STUDIES ON THE EFFECT OF SILICATE FERTILIZATION ON THE UPTAKE OF NUTRIENTS BY RICE PLANT AT DIFFERENT STAGES OF GROWTH

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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 Sri A.K. Sadanandan 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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CHAPTER I

INTRODUCTION

Rice is the principal food of nearly half the world's population. It is the most important food crop of India and about three-fourths of the people in the country subsist on it. It also plays a very important role in international trade and commerce and in the economy of the producing countries, meeting as it does cash requirements of numerous small farmers. Few have, therefore, failed to appreciate the necessity for increasing production efficiency to achieve national self sufficiency. This is particularly the case in the Kerala State which is deficient in rice production by about 40 percent and is facing a very acute shortage of this important food grain.

At the present time efforts are being made not only to produce high yields of agricultural crops but also to secure a high quality of the produce. But yield and quality are determined by a large number of factors of which some are provided by nature and, therefore, cannot be controlled, whilst others can be influenced by suitable agricultural measures such as manuring.

Research work on the manurial requirements of rice was started in India ever since the commencement of agricultural research in the country. A study of the reviews of numerous manurial experiments would show that most of these trials were directed to find out the response to, and the uptake of, the major nutrients by rice, viz., nitrogen, phosphoric acid and potash at varying levels and in different forms combined with lime and bulky organic manures.

Among the nutrients studied, nitrogen is seen to have given universal response. Nitrogen is known as the 'King Pin' in rice fertilization. It is also established that to get economically high yields and to raise the production capacity of the rice soils of India to that of the other rice growing countries like Japan, the yield potential of our existing rice varieties has to be increased by manuring with higher doses of nitrogen. But higher levels of nitrogen tend to make the plant succulent with the consequent danger of lodging. Lodging, depending upon the stage of the crop at which it occurs as well as its intensity, brings about loss in yield of rice grain varying from 18to 60 percent. (Subbiah Pillai and Parasuram, 1950)

It was in this context that work on the other aspects of the physiology and mineral nutrition of rice was undertaken, particularly in respect of silicon nutrition. As early as 1840 Liebig believed that lodging is due to the deficiency of silica in the stem of plants.

He attributed the strength of culms of grass to their potassium silicate content. Possibly silicon serves to stiffen the stem of cereals and fertilization with silica would thereby prevent lodging.

Recent reports from Japan and other rice growing countries emphasise the importance of silicon nutrition in rice. Soluble silicon in the form of sodium silicate or easily available silicon in the form of calcium magnesium silicate is found to minimise the fixation of phosphorus in the soil thereby enabling the plant to absorb fertilizer phosphorus to a greater extent. The recent report of the International Rice Research Institute, Phillipines, 1963, shows that soil application of calcium magnesium silicate at 100 Kg. per hectare increases rice production by 500 Kg. per hectare. The above effects of silicon are particularly noticeable under acid soil conditions.

It may be noted in this connection that a major portion of the cultivated area of the Kerala State has laterite and lateritic types of soil of low productivity. Fertility surveys carried out in the State and soil test data of over 16,000 soil samples show that the soils are deficient in Nitrogen, Phosphorous and Potash to the extent of 20 to 25, 62 to 84 and 84.percent respectively. The high rainfall and the tropical climate have depleted the soils of the major bases and made them acidic. When the H-ions exceed a certain limit, the silicate material in the soil is acted upon by them with the result that free water soluble silica is formed. This gets leached away in the drainage water. Loss of soluble silica leaves an abundance of sesquioxides and a soil of low fertility status.

Even though some research work on the response of rice to silicon nutrition has been conducted, the relationship between the soil application of silicon and its ability to increase the availability and transloca-tion of other nutrients in the different plant parts have not been investigated in any great detail. The present study was undertaken to meet this lacuna to some extent.

In the investigations presented in this thesis, an attempt has been made to study the relationship between silicon uptake and the uptake of the major nutrients including calcium, magneseium and silicon at three important growth phases of the rice plant corresponding to the vegetative, tillering and maturity stages. The number of silicated cells in the leaf and the stem were determind and their influence in the prevention of lodging of the crop at higher levels of nitrogen computed. Growth measurements and tiller counts were made at regular intervels. The yield of roots, straw and grain were recorded at the three growth phases. These plant parts were analysed for major nutrients and their uptake by the crop worked out.

CHAPTER II

REVIEW OF LITERATURE

The part played by silicon as plant nutrient has not so far been studied in sufficient detail. The efforts made by previous workers to throw light on the different aspects of this problem are briefly reviewed in this chapter.

A. Effect of silicon on the growth and yield of crops

Investigations on the effect of silicon on growth and yield of crops date back to the era of Liebig (1840) who classified plants as silica plants, lime plants and potash plants. He regarded silicon as a necessary element in plant nutrition. Experimental evidence for the function of silica as promoter of growth and yield was perhaps first furnished by Wolff and Kreuzhage (1884). They observed that though the total growth of oats was not much increased by the presence of silica, the proportion of grain was considerably raised. Lemmermann and Wiessmann (1922) observed that the greater the amount of silicic acid available, greater was the crop yield, the marked increased being in fields deficient in phosphorus. Similar results were obtained by Brenchley _et al_ (1927) in their water culture studies on barley. Onodera (1927) observed better growth of paddy with silicic acid treatments. The work of Okawa and Kinsaku (1936), revealed the influence of silicic acid on increased growth and yield of rice plant. Sreenivasan (1936) obtained similar results with the application of sodium silicates in conjunction with green manure. Votkevich (1936) attributed the increased yield of rice obtained by silica application to the increased nitrification and solubility of soil phosphorus.

Ishibashi (1937) working with soils of various depths found that the yield of rice, grain and straw, was decreased with a reduced supply of silica and that the same increased even on shallow soil by adding silicic acid. However, Ishibashi and Hayakawa (1939) further observed that the beneficial effects of silica were more marked with large amounts of nitrogen, but decreased with increasing doses of phosphorus. Sreenivasan (1938) reported that best results were obtained when silica was applied in instalments to rice crop. Fritz (1940) observed in water culture experiments that deficiency of silica caused depression of root and shoot growth in cereals. Bastisse (1946) obtained threefold increase of corn in alkali soils and fivefold increase in neutral soils treated with silica. Macintire and Shaw (1946) got increased growth and yield of rice due to the application of silica. Laws (1951) found that sodium and potassium silicate were equally effective in increasing the yield of rice. Hosoda and Takata (1957) recorded 14 percent increased yield in rice on application of calcium silicates in soils of low SiO_2/Al_2O_3 ratio. Ishibashi and Kawano (1957) studying the effect of silica on growth of rice plants in water culture, observed that plants grown in the absence of silicates were smaller and grain yields were only 1/8th of those of silicate supplied plants. Similar results were reported by Okamoto (1957). But Ota and Kobayashy (1957) reported that weight of grain was reduced due to the application of silicates. However, Kido (1958) opined that 1000 grain weight was increased by the application of calcium silicate.

Yoshida et al (1962) reported that silica was not essential for growth and tillering in rice, but was beneficial during reproductive stage and for good grain out put. Mitsui and Takatohu (1960) conducting the nutritional study of silicon in graminaceous crops observed that silicate treated plants produced 70 percent increased yield of dry matter and also that the percentage of ripened grain was higher. Okuda and Tokahasi (1961) got similar results with water culture experiments on rice. In another study on the effect of silicon at various stages of plant growth, Tahahasi (1961) concluded that the absence of silicon in the vegetative stage led to decrease in the top growth, number of tillers and fresh and dry weight. Absence of silicon in the reproductive phase caused a decrease in the number of spikelets per panicle and the percentage of ripe grains.

Conner (1961) found that dicalcium silicate gave better results in pot and field experiments. This he attributed to the superior effect of silicates in reducing the amount of alumina in the soil solution which he considered the most harmful factor in acid soils.

Datta *et al* (1962) observed that application of sodium silicate increased the yield of wheat and rice but not of berseem. Gaussman (1962) got markedly increased yields of spring wheat by the application of silica and he attributed it to the improved moisture holding capacity of soil which increased root growth. Experiments conducted at the I.R.R.I., Phillipines (1963) showed that increased yield of rice could be obtained with the application of silicate as calcium magnesium silicate at the rate of 100 Kg. per hectare. Mitsui and Takatashi (1963) opined that silica plays a role in determining the seed setting of rice plant. Money (1964) reported marked increase in grain yield of rice due to the application of silica in the form of Magnesium silicate. Padmaja and Verghese (1964) observed significant increase in yield of grain and straw by the application of magnesium and silica to rice crop. They further noticed considerable increase in all the productive factors such as tillering, height of plants, length of earheads, thousand grain weight and root development.

B. Effect of silicon on the availability and uptake of nutrients by plants

1. <u>Nitrogen</u>:

Laws (1951) working on the effect of water soluble silicate on soil properties and nutrient uptake by plants observed that the nitrogen content of sudan grass increased with sodium silicate application. But Kobayashi *et al* (1956) reported that the percentage of nitrogen decreased in paddy straw with slag as well as colloidal silicate treatments. Kido *et al* (1958) observed that when calcium silicate was applied to cereals, the nitrogen assimilated by the plant was decreased. The investigations of Okamoto (1959) on the inorganic nutrition of rice plants under insufficient supply of silica, revealed that the amount of nitrogen absorbed and translocated by plants to panicle was reduced considerably when silica was deleted from the nutrients supplied.

Miyoshi and Ishi (1960) reported increased protein content in rice panicle due to silicic acid application, but at the same time noted a decrease in nitrogen content in the stem and leaves. However, Utagawa and Kashima (1963) obtained decreased nitrogen percentage in every plant part on silicon addition though the total translocation of absorbed nitrogen to earhead was accelerated.

2. <u>Phosphorus</u>:

Much work has been carried out to investigate the influence of silicon on the availability and uptake of phosphorus. Wolff and Kreuzhage (1884) were perhaps the first to recognize the importance of silicon-phosphorus relationship. They observed that silicon application produced effects similar to phosphorus treatments. Their observations were later supported by the field experiments conducted by Hall and Morrison (1906) at Rothamsted. The results obtained revealed that the application of silicon improved the capacity of plants to absorb phosphorus. They also emphasised that the seat of reaction is in the plant and not in the soil.

Schollenberger (1922) obtained higher phosphorus percentage in crop when silica was included in the manurial treatment. Gile and Smith (1925) got similar results with silicon application and reported that the increased phosphorus uptake may be either due to its ability to replace phosphorus or by virtue of its solvent action on soil phosphates and thereby rendering them more readily available to plants.

Brenchley et al (1927) working on the effect of different levels of silica and phosphorus concluded that the presence of silica improved the efficacy of phosphorus in the plant. Akhramako (1934) attributed a different reason for the beneficial effect of silica application on phosphorus nutrition. He opined that silicon deposited on plant roots increased its ability to absorb phosphorus. Votkevich (1936) reported increased nitrification and solubility of phosphorus on addition of silica. In their water culture experiments with rice and barley Okawa and Kinsaku (1936) established that silica treated plants had better phosphorus content than plants grown in culture solutions not containing silica.

Bastisse (1946) reported that silica application to soil minimises phosphorus fixation by iron and aluminium. But contrary to this Laws (1951) observed a decrease in solubility and absorption of soil phosphorus on application of sodium and potassium silicates. Bastisse (1952) continuing his investigations on the role of silicon in phosphorus nutrition of plants confirmed his earlier findings and recommended liberal use of silicon in phosphatic fertilizers. Gokhalae et al (1954) reported similar observation. Birch (1948) reported that sodium silicate applied to a very acid heavy clay soil produced growth without phosphate fertilizer almost equal to that on the phosphate fertilized soils. His view of the mechanism of silicate nutrition is that silica either replaces the absorbed phosphate ions thereby making them more available to plants or is itself absorbed in preference to phosphate, the two reactions being probably simultaneous. He has also reported on the superiority of silicophosphate over superphosphate in East African and English soils.

Mariakulandai (1954) in his study on the effect of sodium silicate, superphosphate, and silico phosphate with and without lime and green manure on the laterite soils

Of Nilgiris concluded that silicophosphate treated soils showed nearly double the available phosphorus, when compared to those treated with superphosphate. This effect was continued even after two months. He also recorded that the intake of phosphorus by plants was far greater in the case of plants receiving silico-phosphate Hosoda and Takata (1957) studying the effect of calcium silicate on rice crop, found that available phosphorus in soils as well as phosphorus content of plants increased in treated pots. Kido (1958) reported similar results. In pot culture experiments with rice conducted by Okamoto (1959) it was observed that absence of silica reduced considerably the amount of phosphorus absorbed and translocated to panicle. Yudin (1958) observed similar results in oats. The results recorded by Miyashi and Ishi (1960) were in conformity with the former findings. They also observed that silicic acid decreased the uptake of phosphorus in stem and leaves and also the amount of phosphorus translocated to the ear from the vegetative parts. Okuda and Takahashi (1961) also reported decreased phosphorus content in rice plants with increased supply of silica.

Gurmel Singh and Mann (1962) observed that sodium silicate applied to maize crop improved the soil structure and phosphorus uptake. The later findings of Gaussmann (1962) confirmed these results.

Datta et al (1962) conducting isotopic studies on the effect of sodium silicate on the uptake of soil and fertilizer phosphorus with wheat, rice and berseem recorded that greater uptake of soil phosphorus appeared to be associated with higher phosphorus fixing soils and that of fertilizer phosphorus with low phosphorus fixing soils. They also observed that phosphorus uptake by wheat increased irrespective of whether the silicate was applied alone or in conjunction with phosphate, but in rice the former treatment alone was effective.

Utaga and Kashima (1963) reported that application of silica decreased the percentage of phosphorus in every part of the plant, though the total amount absorbed was increased. Their important observation was that silica application accelerated the movement of phosphorus to earheads. But contrary to these results Mitsui and Takatahu (1963) using tagged phosphorus established that phosphorus remained mostly in the roots, though the major portion of silica absorbed was translocated to shoots and panicle.

Padmaja and Verghese (1964) observed increased availability of phosphorus when silica was applied either alone or in conjunction with calcium and magnesium.

3. Potassium:

Okawa and Kinsaku (1936) conducted water culture experiments with rice and barley to study the physiological action of silicic acid in plants. They observed that plants grown in culture solutions with silica, produced ear head with higher percentage of potassium than the control plants. Fritz (1940) investigating the importance of silicic acid in plant nutrition recorded an accumulation and better utilisation of potassium. From his study on nutrition of rice plants supplied with insufficient silica, Okamoto (1959) reported that plants from silica deficient plots had low potassium content. Utagawa and Kashima (1963) in their classical study on the physiological functions of silicic acid applied to rice and wheat, observed that potash contents of leaf sheath increased with silica treatments. Padmaja and Verghese (1964) obtained increased potash contents in grains and straw of rice on the application of silica either alone or in combination with calcium or magnesium.

4. Calcium:

Schollenberger (1922) was probably the first to observe the effect of silica on calcium uptake. He found that calcium content of the root increased when silica was applied. Fritz (1940) studying the importance of silicic acid in the growth of some cultivated plants and their nutritional uptake, reported an accumulation and better utilisation of calcium by crops like rice, oats, barley, maize and cucumbers with silica application. Laws (1951) obtained results which were not in confirmity with the above findings. He reported a decrease in calcium percentage in sudan grass with the application of soluble silica. Recent work of Utagawa and Kashima (1963) demonstrated the beneficial influence of silica treatments in enhancing the uptake of calcium. They observed that the calcium content of both leaf sheath and roots was increased as a result of silica application. Padmaja and Verghese (1964) reported increase in calcium content of straw of rice in silica treated pots.

5. Magnesium:

Okawa and Kinsaku (1937) studying the physiological role of silicic acid on rice and barley plants recorded a significant increase in magnesium content in plants treated with silica. Using a variety of plants like, rice, barley, oats, maize and cucumber, Frtiz (1940) observed an increased, absorption and effective utilization of magnesium by these plants when silica was included in their culture solutions. Utagawa and Kashima (1963) observed in their investigations on the physiological functions of silicic acid on rice and wheat, that the roots of silica-supplied plants contained a higher percentage of magnesium than those of the control plants.

6. Silicon:

The discovery of silica in plant ash by De Saussre (1804) paved the way for a series of investigations on the role of silicon and its distribution and function in various plant parts. Juddin (1883) showed that plants grown in hydroponics could obtain sufficient silica from the glass of culture vessel.

Hall and Morrison (1906) reported that about 9 percent of the silica absorbed goes to the grain. Schollenberger (1922) observed that the application of sodium or calcium silicate manifested itself in an increased percentage of silicon in the plant. The later workers Okawa and Kinsaku (1936) also recorded similar results. In water culture experiments with rice and barley, they observed that silica supplied plants recorded a higher percentage of silica in plant parts than the control plants.

Bastisse (1951) observed 129 per cent increase in the silica content of wheat straw as a result of repeated addition of silica. Increased silicon content in plants due to silicon application in soil was again established by the work of Okamoto (1957).

Kobayashi _et al_ (1957) also reported similar results. Kido (1958) showed that silica supplied plants absorb more silica and less nitrogen.

Mitsui _et al_ (1961) in their isotopic studies using Si^{31} observed that the silicon uptake by rice was found to be higher than by wheat. They further traced that the absorbed Si^{31} was mostly translocated into shoots particularly to well developed leaves.

Padmaja and Verghese (1964) observed that application of soluble silicon increased the silicon content of both grain and straw.

C. Physiological role of silicon in plants

Hall and Morrison (1906) provided the valuable preliminary lead in throwing some light on the physiological role of silica in plants. They recorded that maturation of grains was speeded up by silicate application. Lummermann and Wiessmann (1922) observed that the influence of silica on the physiological function of plants was more marked when there was a deficiency in phosphorus, less effective in the case of potash deficiency and was absent when there was deficiency in nitrogen. Akhromako (1934) conducting water culture experiments recorded that silica hastens the diffusion of phosphorus. This phenomenon, he attributed to the formation of a silica phosphorus absorption complex. His work also revealed that the rate of diffusion of nitrate was not increased by the presence of silica. Omer (1934) studying the effect of silicon on rye, barley and wheat, concluded that application of silica influenced transpiration in plants and the rate of translocation of nutrients.

Okawa and Kinsaku (1936) observed from their water culture studies with rice, barley and wheat, that silicic acid was necessary for rice plants to ripen, and for barley and wheat to protect the young plant from injury by cold.

Ota and Kobayashi (1957) found that silicon containing slag induces better growth which he attributed to enhanced photosynthesis and to erect position of leaf. He also observed that transpiration rate decreased with increasing silicate content. But contrary to this Kono and Takahashi (1958) did not get any correlation between silica content and transpiration. But the later work of Yoshida (1959) revealed that in silica deficient plants, the transpiration rate was high thus leading to an accumulation of mineral element in plants.

Kido (1958) and Okamoto (1959) recorded an increased production and translocation of carbohydrates and proteins due to silicon treatments. Similar results were reported by Miyoshi and Ishi (1960) in rice plant.

Mitsui and Takatohu (1960) reported increased percentage of matured grain in rice due to silicon application. Okuda and Takahashi (1961) got similar results.

Iwata and Baba (1962) conducting a culture solution experiment indicated that the efficiency of dry matter production of rice plants well supplied with nitrogen could be increased by the addition of silicon. Okuda and Takahashi (1962) in their hydroponic studies with rice in darkness at 30°C, found that the addition of sugars like glucose, fructose, galactose, sucrose or ribose increased the phosphorus uptake but had less effect on silicon uptake. They also found that silicon uptake was much increased by short time illumination, but phosphorus uptake was less affected.

Recent experiment conducted by Utagawa and Kashima (1963) revealed that the moisture content of ears, leaf blades, leaf sheath and roots decreased gradually with maturity, the rate of decrease being speeded by silica application. Utagawa and Kiyoto (1963) investigating the physiological functions of siliciccacid applied to rice and wheat, observed that the percentage and quantity of reducing sugar in ears, leaf blade, leaf sheaths and stalks decreased by application of silica. They also found that the quantity of non-reducing sugar was more in the leaf blades but less in the stalk.

D. Deficiency symptoms

Ishibashi (1937) found brown spots appearing on the surface of grains when plants were devoid of silicon nutrition. He further noticed that the effect was more pronounced when plants were given a high level of nitrogen. Addition of silica was found to reduce the incidence of these symptoms. Okwara and Tanaka (1940) observed that plants like barley and rice develop abnormal narrow leaves, exhibit minute brownish black spots on the leaves within two weeks, which then change to yellow and finally wither away due to the deficiency of silica. Mitsui and Takatohu (1960) observed necrosis on the older leaves due to the absence of silica. However, Okuda and Takahashi (1961) found that silicate deficiency did not induce any disease or abnormality, but produce only leaf dropping during the early stages of crop growth which persists only for a few weeks.

E. Effect of silicon on disease resistance

Lundie (1913) suggested that when silicon is deposited in the cell membrane and in the epidermis of the plant, it may afford a certain protection against fungus disease. Japanese workers Onodera (1927) Kawashima (1927) observed that with increased silicate content in the plant there is greater resistance to blast attack. Memmint (1933) studying the relationship of environmental factors to the occurrence and severity of blast found that susceptibility of rice to blast disease is seen only when soils are deficient in available silica.

Okwara and Tanaka (1940) reported that barley and rice plants exhibited minute brownish black spots on the leaves, developed narrow leaves and finally withered due to silicate deficiency. Fritz (1940) and Hartong (1940) recorded that a high silicon content was correlated with greater resistance to mildew.

Investigations by Ishizuka and Hayakanea (1951) revealed that application of soluble silicates increased the silicon uptake in rice followed by a greater resistance to blast disease. Adyanthaya and Rangaswamy (1952) and Venkitachalam (1954) got specific relationship between the increased number of silicated cells per unit area in the resistant varieties of rice than the susceptible one. Later results of Hosoda and Takata (1957) and Volk et al (1957) supported the view of beneficial effect of silicon on blast resistance. Ota and Kobayashi (1957) reported that silicate application not only reduced susceptibility to blast but also reduced the stem borer attack.

Bruchmann (1958) reported that mildew infection of grain crops can be controlled by soluble silicon application. Takiyima et al (1959) recorded that application of slag containing silica prevented sesame leaf spot and rice blight.

F. Influence of silicon on lodging of plants

Divergent views have been recorded by investigators on the role of silicon against lodging of plants. One of the earliest opinions recorded is that of Davey (1798) who reported that silica had an important role in giving strength to hollow stemmed grasses. Liebig (Phillips, 1936) supported this view and pointed out the influence of potassium silicate in the stem of grasses. Davey's silica theory was later supported by the work and observations recorded by Swee Cicki (Phillips 1936), Hadeen (1916), Doughlas (1916) and Davidson and Leelere (1923).

The importance of the presence of silica in grammaceous plants and its role in strengthening the stem were, however, questioned by a team of investigators. Sachs (1882) Jodin (1883), Knop (1862) and Mayer (1901), showed that plants made normal growth upto maturity with usual leaf and stem size and stability of stem, even in nutrient solutions devoid of silica. They thus questioned the role of silica as emphasized by the Davey's silica theory. Further, another trump card against silica theory was provided by the observations made by Welton and Morris (1931) that the maximum accumulation of silica in the plants was usually in the leaves and not in the stem and thus silicon has little role in providing strength to stem.

Davidson and Phillips (1930) and Phillips (1936) found that application of nitrogenous manure decreased the uptake of silica and made the stem succulent and more susceptible to lodging.

CHAPTER III

MATERIALS AND METHODS

The present work was undertaken with a view to studying the influence of silicates on the uptake of nutrients by the different plant parts at different stages of crop growth and the yield attributes with special reference to lodging. To facilitate this study a pot culture experiment with Completely Randomised Design was laid out. Sufficient number of replications were given to enable chemical analysis of the plant parts during their growth periods.

A. Pot Culture Experiment

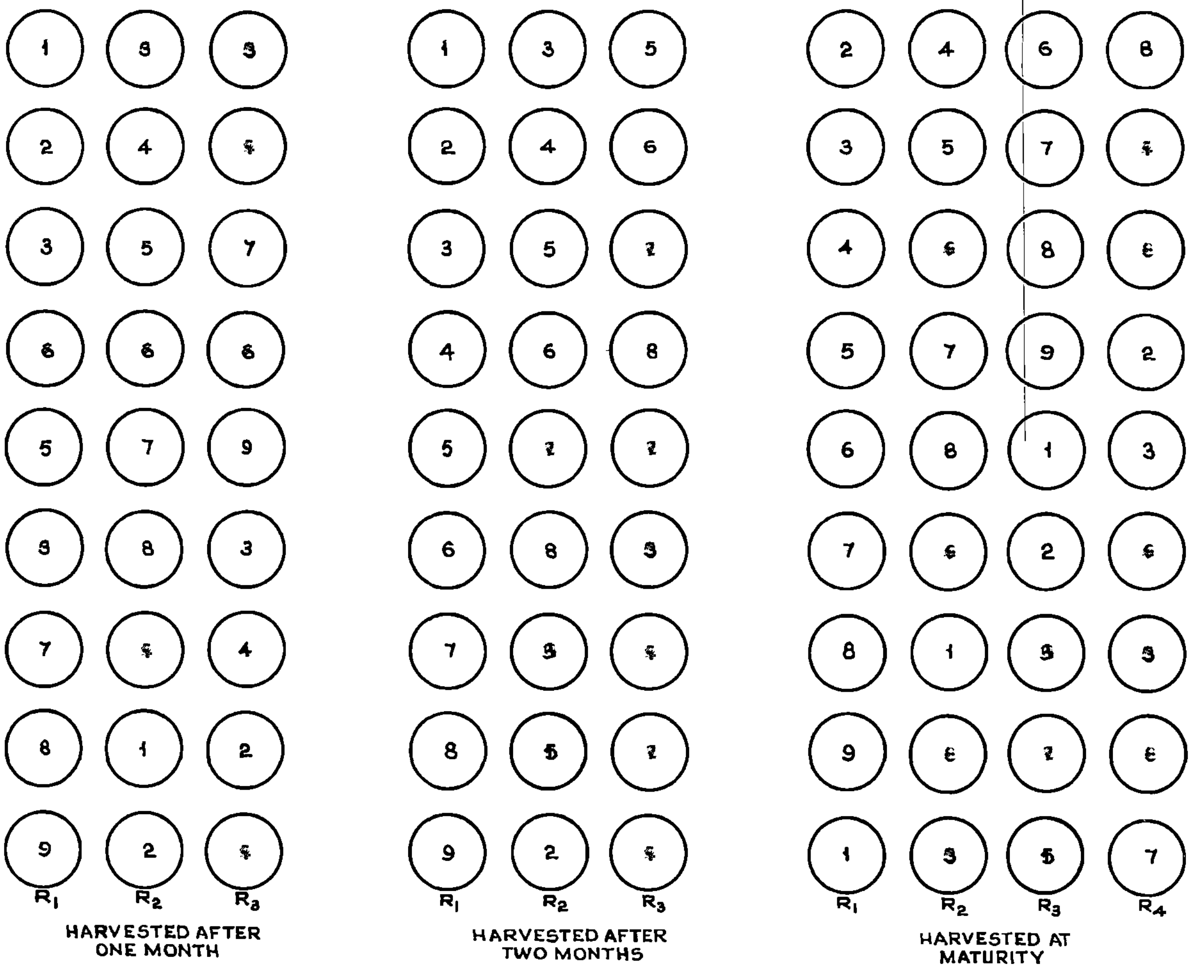
1. <u>Soil taken up for the study</u>

Paddy soil for the study was collected from the "Kayal" land of the Agricultural College Farm, Vellayani. Soils from 6" depth of a field, continuously cropped to paddy, were collected from different representative sites. The soil was then air dried, passed through a 2 m.m. sieve and reduced in bulk by the method of cone and quartering till the quantity required for the study was obtained.

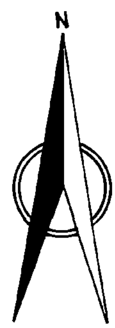
2. <u>Layout of the Experiment</u>

A Completely Randomised Design with nine treatments

DETAILS REGARDING LAYOUT AND TREATMENTS OF THE POT CULTURE EXPERIMENT



TREATMENT 1 N_0S_0 N_0 = 30 lb N PER ACRE
" 2 N_0S_1 N_1 = 60 lb N PER ACRE
3 N_0S_2 N_2 = 90 lb N PER ACRE
4 N_1S_0 S_0 = 0 lb SiO_2 PER ACRE
" 5 N_1S_1 S_1 = 100 lb SiO_2 PER ACRE AS Na_2SiO_3
6 N_1S_2 S_2 = 100 lb SiO_2 PER ACRE AS $CaMgSiO_3$
7 N_2S_0
8 N_2S_1
9 N_2S_2



Note P_2O_5 and K_2O at 30 lb/acre were added as basal dressing

FIG 1

replicated 10 times was adopted. Details of the layout are furnished in Figure 1.

3. Preparation of pots

Clay pots of uniform size (1' x 1') with a capacity to hold 10 Kg. of soil were used for the experiment. Before filling up with soil, the pots were given two coats of bitumen inside 10 Kg. lots of soil thoroughly mixed with the calculated quantities of fertilizers and other nutrients were transferred to the corresponding pots on 24-9-1964 as per the design of the experiment (Figure 1).

Nitrogen was given as ammonium sulphate (20.5 percent N) phosphoric acid as super phosphate (16.0 percent water soluble P_2O_5) and potash as muriate of potash (60 percent K_2O).

Silicates added were as sodium silicate (50 percent SiO_2) and calcium magnesium silicates (10 percent Ca and 15 percent Mg). The latter was prepared in the laboratory as a mechanical mixture of calcium silicate and magnesium silicate by mixing a solution of sodium silicate with one of calcium chloride and magnesium chloride respectively and washing the compounds formed free of chloride.

The entire dose of NPK and silicates was added at the time of sowing. The pots were saturated with water at field capacity and puddled.

4. Seeds amd sowing

Paddy strain selected for the experiment was PTB.10. Seven seeds were sown directly in each pot on 25-9-1964. After 20 days (15-10-1964) all the seedlings were removed and four healthy plants selected from each pot, were transplanted in the corresponding pot. Rest of the seedlings were cut into small bits and buried in the puddled soil.

5. Irrigation

The seedlings were irrigated periodically with rain water so as to maintain a constant level of one inch of water over the surface of the soil.

6. Observations

The following plant observations were recorded to determine the effect of different treatments on plant performance and yield attributes.

a) Plant height: This was recorded at monthly intervals from the date of transplanting. The measurement was made from the surface of the soil to the tip of the last leaf.

b) Total number of vegetative tillers: The tiller counts were made at intervals of 30 days from the date of transplanting.

c) Yield: First crop cutting was made on 15-11-1964. The second cutting was done on 15-12-1964. The crop was finally harvested on 14-1-1965. The yield of straw and roots in the first cutting and that of grain, straw and roots in the next two harvests were recorded after drying in air to constant weight, separately for each pot. The roots were carefully gathered after emptying the pots and washing off the soil completely with water.

B. Analysis of Soil

A representative soil sample was drawn from the bulk sample prepared for pot culture work and was analysed for its chemical constituents, mechanical composition and physical properties as follows:

a) Chemical Constituents

1. Moisture: 5 g. of soil was weighed out in a weighing bottle and kept for eight hours in an air oven at 105°C and the moisture percentage was calculated from the loss in weight observed.

2. Loss on ignition: A weighed quantity of soil was ignited to constant weight in a silica basin at dull red heat over a rose head burner. The loss

in weight on ignition was calculated on oven dry basis after deducting the moisture content.

Preparation of hydrochloric extract

The ignited soil was digested with 1:1 hydrochloric acid and filtered. The filtrate was made upto a known volume. From the hydrochloric acid extract thus obtained, the following analyses were made:-

3. Sesquioxides: Sesquioxides were precipitated in a known volume of the hydrochloric acid extract as hydroxides. They were filtered, ignited and weighed as combined oxides.

4. Iron oxide: Iron oxide was then determined in a separate aliquot of the hydrochloric acid extract by reduction with zinc and dilute sulphuric acid and the ferrous solution thus obtained was then titrated with standard potassium permanganate solution.

5. Aluminium: Aluminium oxide was estimated by difference of 3 and 4 above.

6. Calcium: Calcium was estimated volumetrically from the filterate of iron and aluminia estimation by oxalate method in ammoniacal medium.

7. Magnesium: Magnesium content was determined gravimetrically by precipitation as magnesium ammonium

phosphate from the filterate of calcium.

8. Total phosphoric acid: The ammonium phosphomolybdate method of estimation was followed and the total phosphorus was estimated volumetrically (Piper, 1950).

9. Total potassium: Sodium cobaltinitrite method of determination was adopted and the total potassium was estimated volumetrically (Piper, 1950).

10. Acid soluble silica: A known volume of the hydrochloric acid extract was evaporated to dryness on a sand bath until the last traces of moisture were removed. The dried residue was digested with dilute nitric acid and filtered. The residue was ignited in a platinum crucible and sulphated and weighed. The silica was then converted to volatile silicon fluoride by heating with hydrofluoric acid and the reduction in weight was recorded as silica (Piper 1950).

12. Water soluble silica: 60 g. of soil were shaken with 600 ml. of distilled water in an end over end shaker for 24 hours. The water extract was reduced to a convenient volume and the water soluble silica was estimated gravimetrically as in the case of acid soluble silica.

The other analyses made were as follows:-

13. Available phosphoric acid: Bray and Kurtz extractant No.2 was used for the extraction of phosphorus and it was estimated colorimetrically by reading the molybdic blue colour obtained with red filter in a Klett-Summerson Colorimeter.

14. Available potassium: This was determined by extracting the soil with Morgan's reagent, developing turbidity and reading the same in a Klett-Summerson Colorimeter.

15. Total Nitrogen: Total nitrogen was estimated by salicylic acid method (A.O.A.C.).

16. Available nitrogen: This was estimated as per the alkaline permanganate method (Subbiah and Asija, 1956).

17. Organic Carbon: Organic Carbon was determined by Walkley and Black's titration method (Piper 1950).

18. Cation exchange capacity: This was obtained according to Schollenberger method (Schollenberger and Dreibelbis 1930) using N ammonium acetate for leaching and exchangeable ions.

19. pH: A Photovolt pH meter with glass electrode was used for measurement of pH, using a 1:2 soil water ratio.

20. Conductivity: This was determined with the help of a conductivity bridge (Solubridge) taking a 1:2 soil-water mixture.

b) Mechanical analysis: International "A" method (Piper 1950) was adopted for determining the various mechanical fractions of the soil.

c) Physical properties: The apparent density, specific gravity, water holding capacity and volume expansion were determined by the Keen - Raezkovski method (Piper 1950).

C. Analytical Procedure for Plant material

1. Nitrogen:

This was estimated in 2 g. of plant material by Kjeldahl method.

Preparation of triple acid extract

A weighed quantity of plant material was digested with triple acid mixture containing nitric acid, perchloric and sulphuric acid in the ratio of 4 : 1 : 1. This was filtered and the filtrate was made upto a known volume. The residue was used for silica estimation while the filtrate was used for the phosphorus, potassium, calcium and magnesium determinations.

2. Phosphorus

This was determined in a known aliquot of the triple acid extract colorimetrically. Molybdic blue colour was developed and the intensity of the colour was read in a Klett-Summerson colorimeter using a red filter (Jackson 1962).

3. Potassium

Potassium was determined by turbidity method in the Klett-Summerson colorimeter (Jackson, 1962).

4. Calcium and Magnesium

This was determined by titrating disodium dihydrogen Ethylene diamine tetra-acetic acid with a known volume of triple acid extract using Eriochrome black T indicator (Jackson, 1962).

5. Calcium

Calcium was also determined by the same method using murexide as indicator.

6. Magnesium.

From the difference in values of estimates 4 and 5 above, magnesium was computed.

D. Procedure for counting the number of silicated cells in the leaf and stem

1. Silicated cells in the leaf

The third leaf counted from each of the treatments was cut and preserved in a formaline acetic acid alcohol mixture (1 : 1 : 10). The leaf was divided into three equal parts and the middle one-third of the leaf was selected for the estimation.

The leaf was cut into small bits and kept in a test tube. After addition of concentrated nitric acid sufficient to cover the leaf bits, followed by a few crystals of potassium chlorate and gradual heating until bubbles were evolved, the contents were poured into a dish containing cold water. The peels were stained with safranin. Only the non-silicated cells took the stain while the silicated cells were bright. Counts of silicated cells were made under the microscope (Carl Zeiss 10 x 43). Unit area of four fields were counted for each treatment and the mean number of silicated cells was calculated (Figure 6).

2. Silicated cells in the stem

The middle third of the lower internode of the stem was selected at random from each treatment and silicated cells were determined as above. (Figure 7).

E. Procedure for determining the breaking strength of straw

The equipment devised for determining the breaking strength of straw is illustrated in Figure 8. This chiefly consists of an iron pole (A) with a movable horizontal bar ($B-B_1$). Attached to the bar are two movable clamps ($C-C_1$) so that the distance between them can be adjusted according to the length of the straw. The lower ends of the clamps are hook shaped. These hooks ($D-D_1$) are also adjustable so as to fix firmly straw samples varying in thickness. The two ends ($E-E_1$) of the lower internode were fixed on the two hooks. A balance pan F is suspended from the middle of the internode. Weights are then added on the pan till the straw breaks. This weight was taken as the breaking strength of the straw. For each treatment the breaking strength of four plants were determined and the mean weight was calculated.

TABLE I

ANALYSIS OF ORIGINAL SOIL

(Percent moisture free basis, except for physical properties)

A Chemical analysis

1.	Moisture	1.47
2.	Loss on ignition	8.89
3.	Sesquioxide (R_2O_3)	30.06
4.	Iron oxide (Fe_2O_3)	14.32
5.	Aluminium oxide (Al_2O_3)	15.74
6.	Calcium oxide (C_aO)	0.04
7.	Magnesium oxide (M_gO)	0.04
8.	Phosphorus (Total) (K_2O)	0.03
9.	Potassium (Total) (K_2O)	0.18
10.	Acid soluble silica	4.35
11.	Water soluble silica	Trace
12.	Silica/Sesquioxide ratio	2.07
13.	Nitrogen (Total)	0.15
14.	Nitrogen (Available)	0.03
15.	Phosphorus (Available) (P_2O_5)	0.0013
16.	Potassium (Available) (K_2O)	0.0059
17.	Organic carbon	1.34
18.	Base exchange capacity (me)	6
19.	pH	4.5
20.	Conductivity (Milli mhos/cm)	0.8

TABLE I (CONTD.)

B	Mechanical analysis	
	1. Coarse sand	30.86
	2. Fine sand	14.27
	3. Silt	15.68
	4. Clay	33.19
C	Physical properties	
	1. Apparent density	1.40
	2. Absolute specific gravity	1.61
	3. Volume expansion (Percent)	4.90
	4. Maximum water holding capacity (Percent)	49.50
	5. Porespace (Percent)	38.00

CHAPTER IV

RESULTS

The results obtained in the study are detailed below:

A. Analysis of soil

1. Chemical Constituents (Table I)

The paddy soil used in the pot culture experiment had a low pH value of 4.5. Data presented in Table I show the acidic nature of this soil which influenced its chemical characteristics. The sesquioxides recorded the maximum value of 30.06 percent while the other basic oxides estimated viz., calcium, magnesium and potassium oxides were very low totalling only 0.26 percent. The silica sesquioxide ratio was 2.07. The available major nutrients were: nitrogen 0.03 percent, P_2O_5 0.0013 percent and K_2O 0.0059 percent. Acid soluble silica content recorded a value of 4.35 percent while the water soluble silica was only trace. The soil exhibited a base exchange capacity of 6.0 me. per 100 g. and had a conductivity of 0.8 m. mohs/cm.

2. Mechanical composition: (Table I)

Mechanical analysis revealed that the soil used

TABLE II

CHANGES IN THE pH OF SOIL WITH TIME

Treatments	Days after transplanting		
	30th	60th	90th
T_1	5.5	6.3	5.9
T_2	6.0	5.7	6.5
T_3	5.8	5.9	6.5
T_4	5.8	5.9	6.5
T_5	5.6	6.0	6.5
T_6	5.7	6.1	5.3
T_7	5.6	6.2	6.6
T_8	5.8	6.4	6.7
T_9	5.8	6.3	6.5

for the study had a course fraction of 45.13 percent (Coarse sand 30.86 percent fine sand 14.27 percent) and a fine fraction of 48.87 percent, clay occupying the major portion with 33.19 percent, From the above proportion it may be adduced that the soil may be grouped under loam type.

3. Physical properties: (Table I)

The effect of an equal distribution of coarse and fine fractions has reflected in the physical properties of the soil. The soil has an apparent density of 1.4 and volume expansion of 4.9 percent. Maximum water holding capacity was 49.5 percent. The soil exhibited a pore space of 38 percent.

4. Changes in soil reaction: (Table II)

Soil samples were collected from all the plant-harvested pots during the three stages of crop growth. Their pH and electrical conductivity were determined.

The pH value recorded a regular rise from the 30th day (5.5 to 6.0) to the 90th day (5.3 to 6.7). In the former case the minimum pH value was recorded by the treatment 1 and the highest by sodium silicate treatment (T2). But on the 90th day the lowest pH value noticed was in T6 (Calcium-magnesium silicate) and highest in sodium silicate treatment (T8). pH value exhibited a highly significant correlation with electrical conductivity, r being 0.880*** (Figure 12A).

TABLE III

CHANGES IN THE ELECTRICAL CONDUCTIVITY OF SOIL WITH TIME

(Electrical conductivity in Milli mhos/cm)

Treatments	Days after transplanting		
	30th	60th	90th
T_1	0.15	0.30	0.35
T_2	0.20	0.30	0.30
T_3	0.10	0.20	0.25
T_4	0.15	0.20	0.30
T_5	0.15	0.20	0.25
T_6	0.10	0.20	0.25
T_7	0.10	0.25	0.25
T_8	0.20	0.20	0.30
T_9	0.10	0.25	0.35

TABLE IV

GROWTH CHARACTERS : HEIGHT AND TILLER

COUNTS AT THREE STAGES

Treatments	Height (Cms)			Tiller Counts (Nos)		
	Days			Days		
	30th	60th	90th	30th	60th	90th
T_1	73	80	94	5.0	7.0	7.1
T_2	75	90	114	5.0	8.0	8.2
T_3	80	93	113	5.2	7.2	7.4
T_4	70	99	100	5.0	7.4	7.5
T_5	75	112	116	6.1	8.1	8.9
T_6	75	111	118	5.4	8.2	9.0
T_7	71	91	112	5.0	7.4	7.8
T_8	76	106	115	5.3	8.1	8.3
T_9	76	109	114	5.0	8.1	8.8

5. Electrical conductivity: (Table III)

Conductivity values obtained followed a similar trend as those of pH, the initial stage recording the lowest value (0.10 to 0.20) with a gradual rise at the final period (0.25 to 0.35).

B. Plant Observations

1. Growth measurements: (Table IV)

Growth measurements (Figures 2 to 5) made at all the three stages revealed that no silicate treatments gave the minimum values. At the initial stage T4 recorded the minimum height while in later stages the higher level nitrogen treatments with silica, recorded the maximum values (T5 and T6). (Figure 4)

2. Tiller Counts: (Table IV)

In all the three stages of growth treatment 1 recorded the lowest tiller count. The maximum number of tillers were observed in the initial stage in T5 with 6.1 tillers while both in the second and final stages T6 occupied the first rank with 8.2 and 9.0 tillers respectively

TABLE V

YIELD IN GRAMS PER POT

Treatments	30th day		60th day			90th day		
	Root	Straw	Root	Straw	Grain	Root	Straw	Grain
T_1	0.34	2.34	2.0	14.06	5.39	3.70	19.17	10.72
T_2	0.36	1.90	1.93	14.25	7.43	4.80	26.30	13.53
T_3	0.36	2.60	2.95	15.5	7.36	4.86	23.4	13.50
T_4	0.22	1.37	1.45	13.8	6.72	4.57	22.6	11.6
T_5	0.31	1.40	2.18	19.43	9.85	4.84	25.83	16.13
T_6	0.26	1.66	2.08	15.76	7.45	4.78	26.48	16.40
T_7	0.27	1.47	1.44	14.83	8.82	4.35	23.05	10.73
T_8	0.27	1.80	1.88	14.29	11.34	5.08	25.10	16.66
T_9	0.40	1.81	2.69	15.20	9.07	5.10	26.40	16.56

C. Yield (Table V)

1. Root:

Root weight recorded varied from a minimum of 0.22 g (T4) to a maximum of 0.40 g (T9) on the 30th day and from 1.44 g (T7) to 2.95 g (T3) on the 60th day. At the final stage T1 recorded the minimum (3.70 g) and T9 the maximum root weight. (5.10 g). In the later stages minimum values were obtained in treatments devoid of silicon.

2. Straw: (Table V) Appendix I

The yield data of straw at three stages revealed that the minimum was for treatments without silicates. In the initial and final stages calcium magnesium silicate treatments recorded the maximum values while at the middle stage treatment 5 excelled all the other treatments.

The analysis of variance of the yield of straw at the final stage showed that silicates, individually or in combination, proved better than no-silicate treatments in increasing the yield of straw. It is also proved that at 30 lb nitrogen level sodium silicate treatment fared better than no-silicates. Calcium magnesium silicate treatment at 60 lb and 90 lb nitrogen level gave significantly

TABLE VI

NITROGEN CONTENT OF ROOT

(Percent (N), Moisture free basis)

Treatments	Days		
	30th	60th	90th
T_1	1.36	1.12	0.91
T_2	1.32	0.98	0.93
T_3	1.79	0.93	0.89
T_4	1.76	1.07	0.96
T_5	1.63	0.96	0.87
T_6	1.59	1.06	0.79
T_7	1.95	0.99	0.90
T_8	2.10	1.33	0.75
T_9	2.07	1.22	1.00

higher yields than control (T1). So also, sodium silicate treatment at all the three levels of nitrogen had better influence in promoting the yield of straw, and recorded significantly higher values than control.

3. <u>Grain:</u> (Table V - Appendix II)

The control (T1) recorded the lowest value on the 60th and 90th day (5.39 g and 10.72 g). Sodium silicate treatment (T8) excelled all other treatments at the second stage while the same (T8) ranked first at the final stage. The analysis of variance of grain yield of the final harvest showed that treatments containing silicates had significantly better influence in promoting the yield than treatments devoid of silicates. At 90 lb N level sodium silicate and calcium magnesium silicate, both individually and in combination had significant effect in increasing grain output over the control.

D. Plant Analysis

A. Nutrient Content

1. <u>Root</u>

<u>Nitrogen:</u> (Table VI)

Nitrogen content of root was maximum in the case of sodium silicate treatment on the 30th and 60th day (T8), but the same treatment recorded the lowest value at the final stage. Maximum nitrogen

TABLE VII

NITROGEN CONTENT OF GRAIN AND STRAW

(Percent (N), Moisture free basis)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	3.39	0.90	1.44	0.65	1.16
T_2	3.53	0.94	1.64	0.56	1.28
T_3	3.05	1.01	1.72	0.75	1.32
T_4	4.10	1.15	1.76	0.93	1.56
T_5	4.89	1.21	1.66	0.99	1.42
T_6	3.63	1.19	1.80	0.90	1.53
T_7	3.47	1.23	1.79	0.61	1.54
T_8	3.62	1.34	1.75	0.64	1.62
T_9	3.77	1.09	1.67	0.75	1.47

TABLE VIII

PHOSPHORUS CONTENT OF GRAIN AND STRAW

(Percent (P), Moisture free basis)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	0.29	0.27	0.21	0.12	0.40
T_2	0.37	0.31	0.22	0.14	0.42
T_3	0.35	0.32	0.24	0.16	0.45
T_4	0.31	0.29	0.21	0.15	0.41
T_5	0.32	0.31	0.24	0.17	0.46
T_6	0.39	0.38	0.23	0.21	0.45
T_7	0.42	0.35	0.26	0.18	0.42
T_8	0.44	0.37	0.31	0.21	0.49
T_9	0.51	0.39	0.30	0.25	0.51

content at the final stage was recorded by calcium magnesium silicate treatment (T_9). The N percent exhibited a gradual decrease with the progress of maturity.

2. Straw

Nitrogen: (Table VII - Appendix V)

Plants from treatment 5 recorded the maximum N content on the 30th and 90th day (4.89 per cent and 0.99 per cent respectively) and treatment 8 on the 60th day (1.34 per cent). The T_3, T_1 and T_2 treatments at 30 lb N level recorded minimum values on 30th, 60th and 90th day respectively. The nitrogen percent of straw followed the same trend as that of root, the content decreasing with progress of maturity. The N percent on 30th day exhibited positive correlation with the silica per cent at the same stage, the r value being 0.963*** (Figure 13.B).

b) Phosphorus: (Table VIII - Appendix V)

In all the three stages the calcium magnesium silicate treatment at 90 lb N level ranked first while the control (T_1) was placed last. The p percent of the final stage had significant relationship with silica percent ($r = 0.776^*$). The high values recorded by all the treatments at the initial stage decreased with the maturity of the crop.

TABLE IX

POTASH CONTENT OF GRAIN AND STRAW

(Percent (K), Moisture free basis)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	0.63	0.99	0.59	1.36	0.61
T_2	0.64	1.13	0.63	2.53	0.72
T_3	0.81	1.02	0.69	2.69	0.75
T_4	0.82	0.96	0.61	1.86	0.68
T_5	0.62	1.14	0.65	1.97	0.69
T_6	0.70	1.21	0.68	2.02	0.72
T_7	0.59	0.69	0.59	1.52	0.64
T_8	0.71	0.83	0.72	1.39	0.89
T_9	0.53	0.68	0.74	1.54	0.79

TABLE X

CALCIUM CONTENT OF GRAIN AND STRAW

(Percent (Ca), Moisture free basis)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	0.75	0.57	0.35	0.40	0.29
T_2	0.55	0.58	0.30	0.42	0.27
T_3	0.79	0.61	0.39	0.43	0.36
T_4	0.57	0.47	0.38	0.46	0.31
T_5	0.73	0.51	0.27	0.42	0.26
T_6	0.80	0.59	0.39	0.48	0.38
T_7	0.65	0.57	0.33	0.42	0.21
T_8	0.80	0.55	0.29	0.42	0.26
T_9	0.85	0.71	0.49	0.47	0.37

TABLE XI

MAGNESIUM CONTENT OF GRAIN AND STRAW

(Percent (Mg), moisture free basis)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	0.81	0.63	0.49	0.57	0.36
T_2	0.69	0.67	0.51	0.56	0.33
T_3	0.84	0.67	0.56	0.59	0.45
T_4	0.70	0.59	0.42	0.52	0.39
T_5	0.83	0.58	0.38	0.53	0.33
T_6	0.86	0.64	0.47	0.57	0.41
T_7	0.69	0.52	0.43	0.49	0.29
T_8	0.57	0.60	0.41	0.48	0.32
T_9	0.83	0.82	0.53	0.59	0.43

c) Potassium: (Table IX)

The trend of variation of the K content was found to be the reverse of that of N and P, the maximum value being at the final stage. The influence of treatment on this nutrient content was found to follow no regular pattern, T_4, T_6 and T_3 recording the maximum values on the 30th, 60th and 90th day respectively.

d) Calcium: (Table X)

The percentage calcium content of straw decreased with the progress of growth. The calcium magnesium silicate treatment at 90 lb N level produced the maximum value on the 30th and 60th day while the same treatment at 60 lb N level recorded the maximum value on the 90th day. The minimum values were those of T_2, T_4 and T_1 on the 30th, 60th and 90th day respectively. So this revealed that maximum values obtained were those of treatments containing calcium and the minimum values of treatments without it.

e) Magnesium: (Table XI - Appendix V)

Magnesium content followed the same trend as that of calcium, the percentage values decreasing with the progress of maturity. The treatments containing magnesium produced straw with maximum content of magnesium at all the three stages (treatments T_6, T_9 and T_9) while the minimum values were those of treatments devoid

TABLE XII

SILICA CONTENT OF GRAIN AND STRAW

(Percent (SiO_2), Moisture free basis)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	5.44	7.23	8.07	7.17	5.59
T_2	5.87	8.16	13.07	9.50	9.27
T_3	5.02	7.25	12.84	9.74	8.22
T_4	5.62	6.40	9.50	9.22	8.64
T_5	6.04	7.59	12.37	10.66	7.92
T_6	5.45	6.30	10.82	10.67	9.90
T_7	5.10	5.78	5.53	8.23	7.64
T_8	6.51	7.49	9.81	11.79	9.81
T_9	5.98	7.18	6.70	6.51	6.39

of magnesium (T_8, T_7 and T_1). Magnesium percentage on the 60th day exhibited significant positive correlation with that of silica content, r being 0.669** .

f) <u>Silicon</u>: (Table XII - Appendix V)

Straw obtained from sodium silicate treatments recorded the maximum values for silica at all the three stages (T_8, T_2 and T_8). Silica content increased with the progress of maturity of the crop. The percentage of this constituent exhibited positive significant correlation with nitrogen, magnesium and phosphorus percentage of straw on the 30th, 60th and 90th day respectively. Silica percentage of stem at maturity was found to exhibit positive correlation with breaking strength, r being 0.875**.

3. Grain:

a) <u>Nitrogen</u>: (Table VII)

Nitrogen content of the grain decreased with the progress of maturity and showed the same trend as straw. On 60th day calcium magnesium silicate treatment (T_6) recorded the highest value while on 90th day treatment 8 (Sodium silicate) registered the highest. In both harvests T_1 recorded the lowest nitrogen content.

b) <u>Phosphorus</u>: (Table VIII)

Treatment 8 recorded the highest percentage of phosphorus on 60th day while T_1 and T_4 exhibited the lowest value. At 90th day calcium magnesium silicate (T_9) recorded the highest and T_1 gave the lowest value. As the plant matures, the phosphorus content of grain increases.

c) Potassium: (Table IX)

Earhead analysis for potassium from treatment 9 showed the highest value (0.74 per cent) as against T_1 and T_7 which gave the lowest (0.59 per cent). But on 90th day T_8 excelled all the other treatments. Here again T_1 gave the lowest percentage. In general the potash content was found to increase as the grain came to maturity as in the case of straw.

d) Calcium: (Table X)

Calcium content of the grain of treatment 9 was the highest on 60th day whereas during the same period T_5 recorded the lowest. But at 90th day calcium magnesium silicate treatment (T_6) recorded the maximum value, when compared to T_7 which was the lowest. The pattern of decreasing trend of calcium content with maturity of crop was similar to that of straw.

e) Magnesium: (Table XI)

Magnesium percentage of grain exhibited the same trend as that of magnesium in straw. Treatment 3 gave the highest magnesium content on the 60th day and 90th day. But treatment 5 recorded the lowest values on 60th day and treatment 7 on 90th day.

TABLE XIII

NUTRIENT UPTAKE (Nitrogen) BY ROOT

(Milligrams (N) per pot)

Treatments	Days		
	30th	60th	90th
T_1	4.55	22.4	53.6
T_2	4.75	19.0	44.6
T_3	6.39	27.4	43.3
T_4	3.81	19.6	43.8
T_5	4.97	20.9	43.1
T_6	4.22	22.1	37.8
T_7	5.36	14.3	39.1
T_8	5.77	31.5	48.3
T_9	9.31	32.8	51.0

TABLE XIV

NUTRIENT UPTAKE (Nitrogen) BY GRAIN AND STRAW

(Milligrams (N) per pot)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	79.7	126.0	124	77.8	124
T_2	67.1	134.0	141	123.0	173
T_3	79.3	156.0	177	127.0	178
T_4	56.2	159.0	205	118.0	181
T_5	68.4	235.0	257	164.0	217
T_6	60.3	187.0	252	134.0	266
T_7	64.4	182.0	157	158.0	165
T_8	65.1	191.0	160	198.0	270
T_9	67.8	166.0	199	152.0	243

f) Silicon: (Table XII)

Sodium silicate treatment (T_2) recorded the highest silicon percentage on 60th day with T_7 having the lowest value during the same period. But at maturity, treatment 6 was found to contain the highest SiO_2 level and T_1 the lowest. As the crop matured, the silicon content in the grain was found to decrease.

B. Nutrient uptake

1. Root

Nitrogen: (Table XIII)

Data on uptake of nitrogen by roots showed that at all the three periods treatment 9 excelled the other treatments. However at the first stage T_4 recorded the minimum value while T_7 exhibited the minimum uptake of this nutrient at the second period while T_1 showed least at the final period (Figure 9). Hence it would appear that calcium magnesium silicate has a definite influence on the uptake of nitrogen by the paddy plant.

2. Straw:

a) Nitrogen: (Table XIV - Appendix V)

In the initial stage T_1 was found to have taken the maximum N while treatment 4 which is devoid of silica had the least. But in the second and final stages, treatment with sodium silicate at 60 lb N was found to have taken the maximum while in both cases the control (T_1)

TABLE XV

NUTRIENT UPTAKE (Phosphorus) BY GRAIN AND STRAW

(Milligrams (P) per pot)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	6.82	37.9	23.9	11.8	42.9
T_2	5.43	44.2	35.5	16.3	56.8
T_3	9.53	49.6	37.4	17.6	60.7
T_4	4.24	40.0	33.9	14.1	47.5
T_5	4.48	60.2	44.1	23.6	77.2
T_6	6.47	59.9	55.6	17.1	78.3
T_7	6.19	51.9	46.9	22.9	44.9
T_8	4.66	52.9	51.7	35.2	81.6
T_9	9.18	59.8	56.1	27.2	84.4

TABLE XVI

NUTRIENT UPTAKE (Potassium) BY GRAIN AND STRAW

(Milligrams (K) per pot)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	14.8	138	261	31.8	65.4
T_2	12.2	161	640	46.8	96.1
T_3	21.1	158	629	50.8	101.0
T_4	11.2	132	420	41.0	78.9
T_5	8.70	221	511	64.0	115.0
T_6	11.6	191	539	50.6	125.0
T_7	8.7	101	396	52.1	78.4
T_8	12.8	119	349	81.6	148.0
T_9	9.5	103	407	68.7	126.0

TABLE XVII

NUTRIENT UPTAKE (Calcium) BY GRAIN AND STRAW

(Milligrams (Ca) per pot)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	22.2	63.7	76.7	18.9	30.0
T_2	10.5	82.6	106.0	22.2	36.5
T_3	16.3	94.5	101.0	28.7	48.6
T_4	7.4	64.9	104.0	29.8	35.0
T_5	10.2	99.1	109.0	26.6	43.7
T_6	13.3	73.9	127.0	29.1	66.0
T_7	9.6	67.2	109.0	29.1	22.5
T_8	14.4	78.5	108.0	32.9	43.3
T_9	15.3	85.6	124.0	44.4	51.1

had the least uptake of nitrogen (Figure 9). Nitrogen uptake in stalk on the 30th day was found to have a positive correlation with the silica uptake, the r value being 0.926***. However, at the 60th day nitrogen uptake was negatively correlated with silica uptake (r =-0.711**). But at the final stage N uptake was positively correlated with SiO_2 uptake.

b) Phosphorus: (Table XV)

At the initial stage the uptake of phosphorus was found to be the maximum in calcium magnesium silicate treatment (T_3) and the least in the non-silicate treatment (T_4) while at the second and final stages sodium silicate treatments (T_5 and T_8) recorded the highest. In both these cases control (T_1) recorded the least (Figure 10).

c) Potassium: (Table XVI)

Sodium silicate treatments (T_5) at the second and (T_8) final stages recorded the maximum uptake of potassium while T_7 and T_1 recorded the lowest. But at the initial stage T_3 recorded the maximum uptake of K while T_5 and T_7 recorded the minimum (Figure 11).

d) Calcium: (Table XVII - Appendix V)

Correlation study on the calcium uptake with silicon uptake at 60th day gave a positive relationship, r being 0.746*. T_1 gave the maximum uptake of calcium

TABLE XVIII

MAGNESIUM UPTAKE (Magnesium) BY GRAIN AND STRAW

(Milligram (Mg) per pot)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	19.0	73.6	109.0	26.4	38.6
T_2	13.1	98.3	141.0	37.9	44.6
T_3	21.9	104.0	138.0	41.2	60.7
T_4	9.6	81.4	117.0	28.2	45.0
T_5	11.6	113.0	137.0	34.4	52.1
T_6	14.3	111.0	151.0	35.0	67.2
T_7	10.2	77.1	127.0	31.9	38.0
T_8	10.3	85.7	100.0	46.5	53.4
T_9	149	124.0	156.0	48.1	71.9

TABLE XIX

NUTRIENT UPTAKE (Silicon) BY GRAIN AND STRAW

(Milligrams (SiO_2) per pot)

Treatments	30th day	60th day		90th day	
	Stalk	Stalk	Grain	Stalk	Grain
T_1	128	1120	1375	434	952
T_2	106	1162	2404	971	2184
T_3	131	1016	2278	949	1939
T_4	79	1009	2286	512	1776
T_5	84	1475	2703	1218	1330
T_6	91	869	2818	795	1722
T_7	115	859	1361	502	1788
T_8	117	1060	2958	1113	2615
T_9	88	1090	1721	592	1697

at 30th day, T_5 at the second period and T_9 at the final period. From this it can be inferred that at later atages non-silicate treatments exhibited the least uptake of calcium.

e) <u>Magnesium</u>: (Table XVIII)

Treatments 3, 9 and 9 - calcium magnesium silicate treatments - gave the maximum uptake of magnesium at the 30th 60th and 90th day harvest respectively.

f) <u>Silicon</u>: (Table XIX - Appendix V)

Silicon uptake was found to be positively correlated with nitrogen uptake in stalk at the first period (r = 0.926**) and calcium uptake at 60th day (r = 0.746*). Silicon uptake was also found to be maximum in sodium silicate treatments during second and final stage (Figures 9 to 11).

3. Grain:

a) <u>Nitrogen</u>: (Table XIV - Appendix V)

In general the uptake of nitrogen in grain was found to be highly correlated with silicon uptake at 90th day, r being 0.918***. High nitrogen uptake was recorded by silicate treatment (T_5) at 60th day while non-silicate treatment (T_1) recorded the least (Figure 9).

b) <u>Phosphorus</u>: (Table XV - Appendix V)

Correlation study of phosphorus uptake by grain with silicon uptake at the final stage was positively related, r being 0.757*. Calcium magnesium silicate (T_9) gave the maximum uptake of phosphorus at 60th day and 90th day while control (T_1) recorded the least (Figure 10).

c) Potassium: (Table XVI)

Sodium silicate treatments (T_2 and T_8) recorded the maximum uptake of K at 60th and 90th day respectively while treatment 1 gave the least value at both periods (Figure 11). This shows that sodium silicate influenced the uptake of potassium by paddy grain.

d) Calcium: (Table XVII)

Treatments with calcium magnesium silicate was found to influence the maximum uptake of Ca by grain at the 60th and 90th day. In both cases T_1 and T_7 recorded the least.

e) Magnesium: (Table XVIII-Appendix V)

Magnesium uptake by grain was found to be positively correlated with silicon uptake at 60th day (r = 0.728*). Treatment 9 recorded the maximum uptake of magnesium during the second and final period.

f) Silicon: (Table XIX - Appendix V)

Silicon uptake was found to be positively correlated with nitrogen uptake (r = 0.918***) and with phosphorus uptake (r = 0.757**) at the 90th day on the 60th day there was correlation between silicon and magnesium uptake (r = 0.728*) Sodium silicate treatment

TABLE XX

NUMBER OF SILICATED CELLS IN THE LEAF AND STEM AT MATURITY

Treatments	Leaf	Stem
T_1	40.0	25.3
T_2	40.7	49.3
T_3	39.7	40.7
T_4	32.3	30.0
T_5	40.7	40.3
T_6	40.0	48.0
T_7	39.3	32.7
T_8	45.0	42.7
T_9	44.8	42.0

(T_8) gave the maximum uptake of silicon at 60th and 90th day. In both cases treatment devoid of silicon gave the least uptake (Figure 9 to 11).

E. Other observations

Number of silicated cells.

a) Leaf: (Table XX)

The number of silicated cells in the leaf at maturity ranged from 32.3 (T_4) to 45.0 (T_8). The silica-included treatments had greater influence than those devoid of it, in producing the silicated cells in the leaf. Among treatments the sodium silicate treatment excelled others (Figure 6).

b) Stem: (Table XX - Appendices III and V)

The values observed varied from a minimum number of 25.3 recorded by T_1 to a maximum of 49.3 by T_2 (Figure 7). From the analysis of variance it was revealed that T_2 excelled all other treatments in producing the silicated cells in the stem. T_6 proved to be the next best. In all the other levels of nitrogen, the silica-included treatments proved to be significantly superior to those without silica in the formation of silicated cells. Among the silica-included treatments, sodium silicate treatment was found to be significantly better than calcium magnesium silicate treatment at 30 lb and 60 lb nitrogen levels.

TABLE XXI

BREAKING STRENGTH OF STEM AT MATURITY

Treatments	Wt. in Gms.
T_1	51.0
T_2	84.0
T_3	82.0
T_4	71.0
T_5	86.0
T_6	87.3
T_7	68.0
T_8	101.0
T_9	108.0

The number of silicated cells of the stem at maturity exhibited significant positive correlation with breaking strength of straw ($r = 0.861^{**}$) (Figure 12-B).

2. <u>Breaking strength of straw</u>: (Table XXI - Appendix IV)

From the observations recorded under this item, it was found that the straw obtained from T_9 exhibited the maximum breaking strength (108.0g) while those from T_1, proved to be the lowest (51.0g). The analysis of variance revealed that the silica-included treatments both individually and in combined effect proved to impart more strength to stem to resist breaking than the treatments devoid of silica. (Figure 5) At 30 lb and 90 lb nitrogen level the same trend was observed. T_9 was found significantly superior to T_1 and T_7 and so also T_8 was better than T_1.

The breaking strength of straw at maturity was found to exhibit positive correlations with the silica percentage and the number of silicated cells of the straw, the r values being 0.875^{**} and 0.861^{**} respectively (Figure 13-A)

CHAPTER V

DISCUSSION

The results obtained in this study are discussed below, with particular reference to the influence of silicon on plant behaviour, uptake of nutrients and resistance to lodging.

A. Effect of silicon on plant growth

1. Height

The beneficial effect of silicon on the growth of rice plants is clear from the increased height of plants grown with treatments containing silicon compared to treatments devoid of this nutrient which recorded the minimum plant height at all the three stages of growth. These results are in conformity with the findings of Onodera (1927), Sreenivasan (1936), Tahahashi (1961), Padmaja and Verghese (1964) and others. These workers, however, did not offer any satisfactory explanation for this behaviour. The increased growth shown by the silicon-supplied plants may be attributed to the improvement in moisture holding capacity as found by Gaussmen (1962) and/or to soil nitrification processes reported by Votkervich (1936).

2. Tiller Production

Data on tiller counts for the three stages of growth reveal that T_1 recorded minimum values. Though at the initial stage sodium silicate (T5) was better, the final counts proved calcium magnesium silicates to be the best treatment. The calcium magnesium treatment (T6) with 60 lb N produced the maximum number of tillers both at the 60th and 90th day harvests. Tahahashi (1961) and Mitsui and Tahahash (1963) reported better tiller production due to silicon application. The present study confirms their findings and further goes to show that calcium magnesium silicates as the carrier of silicon fares better than others in producing tillers. The improved tillering capacity observed may be the result of beneficial soil conditions brought about by the calcium magnesium ingredient present in the carrier.

3. Yield

a) Root: Better tillering can result from better root development. The calcium magnesium silicate proved to have better effect on root development. The beneficial effect of calcium and magnesium for the development of root system has been established by Tiedjims (1948) and Rothwell (1957). Result obtained by Gaussmen (1962) shows that silicon increased the growth of roots. The combined effect of these three elements in promoting the root system is reflected also in the present investigation. Treatments devoid of silicon gave the minimum yield of roots compared to calcium magnesium silicate treatments which proved to have better effect on root development throughout the growth of rice plant. As already stated, the calcium magnesium silicate might have improved the physical condition of soil allowing better development and spread of the root system.

2. Straw

The superiority of silicon-included treatments over no-silicate treatments is seen in the case of straw yield also. In all the three harvests the minimum weight of straw recorded was from treatment devoid of silicon. Though calcium magnesium silicate recorded higher values than sodium silicate, the increase was not statistically significant. Analysis of variance of the data shows that sodium silicate at all the three levels of nitrogen proved superior to control and that calcium magnesium silicate treatments showed significant increase over control only at 60 lb and 90 lb nitrogen level. From these observations it can be gathered that the influence of silicate treatments on straw yield is more pronounced at the higher levels of nitrogen. This is in concordance with the findings of Ishibashi and Hayakawa (1939). The increase in straw yield observed may be due to the enhanced nitrification and better utilisation of nitrogen in presence of silicates.

3. Grain

From the mean values of grain yield as well as from the analysis of variance it can be inferred that the silicate treatments proved superior to treatments without silicon. Sodium silicate treatments registered higher values at both the harvests, though its superiority over calcium magnesium silicate is not statistically significant. The beneficial effect of silicon in increasing the grain output was recorded as early as 1889 (Wolff and Khentzhage). Later workers have contributed evidence in support of this. Money (1964) and Padmaja and Verghese (1964) have in their recent work further confirmed these findings. Various hypotheses have been put forward to explain this behaviour. Among them may be mentioned increased phosphorus availability, enhanced nitrification and improved soil physical conditions.

At 90 lb nitrogen level both sodium silicate and calcium magnesium silicate treatments had significant influence in increasing the grain output over the control. Statistical interpretation of the data further revealed that these two treatments when combined had also the same effect. This effect of silicate in increasing grain yield was noted even at the highest level of nitrogen tried.

B. Effect of silicon on the uptake of nutrients

<u>Nitrogen</u>

Data on nitrogen uptake by roots reveal that the uptake was maximum in calcium magnesium treatment (T9) at all the three growth periods, while the minimum values were those of treatment devoid of silicon. This goes to show that silicon has a definite role not only in increasing availability of nitrogen but also in its uptake by plant roots.

In the case of straw sodium silicate treatment at 60 lb nitrogen level is found to have the maximum effect on the nitrogen uptake in the second and final cuttings. The no-silicate treatments had little influence on the nitrogen uptake even at 90 lb nitrogen level. Similar results were reported by Okamota (1959). The effect of silicon on the nitrogen uptake is further evidenced from the positive correlation it exhibited with silica uptake at the initial and final stages in the present study.

The uptake of nitrogen in grain followed the same trend exhibited by straw and root, the silicate treatments improving the uptake better than non-silicate treatments. A linear relationship is found between the nitrogen and silicon uptake at the final stage, the correlation being significant even at 0.1 percent level. All these observations show that silicon application improves the quality of grain since the higher nitrogen uptake would mean corresponding increase in protein content - an observation in conformity with the views of Kido (1958) and Okamota (1959).

It may be recalled that the nitrogen uptake of straw at 60th day exhibited a negative correlation with silicon uptake. A possible explanation for this phenomenon may be the influence of silicon in translocating the assimilated nitrogen from the vegetative part to the panicle at the beginning of the reproductive stage.

2. Phosphorus

The straw obtained from silicon-included treatments was found to contain more phosphorus than the no-silicate treatments throughout the growth period. Though sodium silicate excelled in the initial stage, the lead was taken over by calcium magnesium silicate at the later stages. Many workers - vide Wolff and Kruzhage (1884), Hall and Morrison (1906) and others -

have contributed results in support of the beneficial influence of silicon application on phosphorus availabilit and uptake.

Various explanations have been put forward for the increase of phosphorus uptake by application of silicon. Gile and Smith (1925) opined that the increased phosphorus uptake may be due to the ability of silicon either to replace phosphorus or to make it more available by solvent action. Akhramako (1934) attributed a different reason. He suggested that silicon deposited on plant roots increases their ability to absorb phosphorus. A more feasible explanation seems to be that of Bastisee (1946) who was of the view that silicon application minimised phosphorus fixation by iron and alumina, thereby releasing available phosphorus.

Calcium magnesium silicate treatment (T9) produced grain of high phosphorus content both at 60th and 90th day while the non-silicate treatment (T_1) produced the lowest. The positive correlation exhibited by the phosphorus uptake with that of silicon at the final stage is clear evidence of the influence of silicon on the uptake of this plant nutrient. The fact that calcium magnesium silicate treatments produced grain of higher phosphorus content than sodium silicate can be attributed to the beneficial soil conditions condùcive for phosphorus uptake created by calcium and magnesium.

From the percentage values of phosphorus in grain and straw, it can be observed that as the maturity advances, the phosphorus percentage of straw decreases followed by a uniform increase of phosphorus in the grain. Similar results were obtained by Seetharam Rao (1962).

3. Potassium

The potassium uptake of straw was found to be pronounced by silicon application as evidenced from the better results exhibited by the silicon treated plants in the present study. Between the carriers, the sodium silicate proved to be superior. This can be explained by the relationship exhisting between sodium and potassium in their uptake and utilisation by plants. Utagawa and Kashima (1963) and Padmaja and Verghese (1964) recorded similar results.

The analysis of grain for nutrient uptake has revealed that the potassium uptake followed the same trend as that of straw, the sodium silicate treatment proving superior at both the stages of harvest. Okawa and Kinsaki (1937), Okamoto (1958) and Padmaja and Verghese (1964) were some of the previous authors who obtained the same results.

4. Calcium

The calcium percentage of straw increases with silicon application. At all the three periods of straw analysis, increased uptake of calicum in straw with silicic acid application were reported by Otagawa and Kashima (1963). The positive correlation observed in the present study between the silicon uptake and calcium uptake during the middle period of plant growth tends to show that increased silicon uptake was followed by a corresponding increase in calcium uptake. This may be the possible explanation that can be given for the increased calcium uptake by straw.

The calcium magnesium silicate treatments produced grains with maximum calcium content at both the stages, the non-silicate treatments producing the lowest. But the results obtained by Laws (1951) in his study on sudan grass are not in conformity with the above finding. He reported decrease in calcium percentage by the application of silicon. The increased uptake of calcium obtained in the calcium magnesium silicate treatment in this study may be attributed to the additional influence of calcium and magnesium besides silicon in enhancing the uptake of calcium.

5. Magnesium

Silicon-included treatments were found to produce straw with higher magnesium percentage. Among the carriers, calcium magnesium silicate proved to be better especially at higher doses of nitrogen. The higher levels of nitrogen improving the vegetative growth assisted by silicon in the translocation of magnesium might have resulted in the increased uptake of magnesium.

The calcium magnesium silicate treatment with 90 lb nitrogen predominated in the case of grain also in deciding the mangnesium uptake. The influence of silicon-included treatment in promoting the magnesium uptake by grain is evidenced by the positive correlation which silicon uptake exhibited with magnesium uptake, in the present study.

6. Silicon

The silicon application was found to be followed by an increased silicon uptake by the straw. The sodium silicate form proved to be the better among the carriers tried. The sodium silicate being easily soluble, might have paved the way for greater absorption and translocation into the shoot system. Results of a similar nature were presented by Schollenberger (1922), Okawa and Kinsaku (1937) Padmaja and Verghese (1964) and many others. The higher content of silicon in straw as a result of silicon application in soil has been proved by Mutsui et al (1961), tracing the pathway of translocation using Si^{31}.

Sodium silicate proved to be a better carrier of silicon for grain also with regard to silicon uptake.

It may also be noted that the silicon percentage of straw increases with maturity while that of grain decreases. This may be due to the decreased translocation of silicon to the panicle as the grain reaches maturity.

C. Effect of silicon on anatomical characters

1. Number of silicated cells

a) Leaf: The number of silicated cells in the leaf was found to be influenced by silicate application. In general, silicon-supplied plants produced leaves containing more of silicated cells. The effect was more pronounced at higher levels of nitrogen.

The sodium silicate form was found to be the better carrier in determining the number of silicated cells in the leaf. This may be attributed to the easy solubility of sodium silicate.

b) Stem: The influence of silicon in the production of silicated cells in the stem followed more or less the same trend as in the case of leaf, the sodium silicate proving to be the better form. However, in the present investigation no relationship was noticed between the number of silicated cells in the leaf and stem. The number of silicated cells of the stem at maturity exhibited positive correlation with the breaking-strength of straw. The deposition of silica in cells of stem might have offered resistance against breaking.

D. Effect of silicon on morphological characters

Breaking strength

From the values of breaking strength recorded, it can be seen that silicon-supplied plants produced straw with much greater strength than straw from treatments devoid of silicon. It is further shown that calcium magnesium silicate treatment (T_9) proved to be the best among the treatments. The positive correlation of the breaking strength of straw with silicon percentage and the number of silicated cells explains the importance of silicon application in preventing the lodging of rice. It is an established fact that the paddy crop tends to lodge at higher levels of nitrogen nutrition. But from the present study it is seen that the application of silicon can prevent lodging even at higher doses of nitrogen. Similar results were obtained by Davey (1798) and Liebig (1840).

E. Salient Findings

From the above discussion of the results obtained in the present investigation, it is seen that silicon nutrition of rice has brought about many beneficial effects. The yield of roots, straw and grain is considerably increased. Greater production of roots and stubbles (from the straw) would eventually leave a soil richer in organic matter with all the added benefits which organic matter is capable of inducing. The crop is more resistant to lodging. Further, there is a greater uptake of essential plant nutrients like nitrogen, phosphoric acid, potash, lime and magnesia, the overall effect being the production of higher quantities of grain and straw of better nutritive value. Silicon nutrition may therefore be recommended as one of the methods of increasing the output of rice of better quality.

However, the mechanism which brings about this change is a highly controversial subject and still not understood. It may also be noted that apart from the availability of nutrients in the soil solution, nutrient uptake by plants depends not on a single mechanism but on an interaction of several processes combined with metabolic utilisation of nutrients, the final result being the overall effect of these inter-related mechanisms.

Such being the case, future work is necessary to study the mechanism responsible for bringing about the desirable effects observed by supplying the rice crop with readily available silicates.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The role of silicon in the absorption and translocation of nutrients by rice plant is varied and its effect on increasing the strength of straw is contraversial.

In recent years bumper rice yields have been obtained by judicious fertilisation with major nutrients. The response however was found to be sporadic and confined to particular rice regions. This may partly be due to the continuous removal of the secondary and trace elements by crops season after season and year after year, without adequate replenishments and the starved soil depleted of these nutrients eventaally fails to show any marked response to the major trio.

High nitrogen nutrition produces a crop with profuse growth, which at the same time becomes more succulent and tends to lodge. When phosphorus fertilisation is attempted, the major portion of this nutrient gets fixed and becomes unavailable to plants under the acid soil conditions prevailing in the Kerala State. Due to high rain fall obtained in the State the lime status of its soil is very poor and the rice crop invariably responds very well to liberal applications of lime. With the above picture of rice nutrition with particular reference to the Kerala State in view, a pot culture experiment was laid out with Completely Randomised Design to assess the effect of different forms of silicon applied with various levels of nitrogen on nutrient uptake, growth and yield attributes of the rice crop.

The treatments were No silicate, sodium silicate and calcium magnesium silicate both at 100 lb SiO_2 per acre. These three treatments were given nitrogen at three levels viz. 30, 60 and 90 lb per acre. Phosphoric acid and potash at 30 lb P_2O_5 and 30 lb K_2O per acre were applied as basal dressing.

Soil sample used for the study was analysed for chemical constituents, mechanical composition and physical properties.

Periodical observation of plant behaviours such as growth measurements and tiller counts as well as yield of roots, straw and grain were made. Chemical analysis of various parts of rice plant were carried out at three stages corresponding with the vegetative phase, flowering stage and final stage of maturity. From the analytical values obtained the uptake of Nitrogen, Phosphoric acid, Potash, calcium and magnesium in the different plant parts were computed.

The uptake of silica was also assessed so as to evaluate possible influence on the uptake of the other nutrients during the different phases of crop growth.

At the final stage of maturity, the breaking strength of straw was determined. Silicated cells in the leaf and stem tissues were counted so as to examine whether they have any definite influence in the development of resistance to breaking.

Silicate nutrition was combined with high levels of nitrogen to study the role of silicon in preventing lodging usually associated with heavy nitrogen application.

Correlations were worked out to enumerate the relationship between silicon uptake and that of other plant nutrients.

Analysis of variance of yield of straw, grain, number of silicated cells in the leaf and stem and breaking strength of straw was carried out and the effect of treatments on yield and yield attributes were assessed.

Conclusions

The following were the conclusions drawn from the present studies in the light of observations made, statistical evaluation of data and correlations worked out.

1. The growth measurements recorded revealed the beneficial influence of silicon in promoting growth as assessed by increased height.

2. The tillering capacity of rice plant is observed to be improved by silicon application. Sodium silicate treatment proved better at the initial stage but calcium magnesium silicate took the lead at later stages especially at 60 lb nitrogen level.

3. Application of silica is found to provide a better condition for root development.

4. The straw yield obtained from silica-treated pots were higher than in non-silicate treatments thereby establishing the influence of silicon in promoting straw yield. The influence of silicon on straw yield is better at higher levels of nitrogen.

5. Sodium silicate as well as calcium magnesium silicate have the capacity to increase the grain output. In the presence of these silicates the response of grain yield to higher levels of nitrogen is more marked.

6. The application of silica promotes the availability of nitrogen manifested in the increased uptake of nitrogen by plant roots. Calcium magnesium silicate treatment proved to be the best at all the three levels of nitrogen tried.

7. Silicon promotes the uptake of nutrients by straw. The application of nitrogen alone even at 90 lb nitrogen level did not produce any appreciable increase in the nitrogen uptake while the same treatment in conjunction with silicon proved definitely superior.

8. The observed increasing uptake of silicon by straw and grain is followed by a proportionate increase of nitrogen uptake at maturity.

9. The protein content of grain is seen to be enhanced by silicon application.

10. Silicon encourages the translocation of assimilated nitrogen from the vegetative part to the panicle at the flowering stage.

11. The role of silicon in influencing the availability of soil phosphorus is evidenced from the increased uptake of phosphorus by straw obtained from silica-treated parts.

12. Though sodium silicate was found to be the better carrier in the initial stage, the calcium magnesium silicate proved to be superior at the later stages in improving the uptake of phosphorus by straw.

13. Phosphorus content of grain also increased by silicon manuring, calcium magnesium silicate claiming to be the better form.

14. As the maturity of crop advances, the phosphorus percentage of straw gradually decreased while that of grain registered a uniform increase.

15. Fertilisation with silica especially as sodium silicate is found to result in enhancing the uptake of potassium by straw and grain.

16. Calcium and magnesium uptake of straw and grain is noted to be governed by application of silicon. The effect is more pronounced with calcium magnesium silicate.

17. Soil application of silicon particularly as the more soluble sodium silicate form has resulted in an increased uptake of silicon by straw and grain.

18. There is a continuous absorption of silicon during the life of the plant upto grain formation stage after which the silicon content of straw increases while that of grain shows a gradual decrease.

19. The number of silicated cells in tissues of leaf and stem increases when silicon is included; sodium silicate proved to be the better form.

20. The morphological character of rice plant is found to be modified by silicon application. The increased number of silicated cells and enhanced

silicon content of stalk obtained by silicon nutrition has resulted in the production of straw capable of withstanding lodging to a great extent.

Thus the present investigation revealed that silicon nutrition of rice at the rate of 100 lb SiO_2 per acre brings about various beneficial effects, the more important ones of immediate practical utility being increased yield, increased nutrient content of both grain and straw and increased capacity of the crop to withstand lodging even when manured with 90 lb nitrogen per acre.

REFERENCE CITED

ADYANTAYA, N.R. RANGASWAMY, S. — 1952 — Distribution of silica in relation to resistance to 'Blast' desease in rice. Madras Agric. J., 34 (3) 198-203

AKHRAMAKO, A.I. — 1934 — Influence of silicic acid upon the utilisation of phosphoric acid by the plants from various sources. Bibliography of the literature on minor elements 1: Educational Bureau Inc. 120, Broadway, New York.

ANONYMOUS — 1963 — Annual report of the International Rice Research Institute, Phillipines: 99-100

ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMIST — 1955 — Methods of Analysis. U.S.A.

BASTISSE, E.M. — 1946 — Theoretical and Practical condition that maintain the assimilability of Phosphoric acid in laterite soil. Ann. Agnom: 16, 463-475 Silica in plants Bibliography of the literature on the minor elements. 3; 1953. Educational Bureau Inc. 120, Broadway, New York.

BASTISSE, E.M. — 1952 — Silico Phosphate Potassium fertilizing Ann. Agrom. 3: 111-123

BIRCH, H.F. — 1948 — Soilphosphate - A review of literature The PlantersChronicle XI 113: 23, 574-178

BRENCHLEY, W.M. MASKEL, E.J. and WARRINGTON, K. — 1927 — The interaction between silicon and other nutrient in plant Ann. appl. Biol. 14: 1, 45-82

*BRUCKMANN, G. — 1958 — Control Measures against mildew in different varieties of barley, their efficacy and effect on mineral composition Zpflkramkli 65. 689-93

CONNER, S.D.	1962	Factors affecting the availability of alumina in soi J. Ammer. Soc. Agrom. 25: 735-38
*DATTA, N.P., SHIND, J.E., KAMATH, M.D., and DATTA, S.K.	1962	Effect of sodium silicate on the uptake of soil and fertilizer phosphorus by wheat, rice and berseem. Indian J. agric. Sci. 32; 219 - 227
DE SAUSSRE	1804	Sand Ver suchhsslationmen 30. 161-188 as cited by Hall and Morrison. Proc. of Royal Society London 455-474-1864
*DAVEY SIR HUMPHRY	1798	Elements of Agricultural Chemistry 53 Quoted by Ramaswamy 1963 Madras Agric. J., 50 11 413-425 1963
DAVIDSON, J. and LECLERE, J.A.	1923	Effect of various inorganic compounds applied at different stages of growth on yield, composition and quality of wheat. J. Agric. Res., 23 56-59
*DAVIDSON, J. and PHILIPS, M.	1930	Quoted by Ramaswamy 1963 Madras agric. J.50: (11)
*DOUGHLAS, A.F.K.	1916	Expt. Sta. Rec., 37: 443
FRITZ, W.	1940	The importance of silicic acid in the growth of some cultivat plant, their nutrient relation and their susceptibility to th mildew fungus Chem. abst. 34: 415
GAUSSMANN, W.	1962	Investigations on the effect of silica on the uptake of phosphorus and other nutrients Chem. abst. 59: 5724
GILE, P.L., and SMITH, J.E.	1925	Collidal silica and efficiency of phosphate J. Agric. Res. 31: 247-251

GOKHALE, G.P., KINLE, K.M. and NARAYANAN, K.	1954	Fertilization of a laterite soil with soluble phosphate and effect of soil amendments on phosphorus availability _J. Indian Soc. Soil Sci._ 2 141-147
GURMEL SINGH, and MANN, H.S.	1962	Effect of sodium silicate, farm yard manure and castor cake on maize crop 1. Influence on the soil property _Indian J. Agron._, VI: 4, 289
HADEEN, W.P.	1916	_Colo. Agric. Exp. Sta. Bull_, 219; 231
HALL, A.D. and MORRISON, C.G.T.	1906	On the function of silica in the nutrition of cereals Part I _Proc. Royal Soc. Series_ B. 5: 77, 455 - 477
HARTONG, B.D.	1940	The silicic acid content of malting barley _Herb. Abst._ 10. 2, 171
HOSODA, K., and TAKATA, H.	1957	Effect of calcium silicate on a paddy rice field on black soil _Field crop abst._ 2: 167-178 1959
ISHIBHASHI, H.	1937	Effect of silicon on the growth of cultivated plants. V. The effect of silicon on the growth of rice plants growing on soils of various depth. _J. Sci. Soil Tokyo_ 11: 539-549
ISHIBHASHI, H, and HAYAKAWA, H.	1939	The relationship between the effect of silica and nitrogen and silica and phosphorus in the nutrition of rice plant _J. Sci. Soil Tokyo_ 13: 227-242
ISHIBHASHI, H., and KAWANO, N.	1957	The effect of silicon on the growth of rice plants in water culture _Bull. Fac. Agric. Yamaguri Univ._ 8, 689-692

IZHIZUKA, R., and HAYAKAWA, H, 1951 Resitance to rice plant to rice blast disease and its relation to the silica and magnesium content
J. Sci. Soil Manure Japan 21: 253 - 260

JACKSON, M.L. 1962 The soil chemical analysis
Asia Publishing House, Madras.

JODIN, C. 1883 Land Versuchsslationnen 30. 161-1884 as quoted by Hall and Morrison. 1906

*JODIN, C. 1883 Quoted by Ramaswamy
Studies on lodging in cereals with special reference to rice- a review.
Madras Agric. J. 50 (11) 415-422

KANO, M. and TAKAHASHI, J. 1958 Selective absorption of silicon and calcium by tomato, rice plants.
J. Sci. Soil Tokyo 29: 63-66 (Part I)

KAWASHAMA, R. 1927 The intake of silica by rice plant with reference to blast disease
Quoted by Venkitachalam, S.
Madras Agric. J. XLI (9) 304-9 1954

KIDO, M. 1958 Physiological and ecological studies of rice plants in well drained and ill drained fields. IV differences in quality and ripening rice grains as affected by fertilizers
Proc. Crop Sci. Soc. Japan 26: 1958

*KNOP, W. 1862 Quoted by Ramaswamy.
Madras Agric. J. 50 (11) 415-22

KOBAYASHI, H., KAWAGUCHI, Y. and OTA, A. 1956 The effect of slag on paddy rice
Soil Plant food, 1: 45-6

LAWS, W.D.	1951	Water soluble silicate application to a calcarious clay soil and effect on soil properties and nutrient uptake by plants. Proc. Soil Sci. Soc. Amer. 1951. 15: 89-92
*LIEBIG, G.F.	1840	Quoted by Russel, E.W. Soil Conditions and plant growth Longmans Green and Co., Ltd., London.
*LIEBIG (PHILLIPS)	1936	Quoted by Ramaswamy, K.B. Madras Agric. J. 50 (11) 416-25 1963
LEMMERMANN, O. and WIESSMANN, H.	1922	The yield increasing action of silicic acid in the presence of insufficient phosphoric acid for plant nutrition Bibliography of the literature on Minor Elements. Educational Bureau Inc. 120, Broadway, New York.
LUNDIE, M.	1913	Is silica an indispensable constitutent of plant food? S. African Jour. Sci. 9-10: 263-268
MAC INTIRE, H. and SHAW, N.M.	1946	The property of certain calcium silicate to impart super-saturation of $CaCo_3$ to carbonate water extraction Science 104 4-4 1946
MARIAKULANDAI, A.	1955	Improvement of phosphate availability in the laterite soils of the Nilgiris by application of silico phosphate J. Indian Soc. Soil Sci. 3: 15-22
*MAYER, A.	1901	Quoted by Ramaswamy, K.B. Madras Agric. J. 50 (11) 416-25
*MEMMIT, S.	1933	Relationship of Environmental factors to the occurrence and severity of blast disease in plant.

		Phytopath, Z. Tschr 6 305-324 Annotated Bibliography of rice soil and Fertilizers Edited by Jacks B.V. and Milne, M.K. 1954
/MITSUI, S. and TAKATOHU, M.	1906	Growth of plants without silica and symptoms of silica deficiency. Jour. Sci. Soil Tokyo 30 535-539
MITSUI, S., HIROSHI, R. and TAKATO, K.	1961	Preparation of Si^{31} and its utilization for the valuation of silicon in crops. Chem. Abst. 57 17096-1962
/MITSUI, S. and TAHAHASHI, Y.	1963	Nutritional study of silicon graminaceous crop. J. Sci. Soil Tokyo. 21: 86, 117
MITSUI, S. and TAKATAHU, L.	1963	Preparation of P^{32} and its utilization for the evaluation of phosphorus in crops. Chem. Abst. 57: 17096
MIYOSHI, H. and /ISHI, H.	1960	Effect of silicic acid and silicic slag on paddy rice IV. Effect of silicic acid on the Phosphate metabolism of paddy rice. Soils and Fert. 24: 5, 136-7
MONEY, N.S.	1964	Paper read at the conference of State Agricultural Chemists, 1964
OKAMOTO, Y.	1957	Effect of silica supplied at various stages of growth Pro. Crop Sci.Soc. Japan 25 11-16
OKAMOTO, Y.	1959	Physiological studies on the effect of silicic acid on rice plant. Pro. Crop Sci. Soc. Japan 27: 1-2
OKAWA, A. and KINSAKU	1936	The physiological action of silicic acid on plant. Bibliography of literature on minor elements Vol. I

Educational Bureau Inc. 120 Broadway, New York.

OKUDA, A., and TAKAHASHI, E. 1961 Effect of various amount of silicon supply on the growth of rice plant and its nutritional uptake J. Sci. Manure Japan 32 (11) 533-537

OKUDA, A., and TAKAHASHI, E. 1962 The physiological role of silicon in crop plants. VIII Examination of specific behaviours of low-land rice as regards silicon uptake. J. Sci. Soil Tokyo 33: 217-221

ONODERA, J. 1927 Chemical studies on rice blast disease. J. Sci. Agrl. Sci. 108 106

OKWARA, A., and TANAKA, T. 1940 Study on silicate deficiency of rice plant. J. Chem. Soc. Japan 62: 1243-1250

OMER, N. 1934 Physiological role of silicon rye, barley and wheat. J. Sci. Soil Tokyo 9: 261-268

OTA, A., and KOBAYASHI, B. 1957 Effect of some sugar and organic acid on the silicon uptake of rice J. Sci. Soil Tokyo 34: 114-119

PADMAJA and VERGHESE 1964 The effect of calcium magnesium and silicon on productive factors and quality of rice. Thesis submitted to University of Kerala.

PIPER, C.S. 1950 Soil and Plant Analysis Interscience Publishers, New York, 1950.

PHILLIPS, M. 1936 Studies on lignin in wheat straw with reference to lodging J. Agric. Res. 43: 619-626

RAMASWAMY, K.R. 1963 Studies on lodgings in cereals with special reference to Rice - a review. Madras Agric. J. 50: (11) 413-425 1963

ROTHWELL, D.F. 1957 The effect of lime on root distribution. Soil crop Sci. Soc. Fla. Proc. 17: 67-71

SACHS, R. 1882 Cited by Schollenberger Agrl. Expt. Stat. OHIO Soil Sci. 14: 3147 - 382

SCHOLLENBERGER, C.J. 1922 Silica and silicate relation to plant growth and composition. Soil Sci. 14 347-362

SCHOLLENBERGER, C.J. and DREIBELBIS, F.R. 1930 Determination of cation exchange capacity by using neutral ammonium acetate. Soil Sci., 30: 161

SREENIVASAN, A. 1936 Investigation on the role of silicon in plant nutrition Part IV effect of silicate fertilization in the growth and yield of rice plants. Proc. Indian Acad. Sci. 3B; 302-309

SREENIVASAN, A. 1938 Some aspect of nutrient requirement of rice plant. Proc. Soc. Biol. Chem. India 3: 84 - 85

SUBBIAH, B.V., and ASIJHA, C.L. 1956 A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci. 25: 259-260

SUBBIAH PILLAI, M. and PARASURAM, M.A. 1956 Rice News Tiller, 4:2:71

*SWEEICKI (PHILLIPS) 1936 Quoted by Ramaswamy, K.R. Madras Agric. J. 50 (11) 413-425 1963

SEETHARAM RAO, V. 1962 Uptake of nutrients by rice plant in relation to growth The Andhra Agric. J. IX (5) 255-274

TAHAHASHI, R. 1961 Study on silicon as a promoter of rice crop J. Sci. Soil Tokyo 22: 31-34

*TAKYIMA, V., SHIOJUNA, M. and KONNO, M.	1959	Studies on soils of peaty paddy fields XI. Effect of silicon on the growth of rice plant and its nutrient absorption. Soil and Fert. 24: 1, 181-4, 1961
TIEDJENS, V.A.	1948	How much lime should we use? Truck Expt. Sta. Norlock. Bett. crops. 37: 7
UTAGAWA, I., and KASHIMA, K.	1963	The physiological function of silicic acid applied to rice and wheat. I Effect of silicic acid on the movement of mineral nutrient from leaves, stalk and roots to the ears. Bull. Fac. Agric. Kagashima Univ. 13: 116-165
UTAGAWA, I., and KIYOTO, K.	1963	The physiological function of silicic acid applied to rice and wheat. II Effect of silicic acid on movement of carbohydrates assimilated from leaf blades, leaf sheats and stalks and roots to ears. Bull. Fac. Agric. Kagosilima Univ. 13, 136-154
VENKATACHALAM, S.	1954	The intake of silica by the rice plant with reference to blast disease. Madras Agric. J., (XLI)(a) 304-310
VOLK, R., KAHN, R.P. and WEINTRAUB, R.L.	1957	Silicon content of rice plant as a factor influencing its resistance to infection by Piricularia Oryzae. Phytopathology 47: 35
VOTKEVICH, S.V.	1936	The effect of silica acid on plant development. Bibliography of the literature of mineral elements. Educational Bureau Ins. 120 Broadway, New York.
WELTON, F.A. and MORRIS, V.H.	1931	Ohio Agrl. Expt. Sta. Ohio., Wooster, Bull., 47
WALKLEY, A. and BLACK, I.A.	1934	Soil Sci. 34: 29-38

WOLFF, E. and KREUZHAGE, C.	1884	Land Versuchsslationnen 30: 161 as quoted by Hall and Mörrison - 1906
YOSHIDA, O., OUISHI, K. and KITAGHISHI, L.	1962	Chemical forms, mobility and deposition of silicon in rice plant. Soil Sci. Pl. Natri. 8(3) 15-21
*YUDIN, F.A.	1958	Increasing the effectiveness of phosphate by lime and blast furnace slag on different type of soil Tzv Timviyagar Kihakux No.3: 127-136

* Original not seen

APPENDIX I

ANALYSIS OF VARIANCE OF STRAW DURING THE FINAL STAGE OF CROP GROWTH

Source	F.
Sodium silicate x CaMg silicate	-
Sodium silicate x No silicate	6.35*
CaMg silicate x No silicate	5.58*
Sodium silicate and CaMg silicate x No silicate	8.45*
Sixty lb nitrogen x ninety lb nitrogen	7.09*
Sixty lb nitrogen x thirty lb nitrogen	2.49
Ninety lb nitrogen x thirty lb nitrogen	2.21
Sixty lb nitrogen and ninety lb nitrogen x thirty lb nitrogen	3.13

Conclusion:

Critical difference: 5.59

T_6 - T_1 *

T_9 - T_1 *

T_2 - T_1 *

T_5 - T_1 *

T_8 - T_1 *

* Significant at 5 per cent level

APPENDIX II

ANALYSIS OF VARIANCE FOR YIELD OF GRAINS DURING THE FINAL STAGE OF CROP GROWTH

Source	F.
Sodium silicate x CaMg silicate	-
Sodium silicate x No silicate	4.20
CaMg silicate x No silicate	4.31
Sodium silicate and CaMg silicate x No silicate	5.68*
Sixty lb nitrogen x Ninety lb nitrogen	0.0026
Sixty lb nitrogen x Thirty lb nitrogen	1.69
Ninety lb nitrogen x Thirty lb nitrogen	1.58
Sixty lb nitrogen and ninety lb nitrogen x thirty lb nitrogen	3.53

Conclusion:

Critical difference : 5.83

T_8 - T_1*

T_8 - T_7*

T_9 - T_7*

* Significant at 5 per cent level

APPENDIX III

ANALYSIS OF VARIANCE FOR THE SILICATE CELLS IN THE STEM

Source	F.	
Sodium silicate x CaMg silicate	0.00063	
Sodium silicate x No silicate	47.19	**
CaMg silicate x No silicate	47.19	**
Sodium silicate and CaMg silicate x No silicate	62.38	**
Sixty lb nitrogen x Ninety lb nitrogen	0.0004	
Sixty lb nitrogen x Thirty lb nitrogen	0.0056	
Ninety lb nitrogen x Thirty lb nitrogen	0.00063	
Sixty lb nitrogen and Ninety lb nitrogen x Thirty lb nitrogen	0.0013	

<u>Conclusion:</u>

Critical difference: 7.59

T_2 - T_1 *

T_2 - T_3 *

T_2 - T_7 *

T_2 - T_8 *

T_6 - T_1 *

T_6 - T_4 *

T_6 - T_5 *

T_6 - T_7 *

** Significant at 1 per cent level

APPENDIX IV

ANALYSIS OF VARIANCE FOR THE BREAKING STRENGTH OF STRAW

Source	F.
Sodium silicate x Ca Mg silicate	5.904 *
Sodium silicate x No silicate	6.523 *
Ca Mg silicate x No silicate	7.698 *
Sodium silicate and Ca Mg silicate x No silicate	9.465 **
Sixty lb nitrogen x ninety lb nitrogen	1.059
Sixty lb nitrogen x thirty lb nitrogen	12.732 **
Ninety lb nitrogen x thirty lb nitrogen	3.499
Sixty lb nitrogen and ninety lb nitrogen x thirty lb nitrogen	2.449

<u>Conclusion:</u>

<u>Critical difference</u>: 38.472

T_9 - T_1 *

T_9 - T_7 *

T_8 - T_1 *

* Significant at 5 per cent level

** Significant at 1 per cent level

APPENDIX V

CORRELATION COEFFICIENT FOR DIFFERENT RELATIONSHIPS STUDIED

S.No	Relationship	No of pairs of observation (n)	Correlation Coefficient
	A. Relationship between nutrient content of straw		
1	Silica percentage : 30th day Vs nitrogen percentage 30th day	8	0.963 ***
2	Silica percentage : 90th day Vs phosphorus percentage 90th day	8	0.776 **
	B. Relationship between nutrient uptake of straw		
3	Silica uptake : 30th day Vs nitrogen uptake 30th day	8	0.926 ***
4	Silica uptake : 60th day Vs nitrogen uptake 60th day	8	-0.7104 *
5	Silica uptake : 90th day Vs nitrogen uptake 90th day	8	0.7208 *
6	Silica uptake : 60th day Vs calcium uptake 60th day	8	0.746 *
	C. Relationship between nutrient uptake of grain		
7	Silica uptake : 60th day Vs Magnesium uptake90th day	8	0.728 *
8	Silica uptake : 90th day Vs nitrogen uptake 90th day	8	0.918 **
9	Silica uptake : 90th day Vs phosphorus uptake 90th day	8	0.757 *

APPENDIX V (CONTD.)

D. Other relationships

10	Silica percentage in stem : 90th day Vs breaking strength 90th day	7	0.875	*
11	Number of silicated cells in stem : 90th day Vs breaking point strength 90th day	7	0.861	*
12	pH of soil Vs conductivity of soil during crop growth	24	0.881	***

* Significant at 5 per cent level

** Significant at 1 per cent level

*** Significant at 0.1 per cent level

NITROGEN UPTAKE IN MILLIGRAMS PER POT

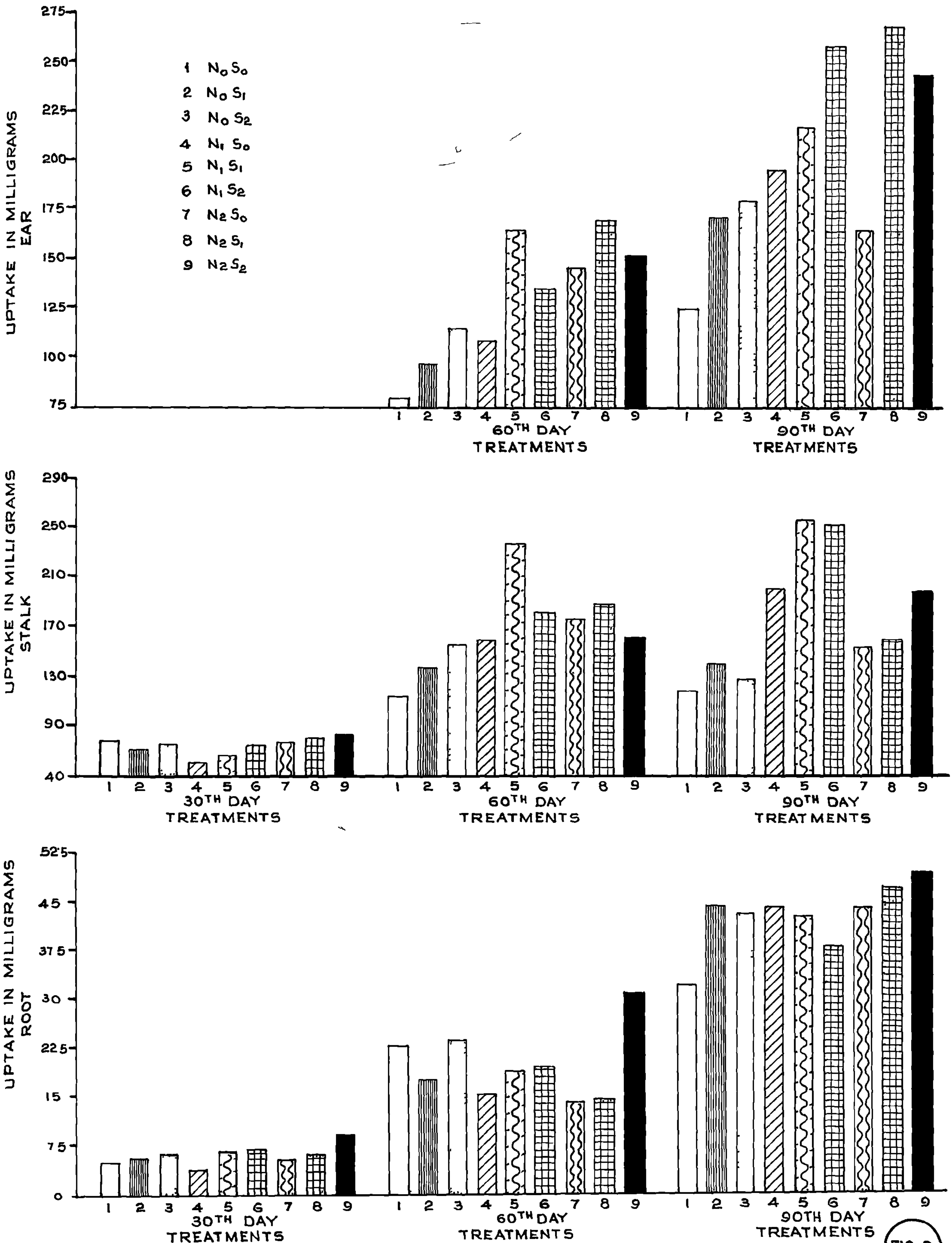


FIG 9

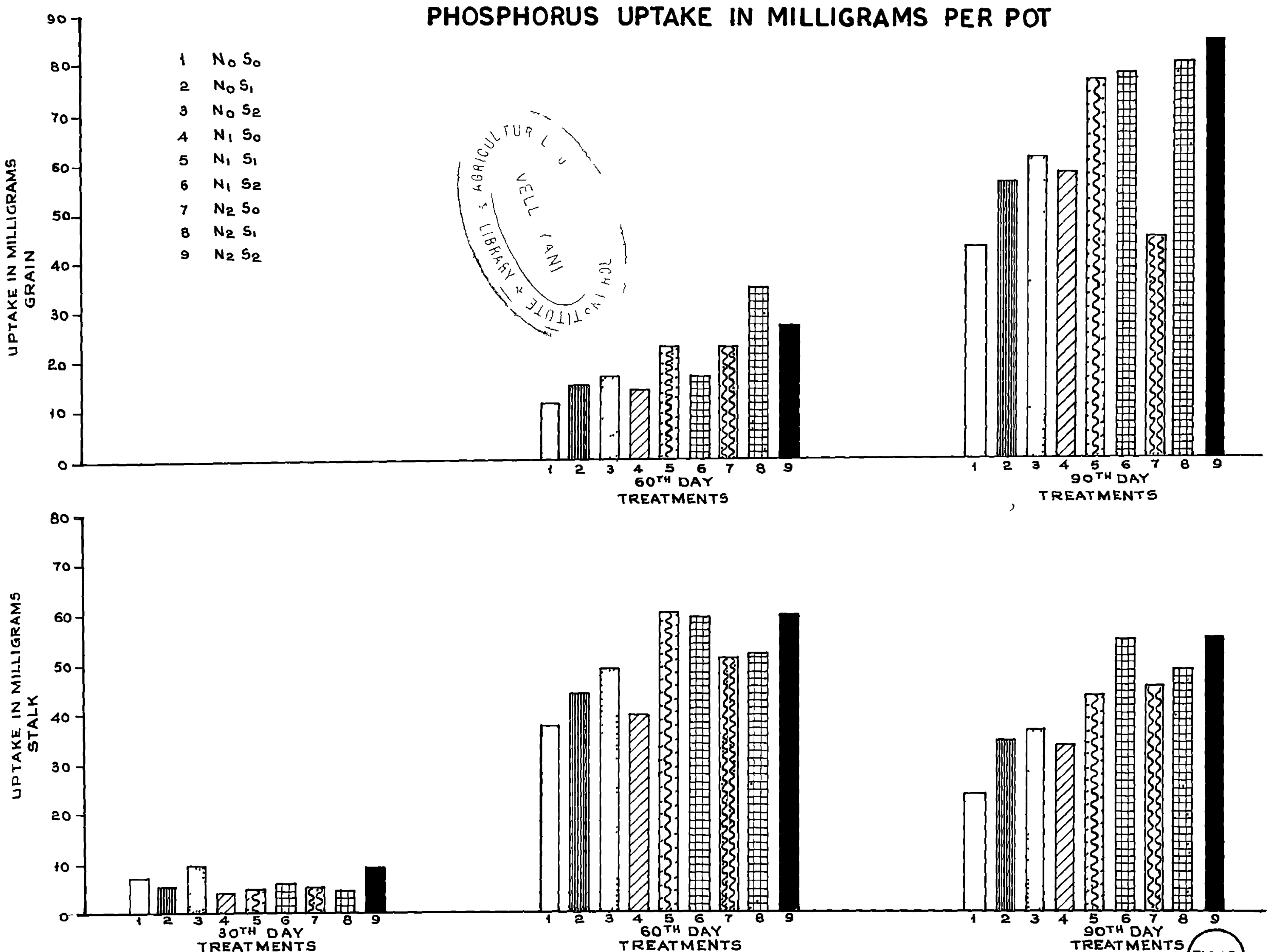

PHOSPHORUS UPTAKE IN MILLIGRAMS PER POT
1 N0 S0
2 N0 S1
3 N0 S2
4 N1 S0
5 N1 S1
6 N1 S2
7 N2 S0
8 N2 S1
9 N2 S2
UPTAKE IN MILLIGRAMS GRAIN
UPTAKE IN MILLIGRAMS STALK
0 10 20 30 40 50 60 70 80 90
1 2 3 4 5 6 7 8 9
30TH DAY TREATMENTS
60TH DAY TREATMENTS
90TH DAY TREATMENTS

FIG 10

POTASSIUM UPTAKE IN MILLIGRAMS PER POT

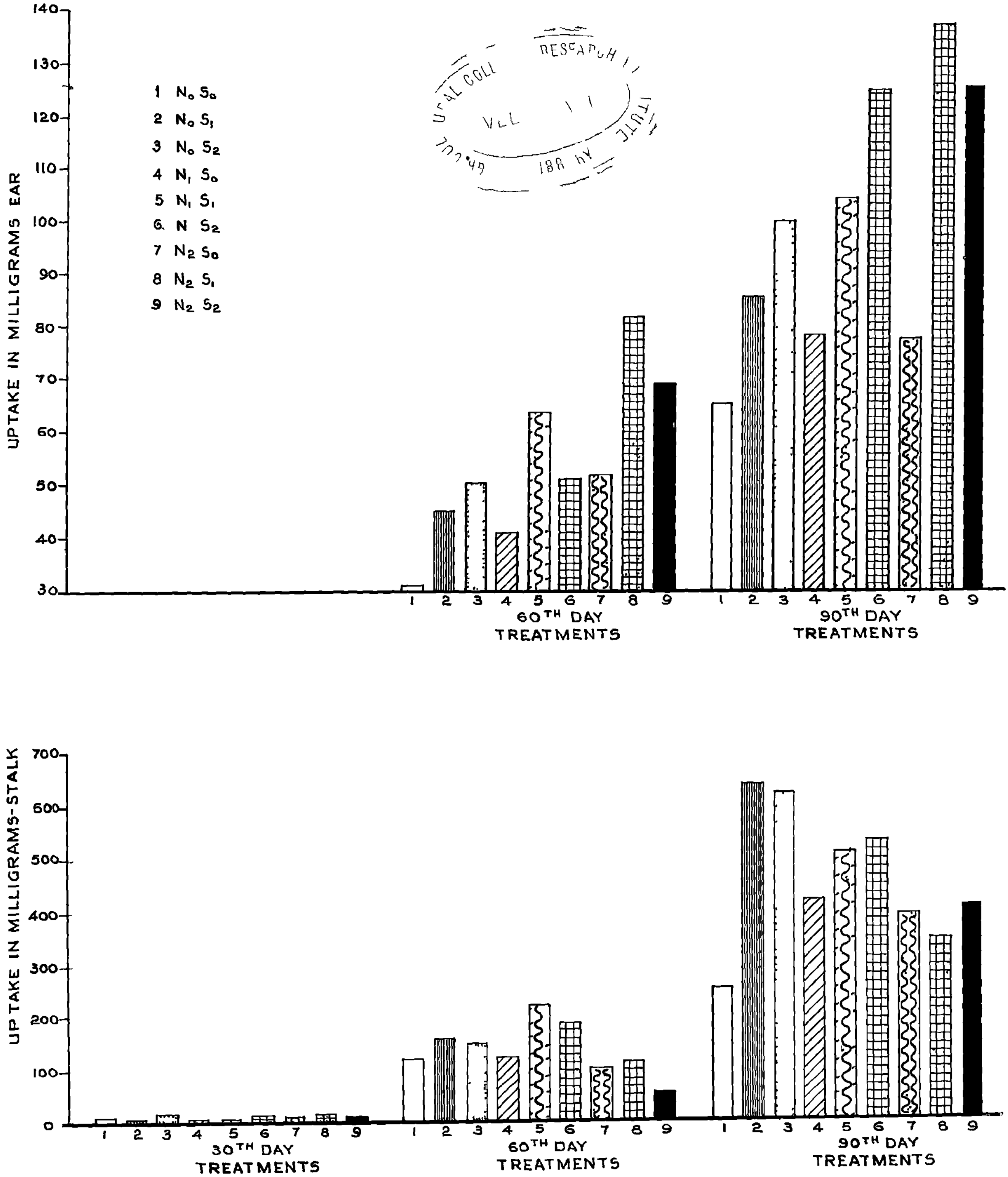
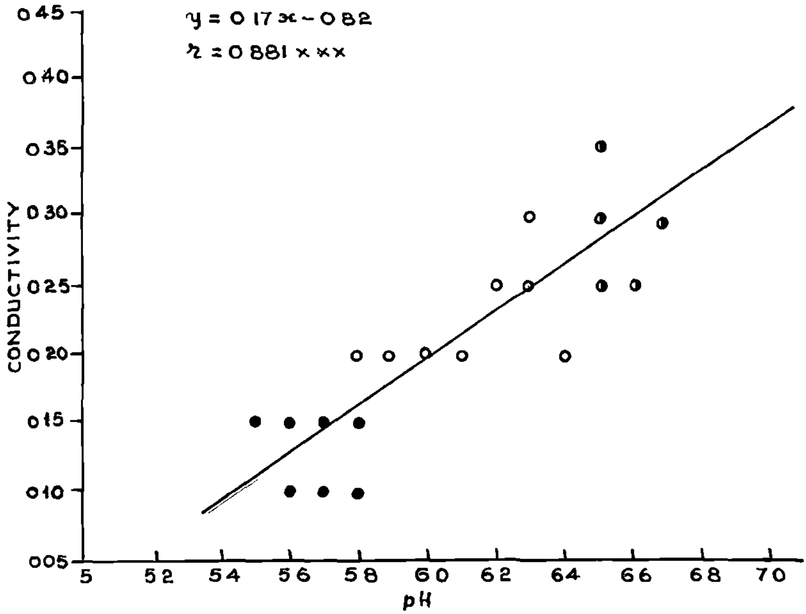


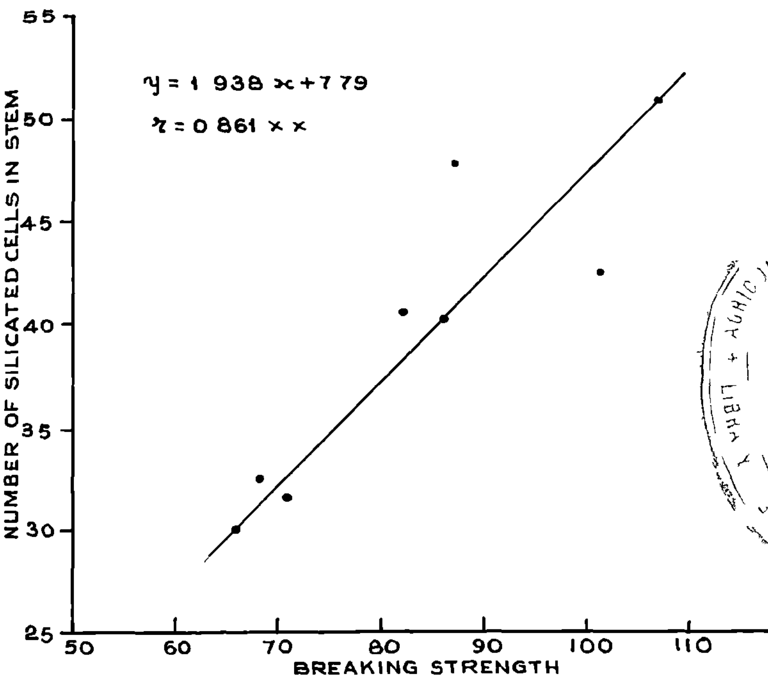
FIG 11

RELATIONSHIP BETWEEN pH AND CONDUCTIVITY DURING CROP GROWTH



(A)

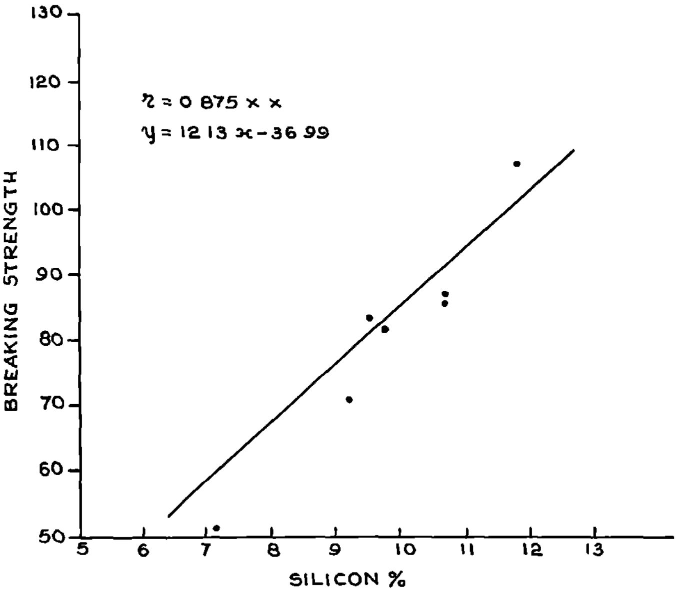
RELATIONSHIP BETWEEN No OF SILICATED CELLS AND BREAKING STRENGTH



(B)

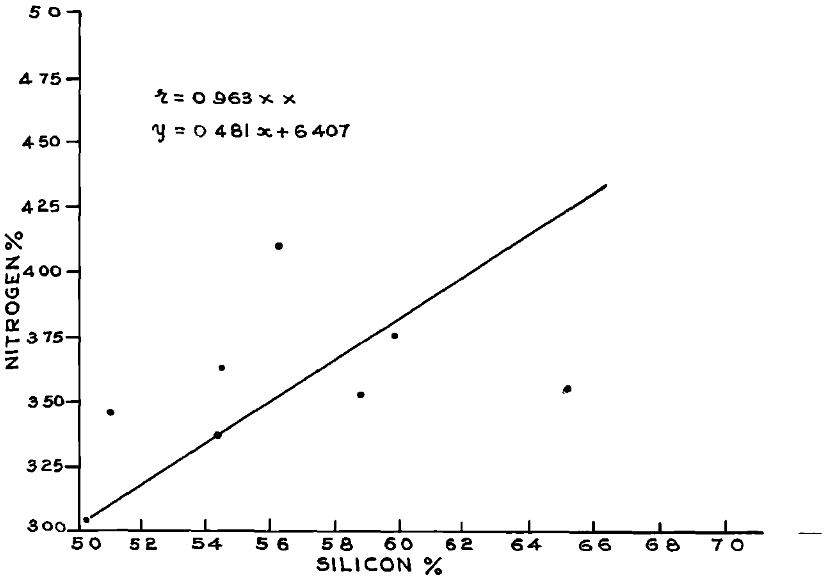
FIG 12

RELALIONSHIP BETWEEN SILICON%
AND BREAKING STRENGTH



(A)

RELATIONSHIP BETWEEN NITROGEN% AND SILICON% IN STRAW ON 30TH DAY



(B)

FIG 13

Fig.2 A GENERAL VIEW OF THE ARRANGEMENT OF POTS

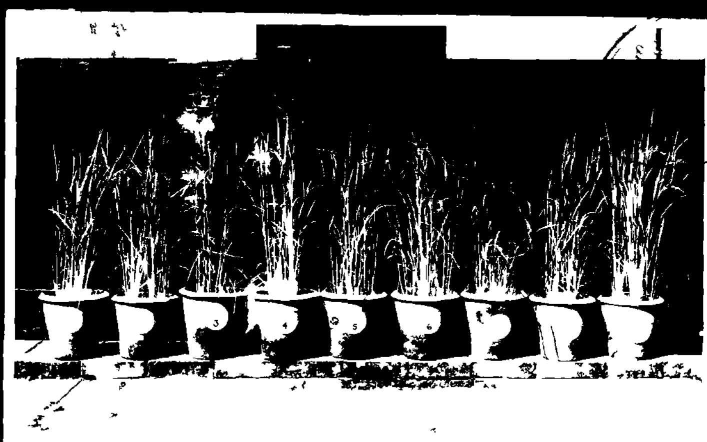


Fig.3 CROP PERFORMANCE OF VARIOUS TREATMENTS

Fig.4 CROP PERFORMANCE AT SIXTY LB NITROGEN LEVEL

Fig.5 EFFECT OF SILICON APPLICATION ON LODGING

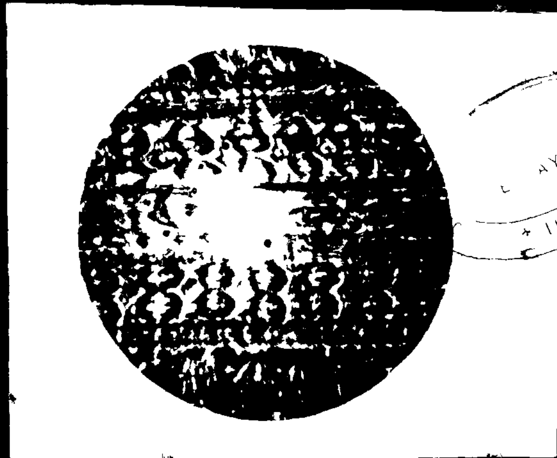


Fig.6 SILICATED CELLS IN THE LEAF EPIDERMIS

Fig.7 SILICATED CELLS IN THE STEM EPIDERMIS

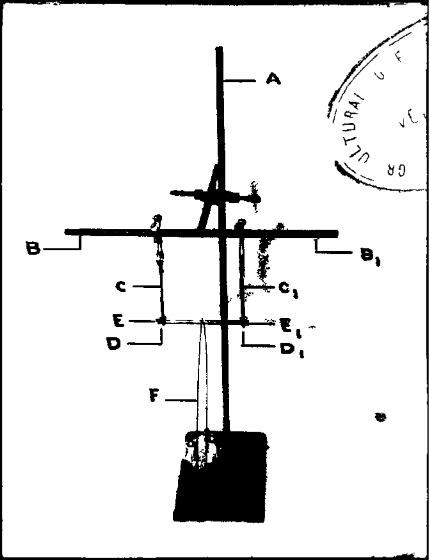


Fig.8 INSTRUMENT FOR DETERMINING THE BREAKING