 100 GRAM
MgO IN MILLIGRAMS PER 100 GRAM.
SiO CONTENT IN MILLIGRAMS PER 100 GRAM.
0
250
500
750
1000
1250
250
200
357
350
1250
1180
750
357
245
221
396
321
345
357
427
328
0
2000
4000
6000
8000
10000
12000
14000
7700
11400
8400
10250
7900
12200
10500
11900
TREATMENTS
CONTROL.
MAGNESIUM
CALCIUM
MAGNESIUM+CALCIUM
SILICON.
MAGNESIUM+SILICON
CALCIUM+SILICON
MAGNESIUM+CALCIUM + SILICON

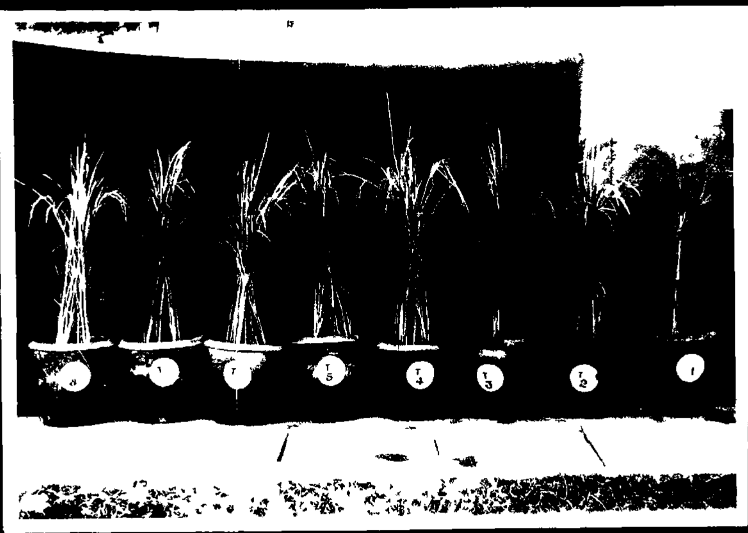


PLATE I

GENERAL APPEARANCE OF PLANTS AT THE FLOWERING STAGE.

Treatment	1	=	Control
"	2	=	Si alone
"	3	=	Mg alone
"	4	=	Mg+Si
"	5	=	Ca alone
"	6	=	Ca+Si
"	7	=	Ca+Mg
"	8	=	Ca+Mg+Si

PLATE II
COMPARISON OF TREATMENTS
Mg+Si(4) and Control(1)

PLATE III
COMPARISON OF TREATMENTS
Mg+Si(4), Ca+Mg+Si(8)
Ca+Si(6)

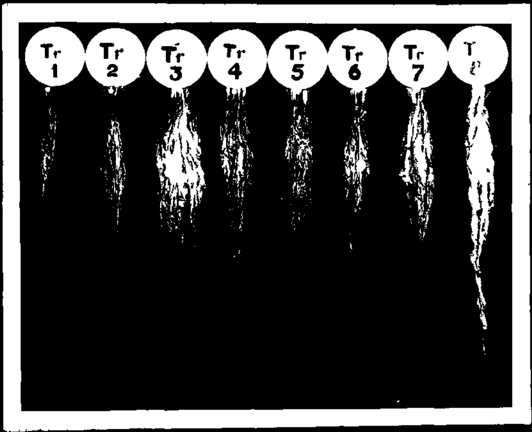


PLATE IV

ROOT DEVELOPMENT

1.Control.
2.Si alone
3.Mg alone
4.Mg+Si
5.Ca alone
6.Ca+Si
7.Ca+Mg
8.Ca+Mg+Si