STATUS OF AVAILABLE SILICA IN THE RICE SOILS OF KERALA STATE

BY

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THESIS

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CERTIFICATE

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

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INTRODUCTION

In the earth's crust silicon contributes over 27 per cent by weight of the elements present. Agricultural soils in general contain about 65 to 95 per cent of silica as silicon dioxide.

Plants normally contain comparativoly a high percentage of silicon and the essentiality of the element for plant growth has been widely discussed. Early physiologists believed that silicon strengthened the stems of cereals and grasses. Silicon, while it often impregnates the cell walls of certain plants and apparently renders them less liable to fungus infection and insect attack by virtue of the hardness of silicated cells, has not been considered essential for plant growth, because normal, healthy plants can be grown without it. However, Raleigh (1939) has obtained evidence which seems to indicate that silicon may have a more fundamental role in plant nutrition. Wagner's (1940) results with rice, barley, corn, tomatoes and several other plants are in agreement with those of Raleigh. Evidence, therefore, exists that plants are benefited by at least small quantities of silicon, but plant physiologists in general consider the essentiality of the element to be an unanswered question.

Silicon is beneficial to certain crops when the supply of phosphorus is limited. There is difference of opinion among workers as to whether silicon increases the availability of phosphorus in the soil or partially substitutes it in plants.

Among cereals, rice plant is considered to be a very heavy feeder of silica. In a recent report from the International Rice Research Institute, Phillippines, it has been emphasised that rice plants remove about 830 kg of silica per hectare.

However the total removal of silica by rice crop obviously depends upon the amount of available silica present in the soil, the types of changes that take place to applied silica and the grain and straw yields obtained. These naturally will vary among soil types. In Kerala, rice is grown mainly on base-unsaturated and partly desilicated laterite soils. It is also grown in river borne alluvial soils, peat soils, and reclaimed kayal soils in the Kuttanad area, and the black soils in the Palghat district. The possibility of enormous losses of silica from these soils by erosion and leaching exists. Therefore a study of the status and distribution of silica in the rice soils of the State, along with investigations on factors contributing to the plant-availability of native silica, was considered desirable.

The present investigation was undertaken with the following objectives.

i. To find out a suitable extractant for evaluating plant available forms of silica in soils.

ii. To study the status and distribution of soluble silica in the various soil types of Kerala.

iii. To evaluate the silica content of irrigation waters from different sources.

iv. To study the influence of soil characteristics on the availability of silica.

v. To investigate the plant-availability of added soluble silicate and their influence in solubilisation of native phosphorus.

vi. To study the influence of iron and aluminium on the availability of added silicates.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Silica is one of the major constituents of soils and plants. Clarke (1924) has placed silicon next to oxygen in the order of abundence in the earth's crust.

Considerable information is available regarding the chemical composition of rocks and that of soils derived from them. Though valuable, such information mainly centres around the ultimate products of weathering containing silicon, and the mechanism of their formation and transformation, has been realised.

SILICA IN SOIL

Though abundant, silicon exists in diverse forms, free or combined. In soils the total silica content varies widely.

Joffe (1949) quotes values over 95 per cent in the case of some coarse textured podzols composed mainly of quartz grains to less than 5 per cent in highly weathered laterites.

Sivaraja Singam et al (1962) reported that some laterite soils contain less than 1.0 per cent SiO_2.

Smithson (1956) reported various forms of crystalline silica viz., quartz, chalcedony and chalcedonite distributed over a wide range which on weathering are presumed to be available as a potential source of silicon in soil. But these are difficulty available and hence the most important form immediately available is considered to be the amorphous forms that are formed in soil as a result of weathering and mineralisation of plant residues containing high amounts of silica.

Amorphous forms.

Mattson (1930, 1931) in a series of papers has given much emphasis on the inorganic, colloidal, amorphous soil components. The iso-electric precipitation of the hydroxides of silicon, iron and aluminium in soils in relation to clay mineral formation has been extensively dealt with in these papers.

Various terms are being used by different authors to describe the amorphous forms present either free or combined.

Ross & Kerr (1934) used the term allophane for mixed gels of aluminium and silicon (Al_2O_3, 2 SiO_2, nH_2O) hisingerite for iron and silicon ($Fe_2O_3 2SiO_2 nH_2O$) and opaline as $SiO_2 nH_2O$.

Jackson (1956), based on the solubility of these amorphous forms, sub-divided the allophane group into unstable allophane, for those that are easily soluble in dilute acids and alkalies and stable allophane for those which are not dissolved by dilute hydrochloric acid at pH 3.5 or by 2 per cent sodium carbonate. The former is presumed to be formed due to the weathering of permeable volcanic ash and the latter as a weathering product of halloysite and kaolinite.

Mc Keague & Cline (1963), from adsorption studies of monosilicic acid, observed that these amorphous forms occur as a surface coating on ferric oxide and other substances. This was supported by the findings of Mehra & Jackson (1960) who observed high silica in the extracts of soil when treated for removal of free iron.

Smithson (1956) reported opaline silica as the common constituent in most of the grass land soils, probably released from plant residues by their decomposition.

Bezilevich et al (1954) estimated that opaline silica occurred to the extent of 1 to 2 percent in the fine sand and silt fractions of many soils.

Solubility of silica in soil.

Though identical in composition, quartz, cristobalite and opaline silica differ in their solubility due to the differences in their structure, surface activity and association with other ions.

Germer & Storks (1939) showed that the mechanism by which aluminium depresses the solubility of silica is by the formation of a coating of hydrated aluminium oxide around the silica particle. The reverse of the process is also possible but is of minor importance.

Iler (1955) found that there is a negative correlation between the density of silicate particles and their solubility in water and hence a decrease in the solubility was found in the order from opal through cristobalite to quartz. He found the solubility in water of quartz particles of sizes 10 m/u, 5 m/u and 3 m/u diameter as 28 ppm, 120 ppm and 930 ppm respectively. He further observed that the solubility of amorphous silica varied linearly with temperature.

Alexander (1957) also emphasised that different samples of amorphous silica may have some what different solubilities depending upon the particle size and the number of Si-OH group in the internal structure.

Alexander et al (1954) showed that the solubility of amorphous silica increases sharply with increasing alkalinity beyond pH 9 due to the formation of silicate ions. However, its solubility between pH 2 and 9 at a temperature of 20°C is independent of the pH of the medium. He also found that in soils where the pH was less than 9, silica existed in the monomeric form, $Si(OH)_4$, slowly polymerising to the colloidal form when the concentration of SiO_2 exceeds a certain limit at room temperature and near neutral pH.

Using soil solution systems Mc Keague and Cline (1963) observed that the concentration of silica in soil when extracted with solutions of varying pH was negatively correlated, and for a loam textured soil the silica content in the extract at pH value 5.2, 7.3 and 8.3 were

8.7, 2.7 and 1.5 ppm respectively. However, the same trend could not be observed in the case of aqueous extracts of different soils.

Raupach (1957) using Hutton's data on silica content of saturation extracts of a large number of Australian soils of varying texture, pH and other properties revealed that there was a decrease in the silica content with increasing pH, and the average content of silica between pH 6 and 9 were found to be 36 ppm and 6 ppm respectively.

Importance of moisture with respect to the release of silica in soil solutions was stressed by various research workers.

Mc Keague & Cline (1963) dealing with soil water system found that the concentration of silica in solution increased with increasing soil to solution ratio.

Effect of various other components of soil on dissolved silica.

King & Mc George (1938) found that the addition of a variety of oxides and hydrous oxides of polyvalent metal ions depressed the amount of soluble silica in solution.

Germer & Storks (1939) reported that the depressing effect of aluminium on solubility of silica was due to the formation of a coating of hydrated aluminium oxide around the silicious particles. This view was supported by KrausKopf (1956).

Mc Keague & Cline (1963) observed that hydroxides of polyvalent metals viz., Fe^{3+}, Al^{3+}, Ni^{2+} and Co^{2+} were effective in removing silica from soil solution and their effectiveness was found to increase with increasing pH upto 9. Thus a pH dependent adsorption reaction plays a major role in controlling the concentration of silica in soil solution.

Okamoto et al (1957) had also made similar observations. They found that aluminium at 20 ppm, the lowest concentration used, reduced the concentration of silica in solution from 35 ppm to 15 ppm when the pH was in the range of 8 to 9 and the silica in solution increased as the pH was above or below this range.

The above views is further supported by the work of Jones & Handreck (1965) who found that silica in soil solution is in the monosilicic form and addition of iron and aluminium oxides lowered the concentration of this form. However, they observed that aluminium oxide could reduce the concentration of silica in solution to a greater extent.

Siever (1962) found a reduction in solubility of amorphous silica in water due to adsorption of colloidal organic matter on their surface. This could be observed in peat soils.

A high concentration of dissolved silica in soils under poor drainage is reported by Ponnam Peruma (1955), the reason attributed being the liberation of silica following the reduction of iron existing in combinations with silica under anaerobic condition.

In the periodical estimation of silica and alumina in soils from a paddy field before and after stagnation, during growth period of rice, Uchiyama & Onikura (1955) found that there was a decrease in both SiO_2 and Al_2O_3 for the initial period of 15 days after stagnation followed by an increase of both for another 45 days and beyond this period SiO_2 concentration alone decreased.

The initial rate of decrease is according to him probably due to the formation of clays from the silica and alumina. The second stage of increase in both SiO_2 and Al_2O_3 is probably due to the weathering of minerals already present or newly formed ones. The reduction of SiO_2 alone in the subsequent period was attributed to the possible alteration of SiO_2 into insoluble forms, crystobalite or quartz.

Biological influence on the solubilization of silica in soils is also of importance and this has been dealt with by various workers.

Jacks (1963) has stressed the important role of plant root excretions in the weathering of silicates.

Rovira (1962) found that the major constituents of root exudations are various amino acids, tannic acids, hydroxy acids and other plant acids, sugars etc. Some of these constituents are well known to be chelating agents. Evidences show that a higher concentration of dissolved silica is found to be associated with relatively stronger acidity and the presence of chelating agents adjacent to the plant roots.

Besides, micro organisms such as Bacillus silicious directly entering into the decomposition of alumino silicates or Pseudomonas spp., producing organic acids such as 2-keto gluconic acid that dissolve silicates are also reported to have influence in controlling the concentration of silica in some soils. (Webley et al - 1960)

SILICA IN WATER

The concentration of dissolved silica in natural waters is controlled by various factors. Clark (1924) observed a wide difference in the concentration of silica in samples from different rivers and from different points of the same river, the down stream waters having less silica than the up stream tributaries.

While estimating the dissolved silica concentration of 225 rivers in Japan Kobayashi (1960) found an average silica concentration as high as 45.1 ppm in rivers flowing through regions of volcanic rock and 10.4 ppm for those flowing through regions of sedimentary rocks.

Acquaye (1960) using data on the chemical composition of a series of drainage and river waters from a variety of catchment areas infers that considerable leaching of silica from soil occurs although in the drainage waters it seldom exceeds 10 ppm. His estimate of the loss of silica through drainage water in a humid region is as high as 25 kg/acre/year. Using data of Handrick and Welsh (1938) on Lysimeter studies at Craibstone, near Aberdeen with an average rain fall of 88.2 cms and mean drainage of 46.7 cms, he estimated the average annual loss of silica to be in the order of 32 kg/acre. He could obtain similar data for other soils also.

A wide variation in the pattern of silica distribution in oceans from surface downwards was observed by Siever (1957). He reports that surface ocean water contain less than 1 ppm while the deep ocean water contain 12 ppm and highest dissolved silica content in alkaline lakes being 300 ppm.

Kovda <u>et al</u> (1958) have given much emphasis on the pH and salt concentration affecting the concentration of dissolved silica in water. The data reveal that in the slightly acidic run off in the foot hills of Amur area in Japan, silica content varied between 30 to 40 ppm, in the nearly neutral waters from 5 to 20 ppm and in the saline surface waters from 2 to 10 ppm.

Though there is considerable dispute over the forms of silica which exist in natural waters, it has been proved beyond doubt, that the dissolved silica in natural waters is mostly of the monosilicic form (Molybdenum reactive).

Many have, however, reported the existence of colloidal and silicate fragments in drainage waters, but Krauskopf (1956) points out that their existence is only temporary in waters undersaturated with respect to amorphous silica as they slowly get dissolved.

SILICA IN PLANT

Silicon, though its essentiality is yet to be proved, is an element which is absorbed by plants in major quantities. This is particularly true of cereals especially rice plants. Large quantities of silica removed by plants are, however, returned to the soil as plant remains and hence there is a continuous silica cycle existing in nature. When the straw of cereals is returned to the field, the silica cycle is not interrupted. Only when the straw is removed in a continuous cropping, the need for application of silicate fertilizers arise.

Russell (1961) reported that, perhaps, twice as much silica is cycled annually through plants as is lost in drainage water and hence the biological deposition of silica proceeds on a grand scale in soils. He estimated an annual return of 100 kg SiO_2/acre through leaf fall in a hard wood forest.

Beavers & Stephen (1958) estimated that the Opaline silica is present to the extent of 1 to 2 per cent in the surface soils in some of the grass land soils.

According to Novorosova (1951) silica returned to an hectare of soil through litter of spruce forest in 1000 years is estimated to be 50 to 60 tons.

Lovering (1959) observed a relatively high content of silica in tropical trees and considered it as one of the reasons which lead to the depletion of silica and enrichment of sesquioxide in laterite soils developed in tropics. Under these conditions, the loss of silica is very high when the litter high in silica are removed by erosion before their silica is released into the soil. He estimated that in 5000 years 2000 tons of silica would be removed from an acre of soil by the forest in tropics. In arriving at this figure he assumed the average silica content of forest trees as 2.5 per cent and the dry matter production as 16 tons/acre/year.

Nature and distribution of silica in plant.

There is notmuch evidence to show that plants contain silica in any form other than opaline although Lanning et al (1958) reported the presence of alfa quartz and opal in Lantana spp.

Jones et al (1963) working on oat plant observed that the silica present in oat is invariably opal (SiO_2nH_2O) and is deposited in intimate association with the material of the cell wall. The distribution of silica varies from organ to organ. In the glume it is about twice as much as in the leaf, while the leaf contains about three times as much as is present in the internode and roots. He found that silica is present in graminacious plant, 10 to 20 times as is present in legumes. Even in the same species of plants variation is found in the silica content depending on the nature of the soil. He also obtained negative correlation between the silica content of the plants with the pH of the soil.

From the reports of the International Rice Research Institute, Phillippines (1964) it is seen that differences in the silica content of rice seedlings of different varieties grown on one and the same tract could not be obtained.

Lanning (1958), in association with other research workers observed the presence of alpha quartz and opal in Lantana species. In 1963 working on rice plant he found that the silica present in rice is entirely of the opal form and described it as biogenetic opal. He further observed that the silica content of various parts varied from 2.63 per cent in the inflorescence to 13.13 per cent in the leaf sheath.

The relative distribution of silica in rice plant and the magnitude of its absorption in relation to other nutrients have been summarised by Kyogoto (1960). According to him, the silicicorous plants like the rice plant is found to contain in the shoot about 10 per cent of silicate and to produce 150 kg. of hulled grain, about 30 kg of silicate would be required. The requirement of nitrogen, phosphorus and potassium for the same being only 3.7, 1.5 and 3.0 kg respectively.

Yoshida et al (1959) found the silicon in rice leaf blade to occur as silica gel, a form different from opal. The polymerised silicic acid fills up the apertures of cellulose micelle constituting cell wall and make up silica cellulose membrane which is supposed to protect the plant from disease.

Adyanthaya & Rengaswamy (1952) studying the distribution of silica in rice plants in relation to resistance to blast disease found that the highly resistant varieties viz., CO.4 and CO.26 have a maximum number of long silicated epidermal cells. They further observed a reduction in number of cells per unit area when higher dose of nitrogen was applied.

Silicon in relation to other nutrients.

Direct and indirect evidences from the researches conducted so far reveal that silicon has probably an influence on the growth, yield and uptake of other nutrients. A correct and precise assessment of the status of plant available silica in soil is, however, not possible unless the relative distribution of other nutrients in plants and soil are reviewed.

Kyogoto (1960) reported that a silicon content greater than 12 to 13 per cent must be present in rice plants to obtain higher yields. Increasing doses of nitrogen cause decrease in silica content in the tissues, since dry matter production proceeds at a pace greater than that of silica absorption. He also found that magnesium deficiency often causes lowered absorption of silica.

Izawa & Kume (1959), from pot culture experiments with humid soils, concluded that higher doses of nitrogen decreased silica uptake leading to increasedlodging and lowered resistance to the incidence of blast.

These two views reveal that even when plant available silica is abundant in soils, high doses of nitrogen probably reduce the uptake of silica from soil.

Miyoshi & Ishi (1960) found that silicic acid decreased the content of inorganic phosphorus in stem and leaves and increased protein nitrogen in the ear head. Application of silicic acid was found to decrease the translocation of absorbed phosphorus from the upper leaves to the ear head.

Okuda and Takahashi (1961) observed a decreased uptake of iron, manganese and phosphorus, and an increased uptake of nitrogen and potassium by the application of silica. They further observed that higher silica content in the plant tops reduced considerably the transpiration in the plant.

Yoshida <u>et al</u> (1959) claimed that an increased supply of silica at the reproductive stage seemed to increase the yield. A higher content of other nutrients especially manganese was observed in silica deficient plants.

From pot trials with rice plant, Nakagawa <u>et al</u> (1955) concluded that silica deficient soils are common in paddy fields of low productivity.

This method of assessing the productivity of a soil is however in contradiction with the work of Nayar (1957) who found that the content of ash and SiO_2 of wheat plants is inversely related to the productivity of the soil when yield is taken as the index of productivity. He also established an inverse relationship between SiO_2 in wheat plants and the available phosphoric acid in soils.

Plant available silica and conventional methods of estimation.

Alkaline extractants such as 2 per cent sodium carbonate and 0.5 N sodium bicarbonate have been commonly used to remove hydrous oxides coating of all minerals. The question arose whether the substances so extracted were amorphous, crystalline or partly amorphous and partly crystalline and whether they could be considered as plant available.

Acidic conditions existing around the root zone of plants promoted the use of weak acids as extractants for studies on correlation of available nutrients in soil with plant uptake.

Keller (1957) reported that the acid environment adjacent to plant root is favourable for the dissolution of silicates.

Nutting (1945) examined the solubility of many silicate minerals and found that many of them could be dissolved completely by 0.01 to 0.4 per cent acid, if bases present are properly neutralised and enough water is added to dissolve the released silica.

Birch (1953) found that in East African soils the amount of water soluble and 1 per cent citric acid soluble silica could be positively correlated with the response of crops to application of phosphatic fertilizers.

According to Japanese workers, the assimilable silicon is the fraction soluble in weak acids. It is a prevalent practice in Japan to assess the guaranteed composition of silicate fertilizers using 0.5 N hydrochloric acid.

Kawaguchi & Hattovi (1958) studying the available silica in paddy soils, stressed the use of 0.2 N hydrochloric acid as an extractant. They inferred that the plant available silica could be estimated from the silica/alumina ratio in 0.2 N hydrochloric acid extracts of the soil and not merely by the amount of silica extracted. A smaller ratio, according to them, means a lowered availability of silica.

Ueda & Yamaoka (1959) tried a variety of extractants viz., 0.025 M citric acid, 2 per cent sodium carbonate (Truog), oxalate-oxalic acid (pH3.0) (Tamm's solution) N acetate, pH4.0, on paddy soils and obtained the best correlation between silica content of straw (rice) and 0.025 M citric acid extractable silica in soil. With 0.025 M citric acid a temperature of 30°C, an extraction period of six hours, and a ratio of soil to extractant of 1:10, gave the most satisfactory results with silica deficient soils or degraded paddy soils derived from granite.

Acquayé & Tinsley (1963) used 0.1 M disodium hydrogen citrate and 0.1 M citric acid to correlate soluble iron and aluminium with soluble silica in soil profiles. In both the solutions soluble silica is inversely proportional to soluble iron and aluminium. They, however, preferred the former extractant. Their objection in using citric acid is due to its ability to keep silica, alumina and iron in solution upto a pH of 8.0 and its ability to form complexes with other elements. However, its suitability for correlation with plant uptake is an aspect worth investigating.

Using dilute acids and alkalies in examining the silicon supplying power of paddy soils, Imaizumi & Yoshida (1958) found that dilute acid soluble silica is significantly correlated with silica absorption by rice plant where as the dilute alkali is not. The silicon dissolving power of various reagents was in the order oxalate > citrate > accetate > chloride.

To sum up, the above review of literature shows the amounts, forms and distribution of silica in rocks and soils with special emphasis on the amorphous forms in soils. The factors affecting solubility of silica in soils and its concentration in the soil solution together with the effect of other nutrients on such concentration are briefly reviewed. The distribution of silica in natural waters of different sources in relation to the depletion and/or addition of soil silica is also given. Literature on the silica cantent of plants, its role in plant nutrition and the influence by other nutrients on its uptake and utilization, with special reference to rice plants has been cited. A review is also made of the different extractants used in the estimation of available silica in soils for correlating it with plant uptake.

MATERIALS AND METHODS

MATERIALS AND METHODS

I. COLLECTION AND PREPARATION OF SAMPLES

A. Soils.

Samples from the top 9" layer of eleven representative tracts of the Kerala State, cropped to wet land paddy and six samples of soil from gardens adjacent to the selected paddy fields, were collected for the study. In addition, three paddy soil samples were taken from the Chittoor district of the State to represent black soil areas, and for a comparative study, one wet land paddy soil and one garden soil from the black soil area of Bellary district (Mysore State).

From paddy fields, the samples were collected during September - October when the crop was in the field. Samples were drawn from six sites in each field, and in between the rows of plants, with the help of a King's soil sampler. The soil collected was thoroughly mixed and a representative sample of about 5 kg was drawn and immediately stored in polythene containers to minimise lose of moisture during transit. A similar procedure was allowed in the case of dry garden land.

B. Plant.

Representative samples of rice plants were obtained from the fields, the soils of which were under investigation. They were removed as whole plants, washed thoroughly in running water followed by distilled water, and the top portions were air dried after removal of roots. The dry weight of straw and grain were separately recorded in each case. Straw was then cut into small pieces and oven dried at 70°C to constant weight. The grain was also oven dried at 70°C prior to storage in polythene containers.

C. Irrigation and drainage waters.

Twelve samples of irrigation and drainage water were collected in polythene bottles previously washed with the respective samples.

Details regarding the locality, type of soil, variety of paddy etc. are furnished in table I and the locality and sources of water samples in table II.

II. TREATMENT OF SAMPLES

A. Soil.

(a) For analysis of soluble silica and other chemical constituents

Dry land samples were air dried and passed through a 2 mm sieve. The wet land samples were mixed well and the moisture percentage was estimated. Portions equivalent to 20 gm of air dry material after removal of coarse fractions greater than 2 mm size were transferred to polythene bottles. Simultaneously 20 gm samples of the dry land soils were also transferred into another set of polythene bottles. Each sample was then treated with 200 ml of distilled water (soil to water ratio of 1:10) and shaken for six hours in a mechanical shaker. The suspensions were filtered and the filtrate collected for analysis of water soluble silica and other chemical constituents. The remaining portions of the wet land soils were then air dried, passed through a 2 mm sieve and stored in polythene containers for further analysis.

(b) Treatment of air dried soils of both wet and dry lands, using different extractants.

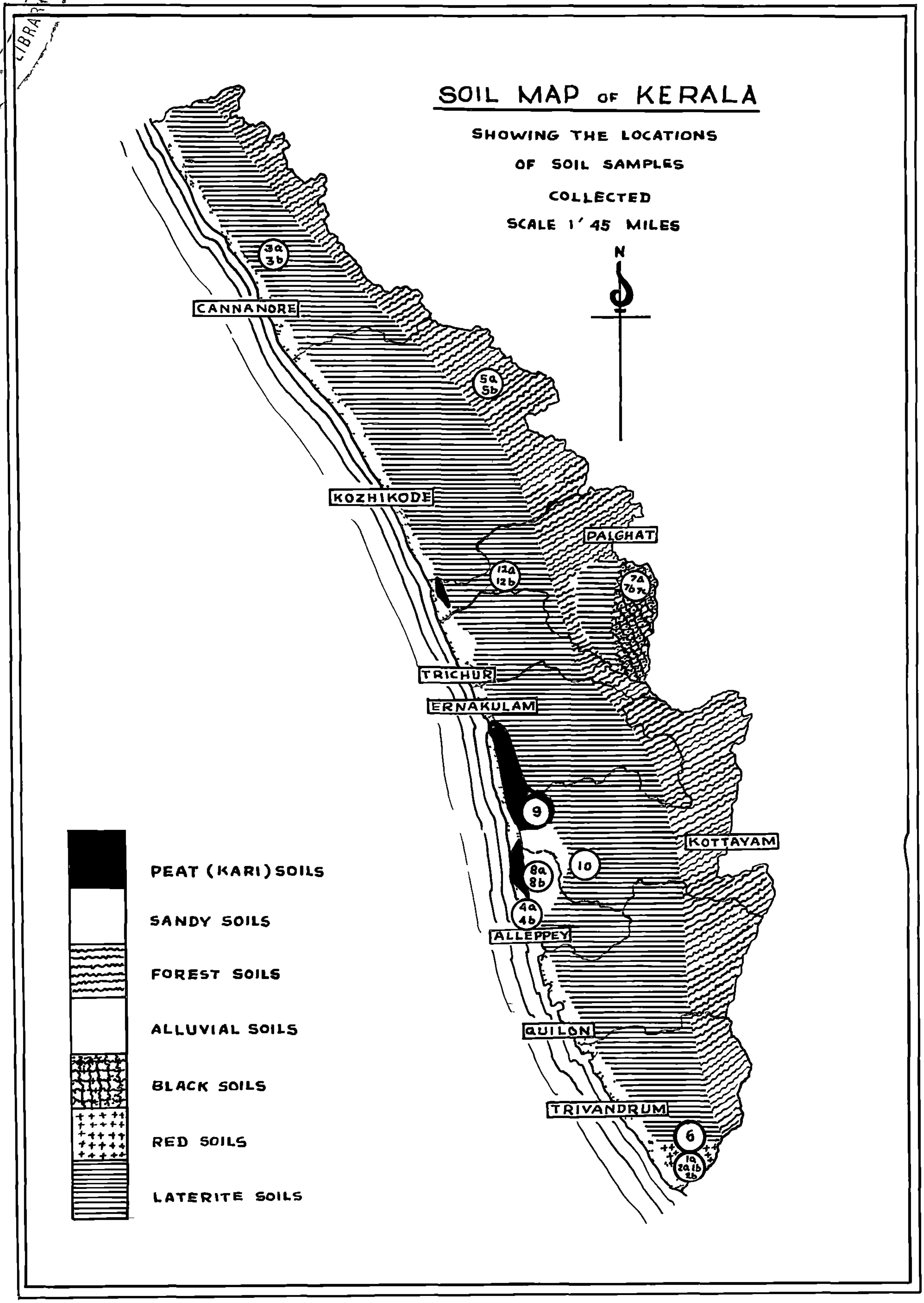
Extractants used.

1. Distilled water.
2. 0.2 N hydrochloric acid (Kawaguchi & Hattovi, 1959).
3. 0.025 M citric acid (Ueda & Yamaoka, 1960)
4. 0.5 N sodium bicarbonate (Olsen's method for available phosphorus)

20 gm of air dried sample was shaken with 200 ml of the above extractants (1:10 ratio) for six hours at room temperature in polythene bottles and filtered under suction. Silica, aluminium, iron and phosphorus were determined in the filtrates. In the case of the citric acid extract, the filtrate was evaporated to dryness and the citrate residue was destroyed by ignition. The residue was brought into solution by acid treatment for analysis of aluminium, iron and phosphorus.

(c) Treatment of soil samples for total silica, ferric oxide and aluminium oxide.

Oven dry samples were fused with sodium carbonate followed by



SOIL MAP OF KERALA

SHOWING THE LOCATIONS OF SOIL SAMPLES COLLECTED

SCALE 1′ 45 MILES

TABLE I

DETAILS OF SOIL SAMPLES USED FOR THE STUDY

Sl. No.	Soil* No.	Location.	Soil condition.	Soil type.
1	1 a	Vellayani	Dry land	Red loam
2	1 b	,,	,,	,,
3	2 a	,,	Wet land - paddy	,,
4	2 b	,,	Wet land - paddy	,,
5	3 a	Taliparamba	Dry land - Modan	Laterite
6	3 b	,,	Wet land - paddy	,,
7	4 a	Onattukara	Dry land - garden	Coastal alluvium (sandy)
8	4 b	,,	Wet land - paddy	,,
9	5 a	Ambalavayal	Dry land	Hills forest soil
10	5 b	,,	Wet land - paddy	,,
11	6	Karamana	Wet land - paddy	Laterite
12	7 a	Chittoor	Wet land - paddy	Black soil
13	7 b	,,	,,	,,
14	7 c	,,	,,	,,
15	8 a	Chithiramangalam	,,	Lake bed soil (kayal)
16	8 b	Alleppey R Block	,,	,,
17	9	Mundar	,,	Kari soil
18	10	Nilamperoor	,,	River borne alluvium (karapadam)
19	11 a^{+}	Bellary	,,	Black cotton soil
20	11 b^{+}	,,	Dry land	,,
21	12 a	Pattambi	,,	Laterite
22	12 b	,,	Wet land - paddy	,,

* as designated in the soil map.

+ } collected from outside State for comparison.
+ }

TABLE II

DETAILS OF IRRIGATION AND DRAINAGE WATER USED FOR THE STUDY

Sl. No.	Location	Source
1	Cannanore	Well
2	Kozhikode	Well
3	Vellayani	Well
4	Kovalam	Well
5	Vellayani	Kayal
6	Kuttanad	River (Kariyar)
7	Chithiramangalam	Canal
8	Perinchani	Dam
9	Pattambi	River (Bharathapuzha)
10	Kovalam	Sea
*11	Bellary	River (Thungabhadra)
*12	Bellary	Well

* included for comparison.

dehydration of silica with perchloric acid. The dehydrated residue in each case was washed free of metallic cations with 6 N hydrochloric acid. The washings were collected and made up to volume for aluminium and iron determinations.

The residue in the filter paper was brought into solution by treatment with hot 5 per cent sodium hydroxide (Jackson, 1958) and silicon determined colorimetrically.

B. Plant samples.

Extraction.

Oven dry samples were digested with triacid mixture of HNO_3, H_2SO_4 and $HClO_4$ in the ratio 10:1:4 and the silica after dehydration was treated with 0.5 N hydrochloric acid. This was filtered through Whatman (No.41) filter paper and the residue was washed free of metallic cations with 6 N hydrochloric acid. The filtrate was collected and made up to volume for further analysis.

The residue in the filter paper was treated as in the case of total silica determination for soils, described earlier.

C. Water.

Prior to analysis, the water samples were filtered to remove suspended impurities.

III. DETERMINATIONS

A. Soils.

1. pH. Determined in soil suspension (soil to water ratio 1:2.5) using glass electrode.

2. Conductivity. Conductivity of water extract (soil to water ratio 1:5) measured using Solu conductivity bridge.

3. Loss on ignition. Weighed quantities of well ground soil ignited in platinum crucible at temperature 700°C for half an hour, cooled in the desiccator and percentage loss estimated.

4. Organic carbon. Wet chromic acid method of Walkley & Black (1947) was followed.

5. Mechanical analysis. International pipette method (Piper, 1950) was followed.

6. Total silica, alumine and feric oxide in soils.

SiO_2. The residue from sodium carbonate fusion dissolved in sodium hydroxide was analysed for total silica.

Silico-molybdate method as modified by Murthy et al (1965) was employed for the purpose. According to this a suitable aliquot was treated with 2 ml of 1:1 hydrochloric acid followed by 2 ml of 10 per cent ammonium molybdate. This was then allowed to stand for 3 to 5 minutes. The interference of ferric iron was removed by the addition of 0.5 ml of 5 per cent solution of hydroxylamine hydrochloride, and of phosphorus by the addition of 1 ml of 10 per cent oxalic acid. The silico-molybdate was then reduced by the addition of 1 to 2 ml of 0.5 per cent ascorbic acid. The mixture was allowed to stand for 15 to 20 minutes to complete the reduction. It was then made up to volume and the blue colour developed was read on a Klett Summerson Colorimeter using the red filter (660 m u)

Aluminium and iron.

The filtrate from sodium carbonate fusion was analysed for aluminium and iron. Aluminium was estimated using aluminon (Aurin tricarboxylic acid) at pH 4.2, in a suitable aliquot (Snell & Snell, 1957). The interference due to ferric iron was removed by the addition of thioglycollic acid.

Iron was determined by the reduction of ferric iron to ferrous with hydroxylamine hydrochloride and the formation of ferrous complex of O - phenanthroline in a slightly acid medium (Jackson, 1958).

7. Silica, aluminium, iron, calcium, magnesium, sulphate, chloride and phosphorus were determined in the water extracts from the soil.

Silica, aluminium and iron were determined by methods already described.

Phosphorus.

Chlorostannous - reduced molybdo phosphoric blue colour method in sulphuric acid system was followed. (Troug & Meyer, 1929.)

Sulphate.

Sulphate was precipitated as barium sulphate on addition of excess of barium chromate (acidified). The excess barium chromate was neutralised with calcium hydroxide, filtered and in the filtrate the yellow colour of the liberated chromate on addition of 1:1 hydrochloric acid was measured using a blue filter (420 mμ). The sulphate equivalent to the chromate liberated was estimated. (Sandell, 1945).

Chloride.

Estimated volumetrically titrating against standard $AgNO_3$ solution using potassium chromate as external indicator (A.O.A.C., 1960).

Calcium and magnesium.

Versene method of Schwarzenbach & Biedermann as modified by Cheng & Bray (U.S.D.A. hand book No.60) was followed. Iron and manganese were removed by treatment with ammonium hydroxide-bromine mixture. The ammonium salt was destroyed and the resultant solution made up to volume. A portion of the aliquot was made alkaline with sodium hydroxide and titrated against standard 0.01 N versenate (EDTA) using ammonium purpurate indicator.

Another suitable aliquot from the above made up solution was treated with ammonium chloride - ammonium hydroxide buffer (pH10.0) and titrated against standard versenate using Eriochrome Black 'T' indicator. From the titre value obtained for calcium plus magnesium, by difference magnesium was estimated. The interference due to copper, cobalt and nickel was prevented by addition of KCN.

The filtrate from the citric acid, hydrochloric acid and sodium bicarbonate extracts were analysed for, silica, aluminium, iron and phosphorus by methods already described.

B. Plant.

The filtrate collected from triacid digestion was analysed for phosphorus, potassium, calcium, magnesium, aluminium, iron and manganese. The determinations were carried out by methods described for soils earlier except for potassium and manganese.

Potassium was determined turbidimetrically using sodium cobalti nitritesolution. (Datta *et al*, 1963).

Manganese.

Method consists of oxidising manganese to potassium permanganate using potassium per iodate in the presence of phosphoric acid (Jackson, 1958). The colour of permanganate developed was read using a green filter (540 mμ).

Total nitrogen.

Total nitrogen in oven dry samples of straw and grain was estimated by Kjeldahl's method.

C. Water.

pH, conductivity, silica, calcium and magnesium were determined by methods already described. Sodium was estimated by zinc uranyl acetate method (USDA hand book No.60).

Laboratory studies on the availability of added soluble silicate (Na_2SiO_3) in laterite and kari soils.

Soils used.	Vellayani wet land - clay loam (S_1) Kuttanad wet land - kari soil (S_2)
Levels of SiO_2 in ppm added.	L_1 = 0 L_2 = 50 L_3 = 100 L_4 = 250
* Moisture levels.	1/3 saturation (M_1) Full saturation (M_2)
Periods of incubation in days.	10 (P_1) 20 (P_2) 60 (P_3)
Extractants used.	Distilled water (E_1) 0.2 N hydrochloric acid (E_2) 0.025 M citric acid (E_3)

* These two moisture regimes were employed to simulate dry land and wet land conditions.

Details of experiment.

Polythene cups of 4" dia x 4" height with proper lids were used for this purpose. 200 gramsof the appropriate soil samples were taken in each cup and treated with the requisite quantity of a solution of sodium silicate, to give the desired dose of the same. Enough water was then added, to bring the moisture status to 1/3 or full saturation capacity. The cups were then tightly closed and left undisturbed.

Periodical analysis.

At the end of 10,20 and 60 days a sample of 20 gm was weighed out from each cup after thorough mixing into polythene bottles. The sample was extracted using distilled water and a shaking period of six hours. The same quantity of each sample was also extracted with 0.2 N hydrochloric acid and 0.025 M citric acid using the same period of shaking. The filtrate in each case was analysed for silica, aluminium, iron and phosphorus by methods already described.

RESULTS

RESULTS

Table III presents data on the physical and chemical characteristics of soil samples taken up for the present investigation. Only those soil properties that have a relationship with the present work have been studied. Besides the typical laterite and red loams of Kerala, samples include the kari soils of Kuttanad containing as high as eleven per cent organic carbon, sandy soils of Onattukara containing as low as three percent clay and Karapadam soils of Kuttanad with 45 to 50 per cent clay. The pH values of the soils range from 2.8 for the Karapadam soils of Kuttanad to 8.0 for the black soils of Chittoor. The conductivity of soil extracts and their sulphate and chloride concentrations reveal a high accumulation of salt in the kari and karapadam soils of Kuttanad.

The soils differ considerably with respect to water soluble silica. A value as low as 8 to 10 ppm for the sandy soils, a medium value of 50 to 70 ppm for the calcareous black soils of Chittoor and the highest value of 75 to 100 ppm for the kayal and kari soils have been recorded. The laterite soils of Kerala have a water soluble silica content of 20 to 30 ppm. The wet land soils contain a higher percentage of water soluble silica compared to the adjacent garden land soils. Correlations between the water soluble silica on the one hand and pH, organic carbon and mechanical composition on the other are not significant.

III

OF SOIL

basis in soil)			Water solubles (as ppm on moisture free basis)							
SiO_2	Al_2O_3	Fe_2O_3	SiO_2	SO_4	Cl	P	Ca	Mg	Al	Fe
nd	nd	nd	15.00	-	-	Tr	Tr	Tr	1.20	0.80
nd	nd	nd	12.00	-	-	Tr	Tr	Tr	1.00	1.00
62.33	17.28	6.43	22.50	50	60	0.13	21	18	0.46	2.24
nd	nd	nd	26.50	125	55	0.11	11	12	0.42	1.50
nd	nd	nd	15.00	Tr	Tr	0.20	Tr	Tr	1.00	1.00
60.10	15.40	10.28	23.50	80	50	0.21	10	12	0.54	0.45
nd	nd	nd	10.00	Tr	Tr	Tr	10	10	1.00	1.50
87.15	3.10	0.71	8.25	38	50	0.12	11	12	0.92	1.34
nd	nd	nd	27.00	Tr	Tr	0.15	21	13	0.63	2.00
nd	nd	nd	33.80	60	-	0.20	40	13	0.56	1.65
nd	nd	nd	16.00	40	Tr	0.15	Tr	Tr	0.50	2.50
65.00	11.54	6.00	70.00	575	100	0.19	105	44	1.60	2.50
nd	nd	nd	75.00	900	90	Tr	399	82	0.85	3.16
nd	nd	nd	50.00	700	Tr	Tr	250	66	1.00	3.00
nd	nd	nd	39.25	375	424	0.05	21	25	0.80	8.50
nd	nd	nd	24.25	250	126	0.05	53	32	0.50	2.00
41.20	14.56	5.39	56.75	5300	2529	0.06	546	781	8.60	41.50
nd	nd	nd	105.00	5500	675	0.08	525	1827	8.80	39.00
70.00	10.50	4.80	50.00	60	Tr	Tr	100	58	0.75	1.00
nd	nd	nd	50.00	93	50	Tr	120	40	1.00	1.50
nd	nd	nd	16.25	-	-	0.23	31	6	0.80	1.25
nd	nd	nd	10.00	Tr	-	0.15	25	5	0.85	0.50

Effect of drying the wet land samples on water soluble silica content.

Water soluble silica, sulphate and chloride in the wet land soils before and after drying are given in table IV.

TABLE IV

WATER SOLUBLE SALTS OF SOILS BEFORE AND AFTER DRYING
(as ppm on moisture free basis).

Soil No.	Before drying			After drying			Increase or decrease		
	SiO_2	Cl	SO_4	SiO_2	Cl	SO_4	SiO_2	Cl	SO_4
2 a	17.50	65	20	22.5	60	50	+ 5.00	- 5	+ 30
2 b	23.50	96	60	26.5	55	125	+ 3.00	-41	+ 65
3 b	22.75	60	13	24.0	50	80	+ 1.25	-10	+ 67
5 b	30.00	Tr	46	34.0	Tr	60	+ 4.00	—	+ 14
6	12.00	Tr	20	16.0	Tr	40	+ 4.00	—	+ 20
7 a	65.13	150	506	70.0	100	575	+ 5.00	-50	+ 69
7 b	61.66	170	571	75.0	90	900	+13.34	-80	+329
8 a	32.97	522	361	40.0	425	375	+ 7.00	-97	+ 14
8 b	21.17	207	238	24.0	126	250	+ 3.00	-81	+ 12
9	49.85	3834	2317	57.0	2529	5300	+ 7.00	-1305	+2983
10	36.50	1103	1215	105.0	675	5500	+68.50	- 428	+4285

Tr = Trace.

The data show that air drying increases both the water soluble silica and sulphate and decreases the chloride. A significant correlation exists between the increase in silica content with the increase in sulphate content consequent to drying. ($r = 0.819$).

Table V presents data on soluble silica extracted by various extractants from different soil samples.

TABLE V

SOLUBLE SILICA CONTENT OF SOILS WITH DIFFERENT EXTRACTANTS

(as SiO_2 in ppm on moisture free basis)

Soil No.	Distilled water	0.5 N sodium bicarbonate.	0.025 M citric acid	0.2 N hydrochloric acid
1 a	15.0	120	200	330
1 b	12.0	100	325	450
2 a	22.5	120	345	480
2 b	26.5	113	345	480
3 a	15.0	50	305	550
3 b	23.5	106	330	510
4 a	10.0	238	90	200
4 b	8.3	240	100	192
5 a	27.0	50	235	600
5 b	33.8	112	325	525
6	16.0	90	380	600
7 a	70.0	250	310	1000
7 b	75.0	512	350	1200
7 c	50.0	412	525	900
8 a	39.3	187	705	780
8 b	24.3	225	645	800
9	56.8	100	375	500
10	105.0	50	435	900
11 a	50.0	175	690	1925
11 b	50.0	187	435	1300
12 a	16.3	63	225	300
12 b	10.0	100	300	350

The data reveal that the acidic extractants viz., 0.025 M citric acid and 0.2 N hydrochloric acid extract greater amount of silica than the alkaline extractant, 0.5Nsodium bicarbonate, except in the sandy soils where the reverse is true. Among the acid extractants hydrochloric acid extracts greater amount of silica than citric acid.

The average content of soluble silica in kg per hectare for the various soil types of Kerala is given in fig. 1. The soluble silica of the black cotton soils of Bellary (Mysore State) is also included in the figure for comparison with the black soil of Palghat.

Table VI presents data on the amount of silica, aluminium and iron extracted by the acidic extractants.

TABLE VI

SOLUBLE SILICA, ALUMINIUM AND IRON WITH ACID EXTRACTANTS
(as ppm on moisture free basis)

Soil No.	0.2 N hydrochloric acid.				0.025 M citric acid			
	Eq.pH	SiO_2	Al_2O_3	Fe_2O_3	Eq.pH	SiO_2	Al_2O_3	Fe_2O_3
1 a	1.20	330	1000	2200	2.60	200	960	1330
2 a	1.25	450	1100	1530	2.70	325	1000	900
4 b	1.20	190	1048	430	2.55	100	556	160
5 a	1.10	600	1184	620	2.60	360	1130	400
5 b	1.10	530	1126	3430	2.60	340	1125	2530
7 a	2.30	1000	2000	30	5.80	310	680	39
7 b	2.15	1200	1800	40	5.20	350	720	50
11 a	2.00	1930	2400	20	4.40	690	204	47

The amount of aluminium extracted with 0.2 N hydrochloric acid

TABLE

ANALYSIS

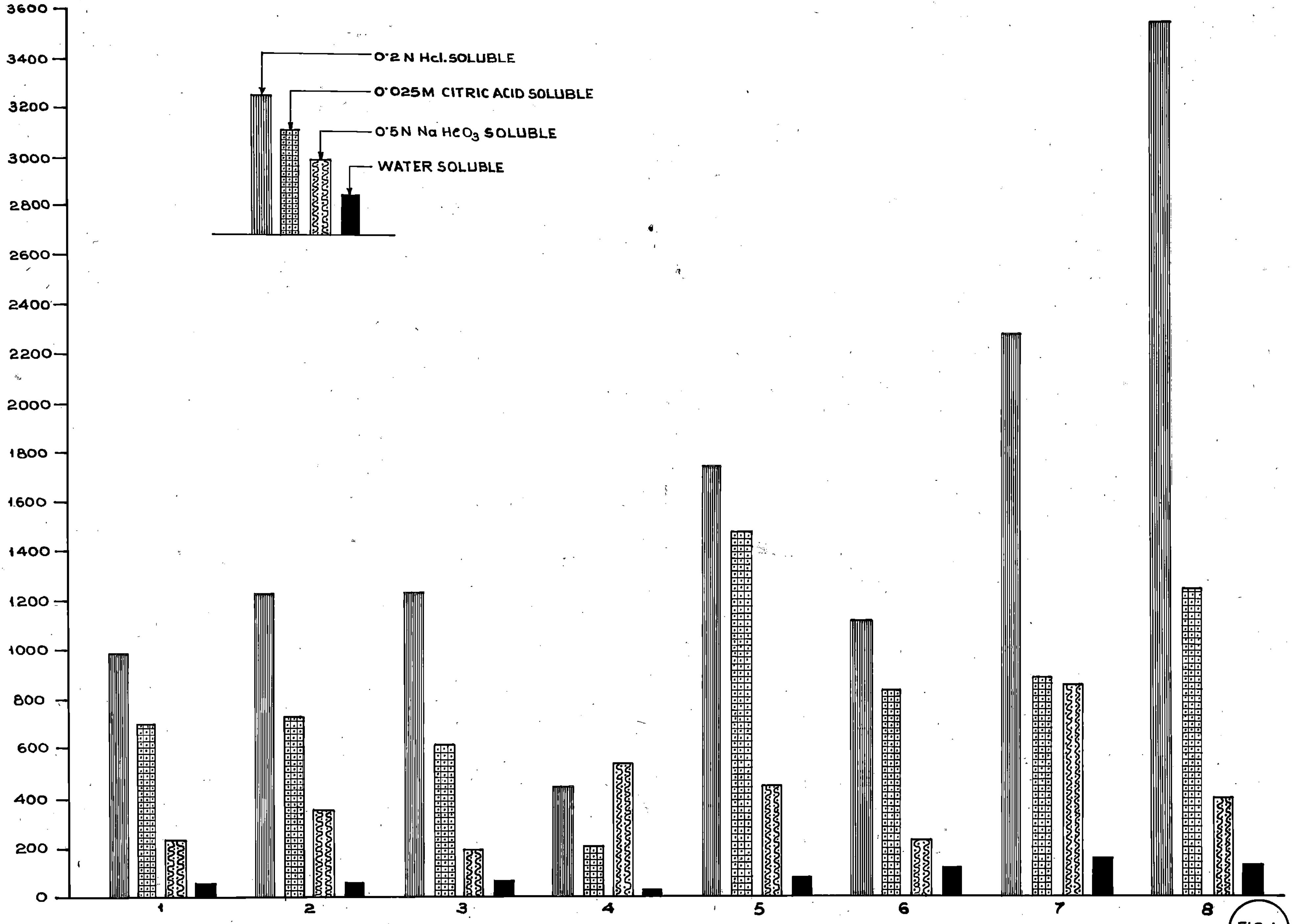
Soil No.	E.C. m.mohs/ cm	pH	Percentage (on moisture free					
			Mechanical composition				Loss on ignition	Organic carbon
			Coarse sand	Fine sand	Silt	Clay		
1 a	0.10	5.20	35.90	14.20	12.10	34.00	7.55	0.54
1 b	0.10	5.20	56.00	11.20	10.60	21.00	6.40	1.03
2 a	0.10	5.10	33.00	16.40	10.50	38.30	9.50	1.75
2 b	0.10	4.80	48.00	10.00	11.20	25.00	6.00	1.56
3 a	0.10	5.40	35.10	15.60	13.60	32.00	15.75	2.21
3 b	0.10	5.25	26.00	23.00	22.80	26.50	11.35	1.54
4 a	0.10	5.50	72.70	14.00	9.30	2.00	1.35	0.31
4 b	0.10	5.35	63.00	23.00	6.70	3.00	3.00	0.68
5 a	0.10	5.10	24.60	24.40	16.00	34.00	10.30	1.03
5 b	0.10	5.25	30.00	26.80	16.50	31.80	6.00	1.09
6	0.10	5.35	21.00	26.40	18.50	31.90	8.70	1.60
7 a	0.25	7.80	30.00	20.50	8.25	35.75	7.30	0.81
7 b	0.30	7.70	27.00	17.00	10.30	39.00	9.00	1.52
7 c	0.30	8.00	33.00	16.00	12.50	35.00	7.00	0.53
8 a	0.30	7.15	6.90	19.00	27.70	36.30	9.30	1.98
8 b	0.25	7.30	6.50	18.00	20.40	42.00	7.90	1.70
9	1.50	3.60	7.82	10.00	7.50	38.75	31.40	11.22
10	0.80	2.80	2.00	12.40	17.30	49.64	18.70	4.27
11 a	0.30	8.65	12.00	18.00	14.00	41.50	13.70	0.64
11 b	0.25	8.30	15.00	19.00	11.00	39.00	11.50	0.35
12 a	0.10	5.60	45.00	19.60	8.50	22.58	6.50	0.57
12 b	0.10	5.40	40.00	20.00	10.00	28.00	7.23	0.69

nd = not determined.

Tr = Trace

FIG. 1 GRAPHIC REPRESENTATION OF SILICA EXTRACTED BY VARIOUS REAGENTS FROM DIFFERENT SOIL TYPES OF KERALA STATE AS SiO_2 IN KILOGRAMS PER HECTARE.

Sl.No.	Soil Type	Location
1	Red loam	Vellayani
2	Laterite soil	Taliparamba
3	Hill soil	Ambalavayal
4	Coastal alluvium (Sandy soil)	Onattukara
5	Lake bed soil (Kayal)	Alleppey R - Block
6	Kari soil	Mundar
7	Black soil	Chittoor
8	Black cotton soil	Bellary



3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0·2 N Hcl. SOLUBLE
0·025M CITRIC ACID SOLUBLE
0·5N Na HCO_3 SOLUBLE
WATER SOLUBLE
1
2
3
4
5
6
7
8

FIG. 1

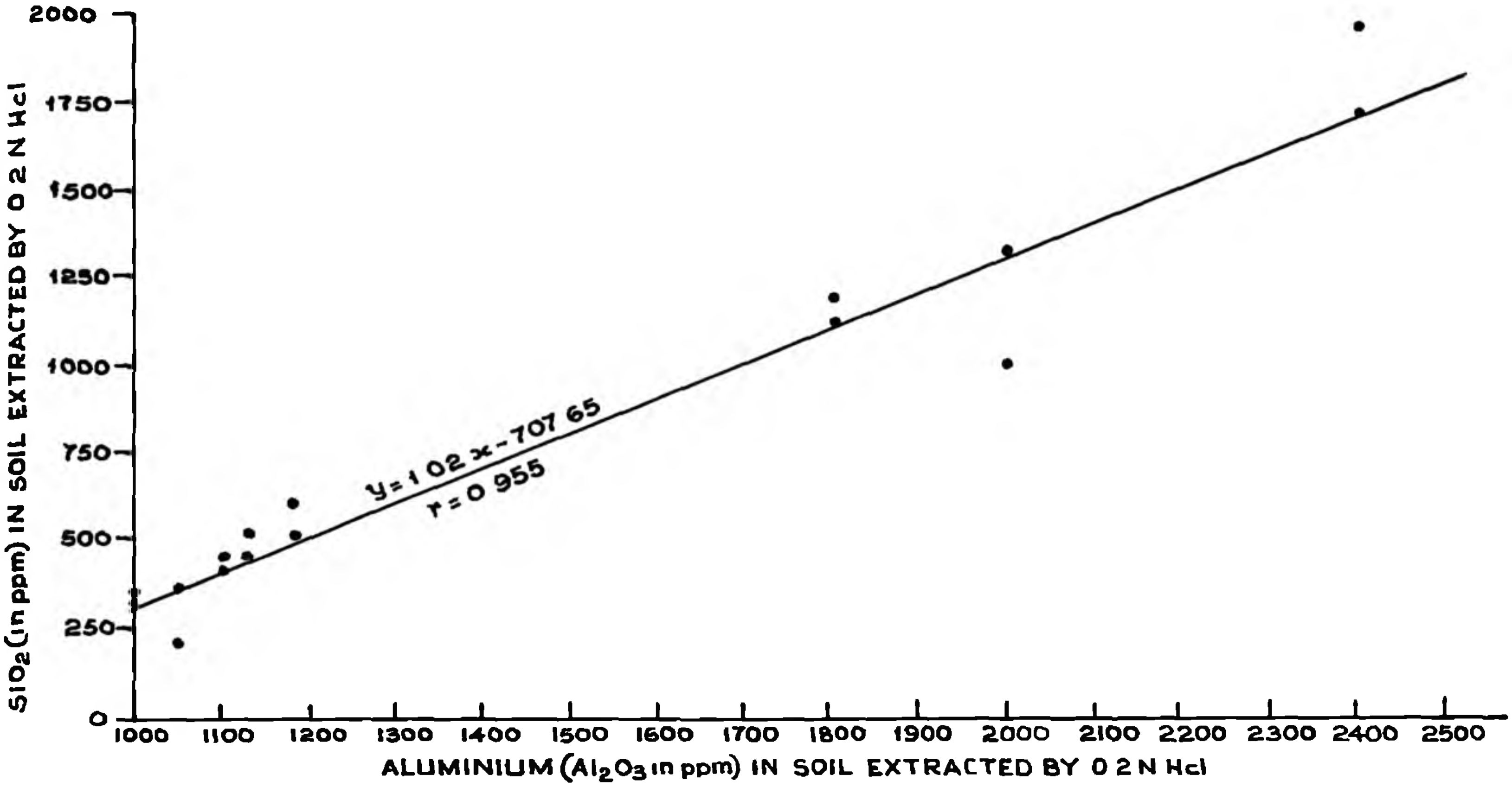

2000
1750
1500
1250
1000
750
500
250
0
SIO2 (in ppm) IN SOIL EXTRACTED BY 0 2 N Hcl
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
ALUMINIUM (Al2O3 in ppm) IN SOIL EXTRACTED BY 0 2 N Hcl
y = 1 02 x - 707 65
r = 0 955

FIG 11

FIG. 2 CORRELATION BETWEEN SILICA AND ALUMINIUM OF THE SOILS EXTRACTED BY 0.2 N HYDROCHLORIC ACID.

increasescorrespondingly with silica, the correlation coefficient being 0.955 (Fig.2). In the case of citric acid with increasing amount of silica extracted there exists a tendency to extract less of aluminium.

The silica extracted by 0.025 M citric acid is positively correlated with the fine fraction (silt + clay) of the soils, the correlation coefficient being 0.748 (Fig. 3).

Soluble silicate at four different levels, was added to two representative soil samples namely; Vellayani red loam (S_1) and <u>kari</u> soil (S_2) and incubated at laboratory temperature of 29± 2°C at two different moisture levels of one third saturation (M_1) and full saturation (M_2) and analysed for silica, iron, aluminium and phosphorus after 10, 20 and 60 days using different extractants namely; water, 0.2 N hydrochloric acid and 0.025 M citric acid.

The analysis of variance tables are given in Appendix I, II, III and IV.

<u>Release of silica.</u>

From the results it is seen that the two soils differ significantly in their release of soluble silica on incubation. The mean values of release being 287.42 and 441.05 ppm respectively. The release of silica under the two moisture regimes also differs significantly, the larger release being at full moisture saturation capacity. The increased release of silica with increasing doses of added silicate is also significant. Further, the release of silica increases with period of

FIG. 3 CORRELATION BETWEEN SILICA EXTRACTED BY 0.025 M CITRIC ACID AND THE FINE FRACTIONS (SILT + CLAY) OF THE SOILS.

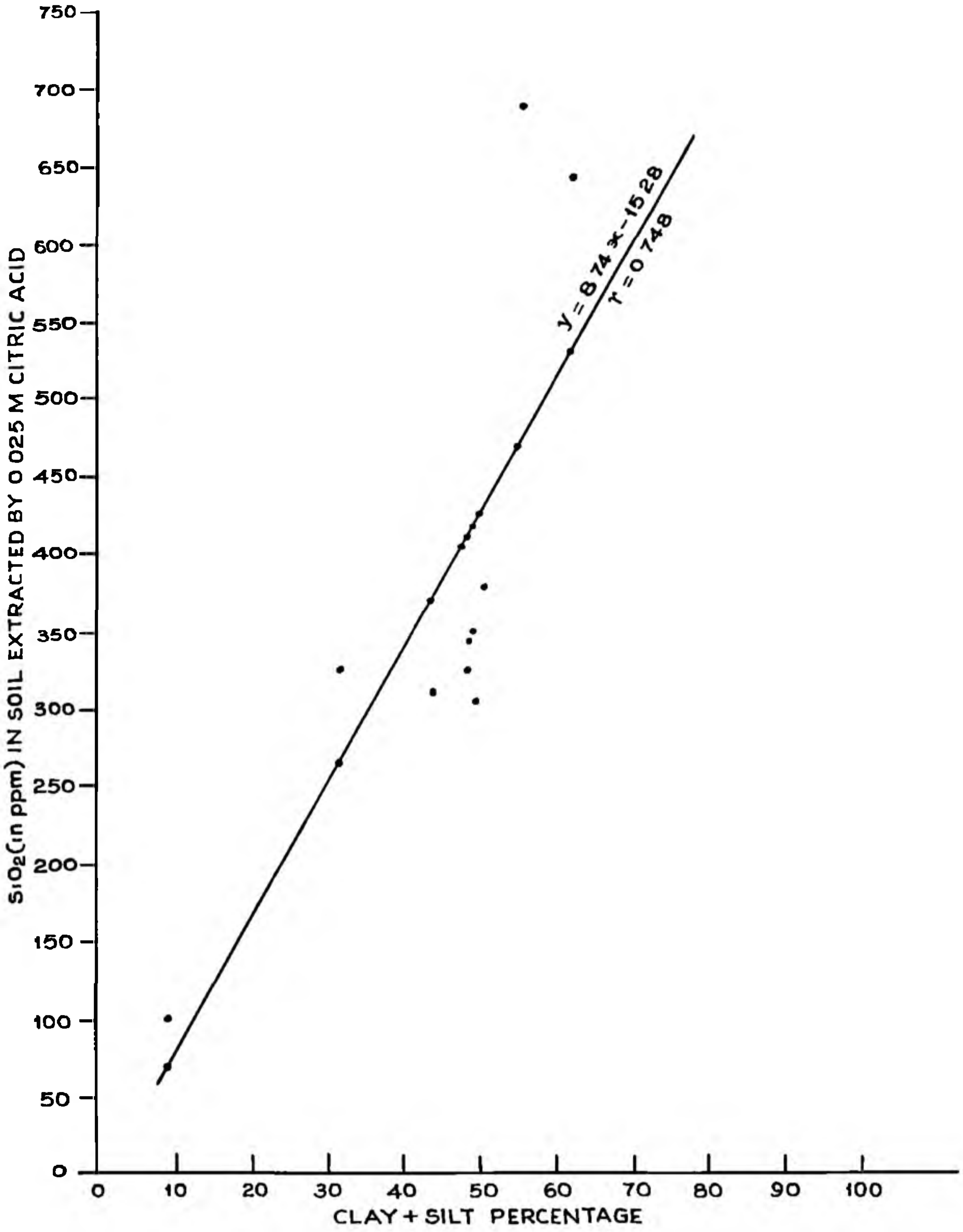

S₁O₂(in ppm) IN SOIL EXTRACTED BY 0 025 M CITRIC ACID
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
y = 8 74 x - 15 28
r = 0 748
0
10
20
30
40
50
60
70
80
90
100
CLAY + SILT PERCENTAGE

FIG III

incubation. There is a significant difference in the efficiency of the extractants in extracting silica. The order of efficiency of the extractants is 0.2 N hydrochloric acid > 0.025 M citric acid > water.

The mean quantities of silica in ppm extracted from the two soils under the two moisture regimes are given in table VII.

TABLE VII

THE SOLUBLE SILICA EXTRACTED UNDER DIFFERENT MOISTURE REGIMES
(mean value as SiO_2 in ppm on moisture free basis)

Moisture regime	Vellayani soil (S_1)	Kari soil (S_2)	Mean
1/3 moisture saturation (M_1)	276.36	407.42	341.89
Full moisture saturation (M_2)	298.47	474.69	386.58
Mean	287.41	441.05	364.23

Critical difference for comparison between means of soils 17.6
 ,, ,, ,, ,, moisture 17.6
 ,, ,, ,, ,, combination 24.9

Increasing the moisture level from 1/3 to full saturation capacity enhances the extraction of silica more in the _kari_ soil than in the Vellayani soil.

The mean release of SiO_2 in ppm corresponding to the levels of silicate added in the two soils are presented to table VIII. The mean release against the levels of added silicate is represented in fig. 4.

FIG. 4 PRESENTS THE MEAN VALUE OF SILICA EXTRACTED FROM THE TWO SOILS AT VARYING LEVELS OF ADDED SOLUBLE SILICATE

S_1 .. Vellayani soil

S_2 .. Kari soil

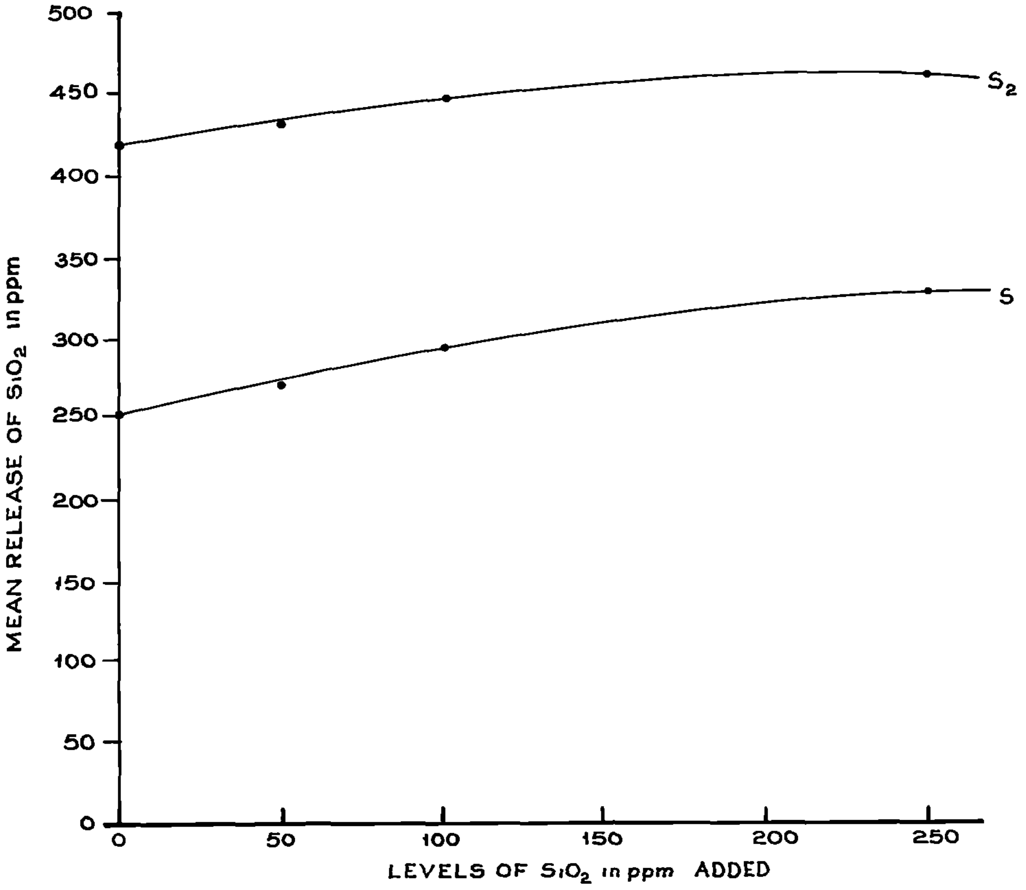

MEAN RELEASE OF SiO_2 in ppm
500
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
LEVELS OF SiO_2 in ppm ADDED
S_2
S

FIG IV

TABLE VIII

SILICA EXTRACTED AT DIFFERENT LEVELS OF ADDED SILICATE

(mean value as SiO_2 in ppm on moisture free basis)

Levels of SiO_2 added in ppm	Vellayani soil (S_1)	Kari soil (S_2)	Mean
L_1 = 0	252.42	419.56	335.99
L_2 = 50	269.27	427.40	348.33
L_3 = 100	295.85	449.58	372.71
L_4 = 250	333.04	468.72	401.07
Mean	287.66	441.32	364.50

Critical difference for comparison between means of soil	17.60
,, ,, ,, ,, levels	24.90
,, ,, ,, ,, combination	37.34

The amount of silica extracted increases with increasing levels of added soluble silicates. However, this is more marked in the Vellayani soil than the <u>kari</u> soil.

The release of silica increases with increasing period of incubation as revealed by table IX.

TABLE IX

SILICA EXTRACTED AT DIFFERENT PERIODS OF INCUBATION
(mean value as SiO_2 in ppm on moisture free basis)

Period in days			Vellayani soil (S_1)	Kari soil (S_2)	Mean
P_1	=	10	228.69	355.86	315.81
P_2	=	20	256.80	400.36	355.04
P_3	=	60	311.23	466.39	420.12
Mean			267.42	441.41	361.91

Critical difference for comparison between means of	soil	17.60
,, ,, ,, ,,	period	21.56
,, ,, ,, ,,	combination	30.50

The rate of release with period is greater in the case of kari soil than in the Vellayani soil. The mean rate of release against period is represented in fig. 5.

The mean release of SiO_2 in ppm as extracted by the three extractants from the two soils with added silicate is given in table X and fig. 6.

FIG. 5 SHOWING THE RELATIONSHIP BETWEEN THE MEAN VALUES OF IRON, ALUMINIUM, SILICA AND PHOSPHORUS EXTRACTED FROM THE TWO SOILS AT VARYING PERIODS OF INCUBATION.

S_1 .. Vellayani Soil
S_2 .. Kari Soil

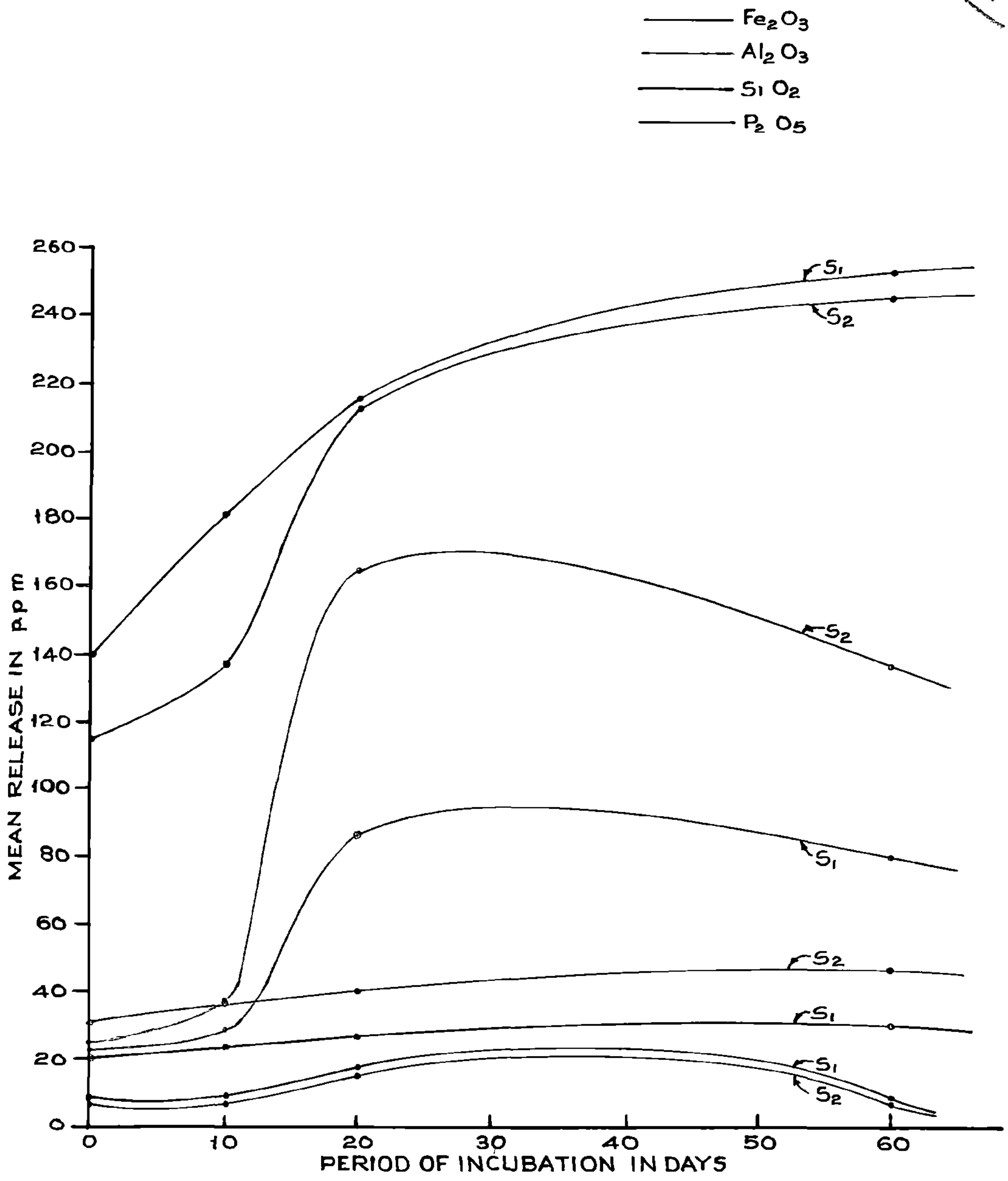

Fe_2O_3
Al_2O_3
SiO_2
P_2O_5
MEAN RELEASE IN p.p.m
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
PERIOD OF INCUBATION IN DAYS
S_1
S_2
S_2
S_1
S_2
S_1
S_1
S_2

FIG V

FIG. 6 SHOWING THE EFFICIENCY OF THE THREE EXTRACTANTS IN EXTRACTING SILICA FROM THE SOILS AT DIFFERENT LEVELS OF ADDED SOLUBLE SILICATE.

E_1	..	Distilled Water
E_2	..	0.2 N hydrochloric acid
E_3	..	0.025 M citric acid

FIG. 7 SHOWING THE EFFECT OF ADDED SOLUBLE SILICATE ON THE RELEASE OF NATIVE PHOSPHORUS IN THE TWO SOILS.

S_1	..	Vellayani Soil
S_2	..	Kari Soil

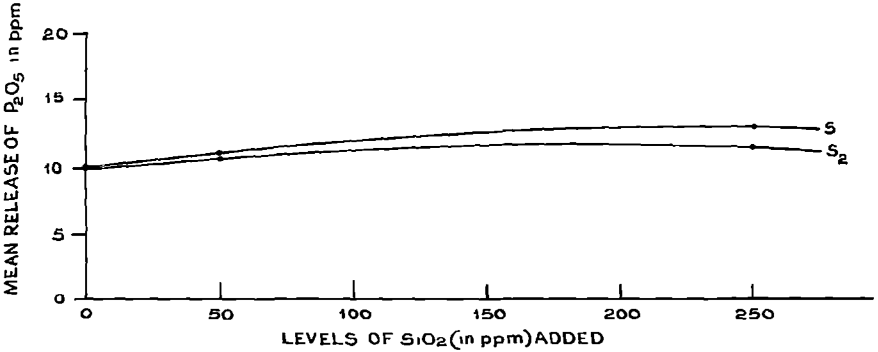

MEAN RELEASE OF P_2O_5 in ppm
20
15
10
5
0
0
50
100
150
200
250
LEVELS OF SiO_2 (in ppm) ADDED
S
S_2

FIG VII

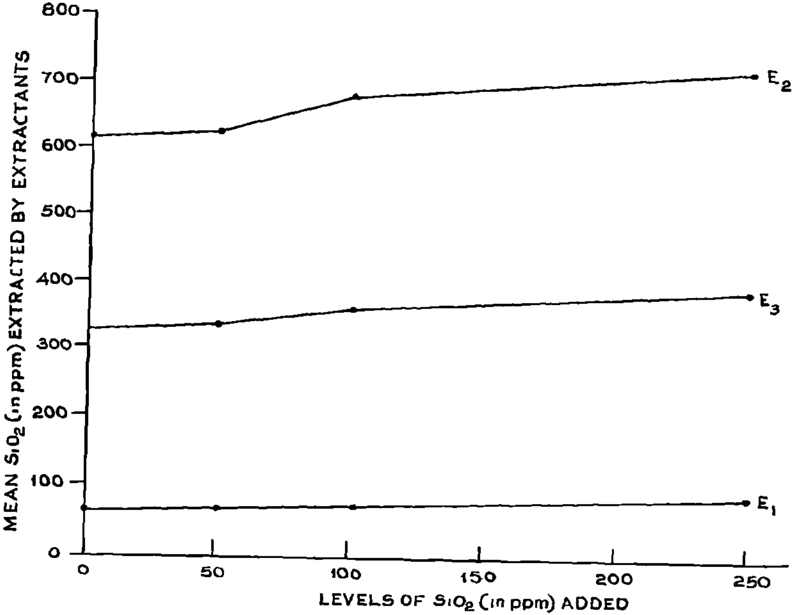

MEAN SiO_2 (in ppm) EXTRACTED BY EXTRACTANTS
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
LEVELS OF SiO_2 (in ppm) ADDED
E_2
E_3
E_1

FIG VI

TABLE X

SILICA EXTRACTED WITH DIFFERENT EXTRACTANTS AT VARYING LEVELS OF ADDED SILICATES

(mean value as SiO_2 in ppm on moisture free basis)

Extractants	Levels of SiO_2 added				Mean
	L_1	L_2	L_3	L_4	
Distilled water (E_1)	61.17	65.25	71.75	90.00	72.04
0.2 N hydrochloric acid (E_2)	616.00	629.17	682.33	722.67	662.54
0.025 M citric acid (E_3)	330.00	349.75	363.17	397.92	360.21
Mean	335.72	348.06	372.42	403.53	364.93

Critical difference for comparison between means of levels	24.90
,, ,, ,, ,, extractants	21.56
,, ,, ,, ,, combinations	43.14

The extractants differ considerably in their efficiency with regard to the extraction of silica. Application of silicate at 100 kg per hectare does not significantly enhance the amount of silica extracted by any of the three extractants. However, application of soluble silicate at higher doses viz., 200 kg and 500 kg enables more soluble silicate to be extracted by the acidic extractants of which 0.2 N hydrochloric acid appears to be more efficient.

Release of phosphorus.

The release of phosphorus consequent to the application of different doses of soluble silicate to the two soils is given in table XI and fig. 7.

TABLE XI

PHOSPHORUS EXTRACTED AT DIFFERENT LEVELS OF ADDED SILICATE
(mean value as P in ppm on moisture free basis)

Levels of SiO_2 in ppm added	Vellayani soil (S_1)	Kari soil (S_2)	Mean
L_1 = 0	4.49	4.32	4.41
L_2 = 50	4.81	4.64	4.73
L_3 = 100	4.08	4.76	4.42
L_4 = 250	5.69	5.00	5.35
Mean	4.77	4.68	4.73

Critical difference	for comparison	between means of	soils	0.75
,,	,,	,,	levels	1.08
,,	,,	,,	combination	1.52

There is a steady increase in the release of phosphorus, with increasing doses of silicates applied, in both the soils. But a relatively greater release is observable in the Vellayani soils at the highest dose of silicate applied.

Release of phosphorus increases with increase in moisture status of the soils as revealed in table XII.

TABLE XII

PHOSPHORUS EXTRACTED AT DIFFERENT MOISTURE REGIMES

(mean value as P in ppm on moisture free basis)

Moisture levels	Vellayani soil (S_1)	Kari soil (S_2)	Mean
1/3 saturation (M_1)	4.23	4.08	4.16
Full saturation (M_2)	5.31	5.27	5.29
Mean	4.77	4.68	4.73

Critical difference for comparison between means of soil 0.75
,, ,, ,, moisture 0.75
,, ,, ,, combination 1.08

The mean release of phosphorus with time obtained on addition of silicate to the two soils is given in table XIII and fig. 5.

TABLE XIII

PHOSPHORUS EXTRACTED AT DIFFERENT PERIODS OF INCUBATION

(mean value as P in ppm on moisture free basis)

Period in days	Vellayani soil (S_1)	Kari soil (S_2)	Mean
P_1	3.80	3.36	3.58
P_2	7.50	7.32	7.46
P_3	3.00	3.35	3.18
Mean	4.47	4.68	4.73

Critical difference for comparison between means of soil 0.750
,, ,, ,, extractants 0.924
,, ,, ,, combination 1.308

The rate of release of phosphorus increases significantly only during the initial period of incubation. But during the later period thereis a decrease in the amount of phosphorus released from both the soils.

Release of aluminium.

The mean release of aluminium in ppm with period in the two soils applied with sodium silicate is given in table XIV and fig. 5.

TABLE XIV

ALUMINIUM EXTRACTED AT DIFFERENT PERIODS OF INCUBATION

(mean value as Al in ppm in moisture free basis)

Period in days	Vellayani soil (S_1)	Kari soil (S_2)	Mean
P_1 = 10	141.2	181.6	161.40
P_2 = 20	430.0	822.0	626.00
P_3 = 60	403.7	684.1	543.90
Mean	325.0	562.55	443.80

Critical difference for comparison between means of soil	40.44
,, ,, ,, ,, periods	50.86
,, ,, ,, ,, combination	72.46

The increased release of aluminium with duration of incubation is significant only upto 20 days in both the soils beyond which there is a decrease in the amount extracted.

Table XV presents data on the extraction of aluminium in ppm by different extractants in the two soils.

TABLE XV

ALUMINIUM EXTRACTED WITH DIFFERENT EXTRACTANTS

(mean value as Al in ppm on moisture free basis)

Extractants	Vellayani soil (S_1)	Kari soil (S_2)	Mean
Distilled water (E_1)	3.4	7.3	5.35
0.2 N hydrochloric acid (E_2)	623.2	916.6	769.90
0.025 M citric acid (E_3)	348.3	763.7	556.00
Mean	325.0	562.5	665.63

Critical difference for comparison between means of soil	40.44
" " " extractants	50.86
" " " combination	72.46

The extractants differ significantly in their ability to extract aluminium.

From the analysis of variance tables given in Appendix III it is seen that addition of silicate at different doses does not decrease or increase the amount of aluminium extracted by different extractants. The two moisture regimes tried for the incubation experiment also do not affect the amounts of aluminium extracted by the reagents.

Release of iron.

Table XVI presents data on the release of iron in ppm in the two soils treated with silicate and kept under two moisture levels.

TABLE XVI

IRON EXTRACTED AT DIFFERENT MOISTURE REGIMES
(mean value as Fe in ppm on moisture free basis)

Moisture levels	Vellayani soil (S_1)	Kari soil (S_2)	Mean
1/3 moisture saturation (M_1)	642.7	2401.7	1522.20
Full moisture saturation (M_2)	662.3	2120.4	1391.55
Mean	652.5	2261.05	1456.78

Critical difference for comparison between means of soil	124.80
" " " moisture	124.80
" " " combination	176.60

While there is an increase in the quantity of iron extracted from Vellayani soil, there is a decrease in the same with respect to the *kari* soil.

The mean release of iron with period of incubation in the two soils treated with silica is given in table XVII and fig. 5.

TABLE XVII

IRON EXTRACTED AT DIFFERENT PERIODS OF INCUBATION

(mean value as Fe in ppm on moisture free basis)

Period in days.			Vellayani soil (S_1)	Kari soil (S_2)	Mean
P_1	=	10	447.3	1771.33	1106.7
P_2	=	20	577.3	2438.10	1504.1
P_3	=	60	932.9	2573.70	1749.1
Mean			652.5	2261.00	1455.6

Critical difference for comparison between mean of soil 124.80
" " " period 153.00
" " " combination 208.46

A significant increase in the iron extracted with increasing period of incubation is observed.

Table XVIII presents data on the amount of iron in ppm extracted by the three extractants at different periods of incubation.

TABLE XVIII

IRON EXTRACTED WITH DIFFERENT EXTRACTANTS AT VARYING PERIODS OF INCUBATION

(mean value as Fe in ppm on moisture free basis)

Extractant		Period			Mean
		P_1	P_2	P_3	
Distilled water	(E_1)	17.7	32.0	17.5	22.4
0.2 N hydrochloric acid	(E_2)	1574.1	2121.3	3057.1	2250.8
0.025 M citric acid	(E_3)	1733.3	2366.2	2181.0	2093.5

Critical difference for comparison between mean of period 153.0
" " " extractants 153.0
" " " combination 840.0

From the above mean values, it is evident that 0.025 M citric acid extracts more iron in the first two periods than the other extractants.

A consistent increase in iron with time of incubation is obtained only with 0.2 N hydrochloric acid. However, in the other two cases there is a considerable reduction in the degree of solution of iron beyond 20 days of incubation.

ANALYSIS OF PLANT

The results of chemical analysis of grain and straw together with the dry weight of 100 plants are presented in table XIX.

Silica content of both straw and grain is fairly constant for the same soil type eventhough the varieties grown are different. But variations in soil type tends to induce appreciable differences in the silica content of the plants. The plants from sandy soils of Onattukara analysed the lowest amount of silica being 4.5 per cent in the straw and 2.54 per cent in the grain. The highest value viz., 12.1 per cent in straw and 6.24 per cent in the grain are obtained in plants from black soil tract of Chittoor, comparable with those of black cotton soil of Bellary. Irrespective of the varietal differences, the rice plants grown in the laterite regions analyses to an average percentage of 8.5 and 4.25 of SiO_2 in straw and grain respectively. The differences in type of soil and variety do not affect the relative amount of silica in grain and straw, the ratio between the two being maintained at 1:2.

TABLE

CHEMICAL ANALYSIS OF

(results expressed as

Soil No.	Variety*	Dry matter weight in grams per hundred plants		SiO_2		N		P_2O_5		K_2O	
		S	G	S	G	S	G	S	G	S	G
2a	PTB.9	2350	1833	8.89	4.40	1.070	1.145	0.058	0.529	1.087	0.258
2a	PTB.26	2300	2150	8.44	5.27	0.812	1.102	0.073	0.612	0.992	0.211
3a	Moden	500	300	5.27	2.43	0.309	0.782	0.340	0.520	0.912	0.373
3b	PTB.9	1824	1620	8.66	3.07	0.562	0.853	0.152	0.619	1.316	0.288
4b	UR.19	1000	800	4.49	2.54	0.737	1.372	0.428	0.713	1.597	0.438
5b	WND.2	3133	3200	8.48	3.66	0.616	1.162	0.063	0.447	1.110	0.240
5b	SLO.17	2233	1133	8.37	3.66	0.710	1.006	0.047	0.290	1.648	0.336
5b	MTU.19	6666	5470	8.78	3.56	0.650	1.100	0.052	0.331	1.732	0.361
6	Taichung 65	3700	4440	8.63	3.50	0.919	1.404	0.182	0.704	2.420	0.219
6	PTB.4	4375	4000	8.09	4.50	0.476	1.092	0.181	0.703	1.239	0.360
6	PTB.16	5000	4000	8.96	5.33	0.434	1.120	0.165	0.720	1.440	0.360
7a	PTB.26	2130	1820	12.10	6.25	0.350	0.980	0.047	0.426	1.998	0.216
1a	GEB.24	2800	2000	13.50	6.62	0.400	0.760	0.050	0.400	1.600	0.310

* All, except Taichung 65 (Japonica), are Indica varieties.

XIX

RICE PLANT

percentage on moisture free basis)

CaO		MgO		Al_2O_3		Fe_2O_3		MnO_2	
S	G	S	G	S	G	S	G	S	G
0.358	0.112	0.334	0.204	0.089	0.0114	0.060	0.0072	0.065	0.0090
0.437	0.132	0.318	0.238	0.125	0.0150	0.084	0.0197	0.062	0.0135
0.692	0.145	0.309	0.265	0.242	0.0060	0.114	0.0190	0.039	0.0125
0.197	0.077	0.298	0.206	0.085	0.0240	0.126	0.0130	0.068	0.0068
0.437	0.182	0.345	0.265	0.173	0.0150	0.114	0.0126	0.050	0.0068
0.644	0.112	0.265	0.194	0.120	0.0290	0.129	0.0715	0.075	0.0093
0.672	0.098	0.286	0.171	0.177	0.2140	0.083	0.0090	0.090	0.0126
0.560	0.112	0.268	0.163	0.132	0.0170	0.057	0.0030	0.075	0.0135
0.497	0.057	0.408	0.177	0.197	0.0070	0.088	0.0097	0.076	0.0107
0.308	0.208	0.428	0.224	0.090	0.0086	0.099	0.0094	0.098	0.0094
0.300	0.206	0.367	0.245	0.086	0.0094	0.060	0.0072	0.101	0.0112
0.437	0.125	0.388	0.133	0.066	0.0140	0.039	0.0140	0.010	0.0030
0.525	0.131	0.360	0.150	0.058	0.0070	0.040	0.0090	0.015	0.0040

S = straw

G = grain

The silica content of the whole plant and that of the straw are positively correlated with the soluble silica of the soil. This is true with regard to both the extractants (Fig. 8 A & 8 B), 0.2 N hydrochloric acid, however, gives a higher coefficient of correlation (0.960).

The removal of silica and other nutrients by rice plant, estimated from the analytical data (Table XIX) is graphically presented in fig. 9.

A low content of silica in the rice plant is associated with high values for phosphorus. A high value for silica is associated with low values for metallic cations like aluminium, iron and manganese.

ANALYSIS OF WATER SAMPLES

Table XX presents the data on the analysis of water samples from different sources. The sodium adsorption ratio (S.A.R) in each case has also been worked out.

TABLE XX
ANALYSIS OF WATER SAMPLES

No.	Source	pH	SiO_2 (in ppm)	S.A.R.
1	Well (Cannanore)	6.7	5.80	nd
2	Well (Kozhikode)	6.5	6.80	nd
3	Well (Vellayani)	6.8	6.90	0.72
4	Well (Kovalam)	6.2	6.50	1.95
5	Kayal (Vellayani)	6.9	5.00	2.00
6	Kariar river	5.7	5.00	7.37
7	Chithiramangalam canal	5.7	6.30	4.52
8	Perinchani dam	6.0	12.00	0.90
9	Bharathapuzha river (PTB.)	7.2	10.50	1.57
10	Sea (Kovalam)		1.60	58.50
*11	Thungabhadra river (Bellary)	6.9	10.00	1.50
*12	Well (Bellary)	7.8	50.00	15.50

* Analysed for comparison. nd = not determined.

FIG. 8 A. SHOWING CORRELATION BETWEEN THE SILICA CONTENT IN RICE PLANT AND THE SOLUBLE SILICA EXTRACTED BY 0.2 N HYDROCHLORIC ACID FROM THE CROPPED SOILS.

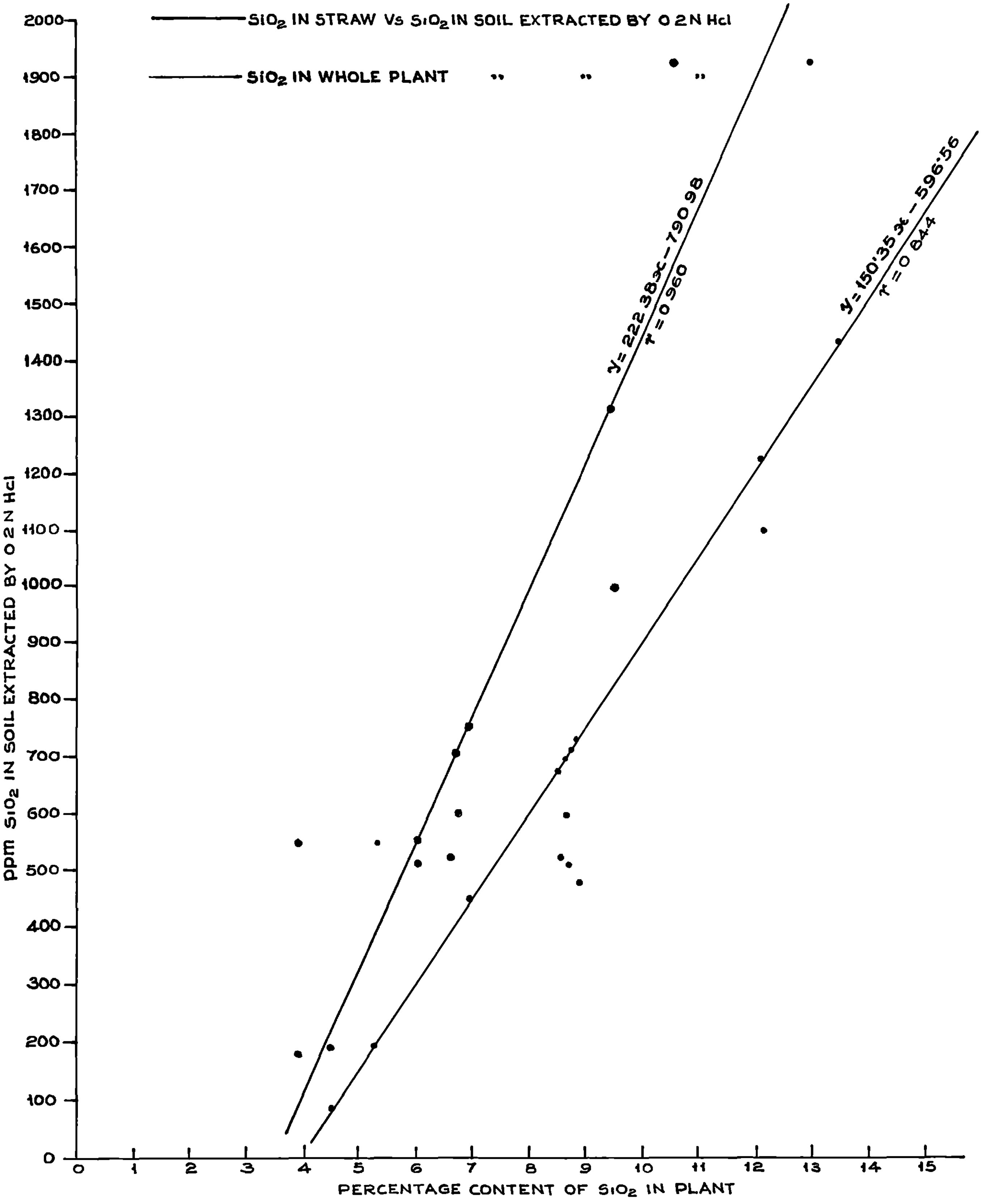

SiO2 IN STRAW Vs SiO2 IN SOIL EXTRACTED BY 0 2 N Hcl
SiO2 IN WHOLE PLANT " " "
y = 222 38x − 790 98
r = 0 960
y = 150·35x − 596·56
r = 0 844
ppm SiO2 IN SOIL EXTRACTED BY 0 2 N Hcl
PERCENTAGE CONTENT OF SiO2 IN PLANT
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

FIG VIIIA

FIG. 8 B. SHOWING CORRELATION BETWEEN THE SILICA CONTENT IN RICE PLANTS AND THE SOLUBLE SILICA EXTRACTED BY 0.025 M CITRIC ACID FROM THE CROPPED SOILS.

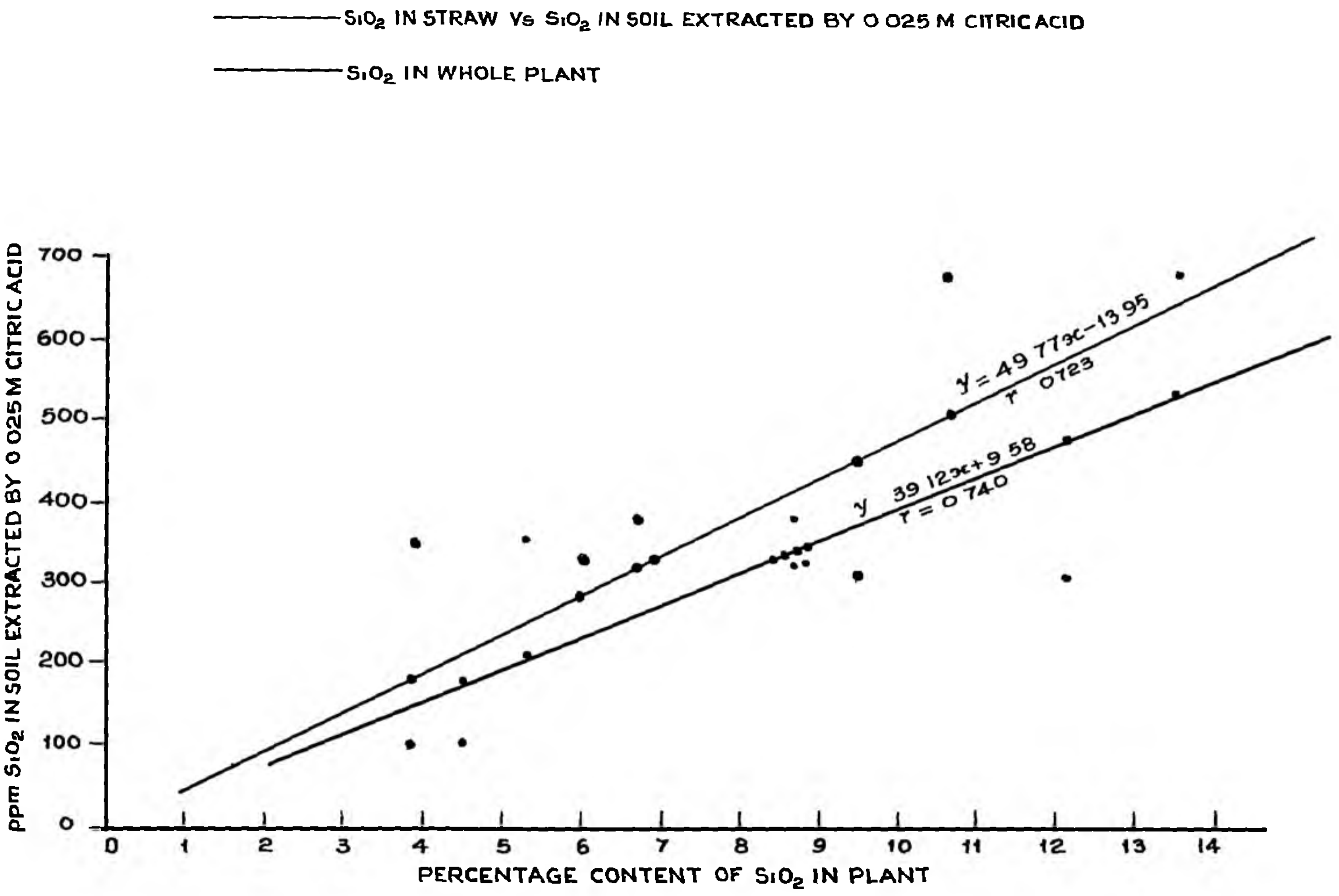

SiO2 IN STRAW Vs SiO2 IN SOIL EXTRACTED BY 0 025 M CITRIC ACID
SiO2 IN WHOLE PLANT
ppm SiO2 IN SOIL EXTRACTED BY 0 025 M CITRIC ACID
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
PERCENTAGE CONTENT OF SiO2 IN PLANT
y = 49 77x − 13 95
r 0 723
y 39 12x + 9 58
r = 0 740

FIG VIIIB

FIG. 9 SHOWING THE AVERAGE REMOVAL OF SILICA BY STRAW AND GRAIN OF RICE PLANTS AS COMPARED TO OTHER NUTRIENTS.

Average yield in Kg/hectare:

Straw = 2000
Grain = 2000

Nutrient	Nutrient content in plant (Percentage on moisture free basis)	
	Straw	Grain
SiO_2	8.425	4.325
N	0.700	1.000
P_2O_5	0.162	0.549
K_2O	1.570	0.316
CaO	0.463	0.126
MgO	0.345	0.201
Al_2O_3	0.120	0.026
Fe_2O_3	0.081	0.016
MnO_2	0.056	0.008

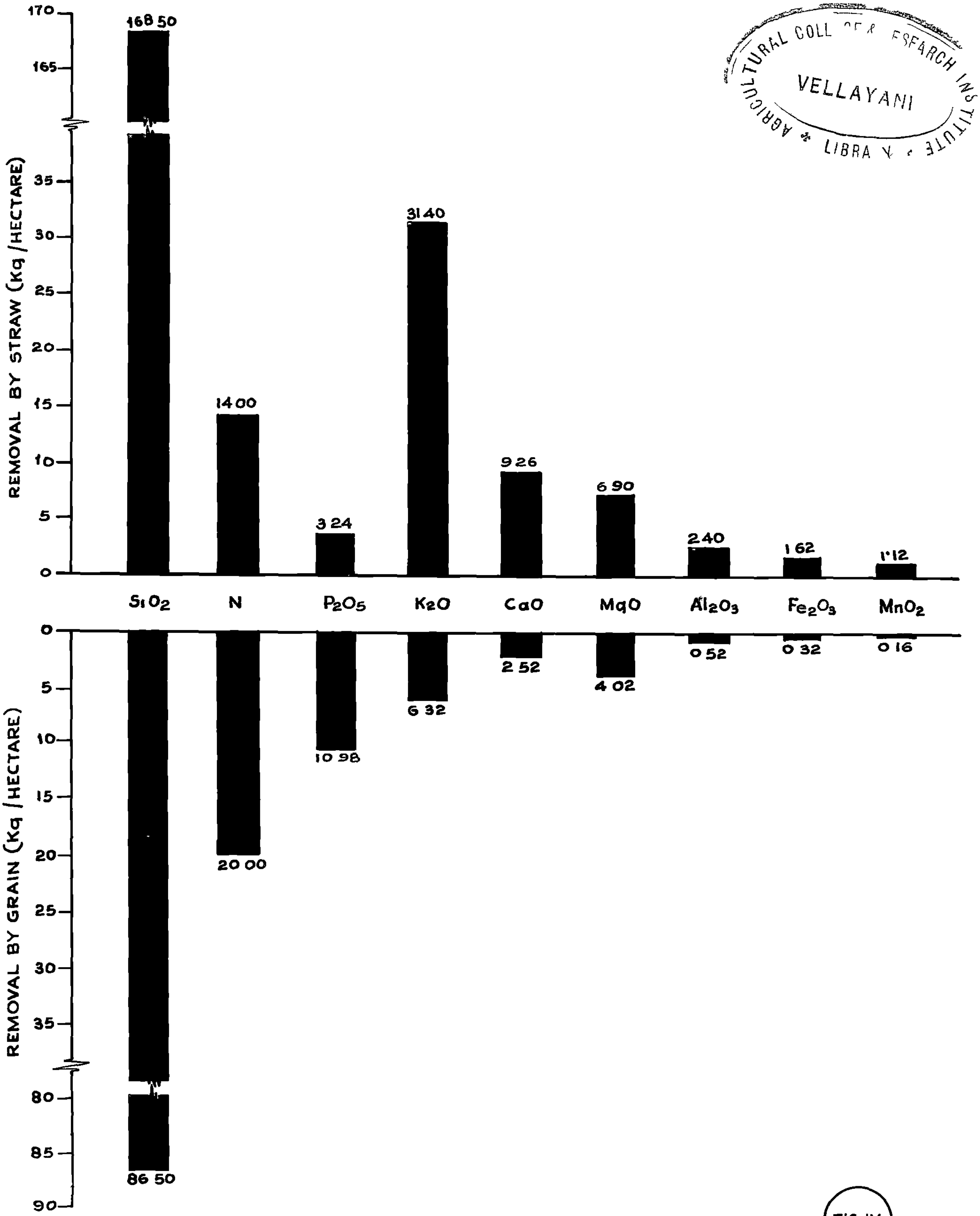

REMOVAL BY STRAW (Kg /HECTARE)
170
165
35
30
25
20
15
10
5
0
168 50
14 00
3 24
31 40
9 26
6 90
2 40
1 62
1·12
SiO_2
N
P_2O_5
K_2O
CaO
MgO
Al_2O_3
Fe_2O_3
MnO_2
REMOVAL BY GRAIN (Kg /HECTARE)
0
5
10
15
20
25
30
35
80
85
90
86 50
20 00
10 98
6 32
2 52
4 02
0 52
0 32
0 16

FIG IX

The results show that the average silica content of river waters of Kerala ranges from 5 to 12 ppm, lowest being 1.6 ppm. The well waters have a lower value ranging from 5 to 7 ppm. Sea water contains the lowest, being 1.6 ppm. The silica content tends to increase with increasing pH. This is particularly noticeable in the case of the Bellary samples.

DISCUSSION

DISCUSSION

The results of the present investigation on available silica in various soil types of Kerala in relation to uptake by rice plants, as well as the fate of added soluble silicate in some of the important rice soils of the State as adjudged by different extractants namely, water, 0.5 N sodium bicarbonate, 0.2 N hydrochloric acid and 0.025 M citric acid are discussed in the following pages.

The study on available silica in the various soil types (Table III & V) shows that the amount extracted depends not only on the nature of the extractants, but also on soil characteristics such as, texture, pH, moisture regime, amount of aluminium and iron.

The sand fraction does not seem to have appreciable influence on the amount of silica extracted by any of the extractants other than 0.5 N sodium bicarbonate which extracts a relatively higher amount of silica from soils containing higher percentage of fine sand. From the Onattukara sandy soil having less than 3 per cent clay and 10 per cent fine fraction (silt + clay), sodium bicarbonate extracts a relatively higher amount of soluble silica than the other extractants. Under the alkaline conditions of extraction, crystalline silica or silicate minerals go into solution as silicate anions. (Jackson and Sherman, 1953). The silica extracted by the alkaline extractant appears to be not entirely available to plants as revealed by the low uptake of silica by rice plants grown on sandy soils. (Table V & XIX).

Gross-Brauckmann (1956) found that uptake of silica by cereals enhanced with the increase in clay content of soil. The silica extracted by the acidic extractant, 0.025 M citric acid is found to be positively correlated with the fine fraction (silt + clay), r = 0.748. (Fig. 3). This would suggest that the citric acid soluble silica is more available to plants than that extracted by the other reagents used. A similar correlation could not be obtained for the hydrochloric acid soluble silica. Moreover, with the increasing quantity of silica extracted a concomitant release of aluminium could be observed. A significant positive correlation (r = 0.955) exists between the amounts of aluminium and silica extracted in the case of hydrochloric acid (Fig.2); while no such relationship is evident between silica and iron. The lack of such a definite relationship in the latter case is probably due to the existence of iron in tropical soils in the oxide form rather than in combination with silica as clay minerals, whereas a definite relationship intho former case is attributable to the simultaneous release of silica and aluminium by the hydrolysis of alumino silicate minerals present in the soil. This corroborates the findings of Jackson and Sherman (1953) and Acquaye (1960), who have found that an acidic environment leads to dissolution of alumino silicates in humid regions. Both citric acid and hydrochloric acid extract larger amounts of silica from the black cotton soils of Chittoor and Bellary (Table V) which contain high amounts of montmorillionite type of clay minerals.

Inspite of the considerable removal of silica by rice crop, the wet land soils have a higher amount of soluble silica when compared with the adjacent uplands. (Table I & III). The enrichment of the low land soils with soluble silica may be due to the accumulation of washed down silica from uplands or the solubilisation of silicates by mineral acids produced in them.

Wet land soils when subjected to drying are found to release high amounts of water soluble silica. This may be attributed to the dissolution of silica by the sulphuric acid produced on oxidation of sulphides present in them. (Table IV). Mineral acid production in acid kari soils has been demonstrated by Money (1961).

In the present study, four different extractants have been employed, two of them being acidic (0.025 M citric acid and 0.2 N hydrochloric acid), one alkaline (0.5 N. sodium bicarbonate) and the other neutral viz., water. Acidic extractants have been usually used by many workers, for estimating the available silica in rice soils. Kawaguchi and Hattovi (1958) used N/5 hydrochloric acid while Ueda and Yamaoka (1959) employed 0.025 M citric acid.

An inverse relationship appears to exist between the soluble silica and iron and aluminium extracted by citric acid from soils. (Table VI). Analysis of plant tissue reveals that a high content of silica is invariably associated with a low content of aluminium and iron. (Table XIX). Therefore it seems justifiable to consider the citric acid extractable silica in soil as more plant available than that extracted by other reagents used.

Significant correlation exists between the silica content of rice plants and the amount of silica extracted by the acidic extractants from the soils. The correlation coefficients and regression equations are given below:-

TABLE XXI

CORRELATION BETWEEN PLANT SILICA AND ACID SOLUBLE SILICA IN SOILS.

	Hydrochloric acid		Citric acid.	
	Correlation coefficient	Regression equation	Correlation coefficient	Regression equation
Straw	0.844	$Y = 150.35x-596.56$	0.740	$Y = 39.12x+9.58$
Whole plant	0.960	$Y = 222.38x-790.98$	0.723	$Y = 49.77x-13.95$

Thoughahigher correlation coefficient was obtained in the case of hydrochloric acid, a study of the steepness of the regression lines (Fig. 8a & 8b) would reveal that citric acid is the more reliable extractant for evaluating plant available silica. This result corroborates the findings of Ueda and Yamaoka (1959) who observed a significant correlation between the available silica in the 'degraded' soils of Japan as extracted by 0.025 M citric acid and the silica content in rice plants.

The availability of four levels of added silicate on a laterite soil and a <u>kari</u> soil as well as their influence on the availability of native phosphorus under different moisture regimes during different periods were studied under laboratory conditions.

The amount of silica extracted increases with the increase in moisture status, amounts of added silicate and duration of incubation. (Table VII to X).

It is evident that high moisture level tends to solubilise more of silica and hence available silica will be higher in waterlogged soils. Sreenivasan (1936) has reported a higher content of soluble silica in waterlogged rice soils.

Though, with increasing levels of added silicate there is an increase in the total amount of silica extracted, the percentage availability of added silica decreases with the increasing doses. (Table XXII).

TABLE XXII

AVAILABILITY OF ADDED SOLUBLE SILICATE IN SOILS.

Levels of SiO_2 added (in ppm)	Citric acid extractable SiO_2 in ppm		Percentage availability of added silica in soils		Average for the soils
	Vellayani soil	Kari soil	Vellayani soil	Kari soil	
50	40	27	80	54	67.0
100	47	40	47	40	43.5
250	85	75	34	30	32.0

From this it would appear that a steady concentration of soluble silica is maintained in the soil and any excess above this limit gets reverted to insoluble forms. Jones and Handreck (1965) have reported that soils have a capacity to maintain a uniform concentration of silica much below the saturation points.

It may be suggested that application of soluble silicates above the level of 100 kg per hectare would not appreciably increase the soluble silica status of these soils.

There is a sharp increase in the amount of soluble silica extracted up to 20 days of incubation beyond which it maintains a fairly steady concentration (Table IX and Fig.5). The concentration of aluminium is also highest at about 20 days after which it is reduced (Table XIV and Fig. 5). The maintenance of a uniform concentration of silica and a decrease in the concentration of aluminium in the soil solution beyond this period may be due to their interaction. This is substantiated by the findings of Jones and Handreck (1965) who reported that aluminium and iron oxides had a great effect in adsorbing monosilicic acid.

Considering the efficiency of the three different extractants used, citric acid appears to be more reliable than the others,as is evident from the smoothness of the curve for the mean quantities of silica extracted at different levels of added silicate (Fig.6). However, it may be noted that hydrochloric acid extracts greater amounts of silica than citric acid. But because this is accompanied by greater solubilisation of aluminium and iron which is not reflected in the actual uptake by plants, hydrochloric acid cannot be recommended for evaluation of plant available silica.

The differential behaviour of the two different soils, viz., laterite soil and _kari_ soil, with respect to the release of soluble silica as influenced by moisture regimes, levels of added silicate and periods of incubation is discussed below.

The _kari_ soil has a higher soluble silica content than the laterite soil (Table VIII and Fig.4). This may be due to the contribution of opaline silica in the organic matter. An increase in the moisture regime tends to release more soluble silica in _kari_ soil than in laterite soil.

The percentage availability of added silica (Table XXII) is invariably low in the organic matter rich _kari_ soils. This may be ascribed to the fairly high concentration of soluble silica already existing in the kari soils and the consequent precipitation of the added soluble silicates. Probably the high aluminium and iron contents of the _kari_ soils contribute to this process. (Table XIV to XVII).

The rate of release of soluble silica is considerably higher in the _kari_ soil than in the laterite soil (Fig.5). This may probably be due to the difference in the forms of silica that undergo solubilisation.

Applications of soluble silicates have been shown to increase the availability of native phosphorus and to reduce the fixation of added soluble phosphatic fertilizers. (Albritton and Ellis, 1957, Raupsch and Piper, 1959). In the present investigation, it is found that in the case of the laterite soil only the highest dose of added silicate viz., 500 kg per hectare, registers a statistically significant increase in the available phosphorus. In the kari soil however even the highest dose of added silicate does not increase the availability of native phosphorus (Table XI and Fig.7).

Anion exchange between phosphate and the added silicate could be the cause for the release of phosphorus. The rate of release of phosphorus decreases beyond 20 days (Table XIII and Fig.5). This is perhaps due to the precipitation of released phosphorus by aluminium, the concentration of which is also found to decrease beyond 20 days. An increased release of phosphorus with an increase in the moisture status of the soil is observed (Table XII). This corroborates the findings of Nair (1965) who recorded an increased release of native phosphorus from most of the soils of Kerala State on incubation at full saturation.

A study of the nutrient uptake by different varieties of rice grown in various tracts of Kerala under the local cultivation practices reveals certain general trends in the silica uptake and brings out its influence on the absorption of other nutrients(Table XIX). Irrespective of the varietal differences and soil variations, ratio of silica content in straw and grain is maintained approximately at 2:1. Variation in total silica content of plants could mainly be attributed to the differences in available silica status of the soils. PTB.26 grown in different soils, namely; laterite soil of Vellayani and the black soil of Palghat, shows a remarkable difference in their silica contents. Different indica varieties namely; SLO.17, MTU.19 and WND.2 grown in the hill soils of Ambalavayal show no significant difference in the total silica content of grain and straw, inspite of considerable variation in their dry matter yields. Indica varieties namely; PTB.4 and PTB.16 and the japonica variety taichung 65 grown on the same tract at Karamana show no significant difference in silica content of grain and straw, though the yields are comparable. It is significant here to note that the japonica variety has a higher grain to straw ratio than the indica varieties. For this reason, for comparable grain yields, indica varieties are likely to remove more silica than the japonica variety.

The silica content of the rice plant is found to be quite independent of the varieties but, is dependent on the available silica status of the soil. Similar results have been reported from Japan (Rural Research Report No.7, 1964).

Kyogoto (1960) found that the average silica content of the rice plant varies from 3 to 20 per cent and has claimed a minimum content of 12 to 13 per cent to be essential for higher rice yields. In Kerala, it varies from 4 to 12 per cent and plants with a silica content of 8 per cent gave fairly high yields. Kyogoto (1960), however, obtained a positive correlation between the silica content and the yield. No such relationship seems to exist between the silica content and yield under normal cultivation practices of the State.

When the relationship between silica content of rice plant and each of the nutrients viz., nitrogen, phosphorus, potassium, calcium, magnesium, iron, aluminium and manganese is considered (Table XIX) the following general trends could be observed. A low content of silica in the plant tissue is associated with relatively high value for phosphorus. Nevertheless, a higher percentage of silica does not seem to influence the phosphorus content. However, a higher content of silica in plant is invariably associated with low values of metallic cations namely; iron, aluminium and manganese. Similar nutrient interactions in rice plants have been recorded by Okuda and Takahashi (1961) but from nutrient culture studies.

The contribution of irrigation waters to the silicon nutrition of rice is considerable. Imaisumi & Yoshida (1958) are of the opinion that 30 per cent of the requirements of silica could be met from this source alone.

The river waters of Kerala are found to have a higher content of silica namely; 12 ppm, while the well waters recorded only lower values, ranging from 5 to 7 ppm (Table XX). The values obtained from river waters are in agreement with those reported by Acquaye (1960). The silica content of well water from a typical black cotton tract is relatively high, namely; 50 ppm. This may be, perhaps, due to the prevailing high temperature and pH. Sea water from Kerala coast registers the lowest value of silica being 1.6 ppm, which is almost in agreement with the value of 1.0 ppm reported by Siever (1957).

Based on the results of the present study on the available silica status of Kerala soils and irrigation waters, it is estimated that on an average the soils contain 600 to 700 kg of soluble silica per hectare (Fig.1) and the irrigation waters contribute about 30 kg per hectare. An average rice crop in Kerala removes about 250 kg of silica per hectare per crop (Fig.9). For a high yielding crop, it has been reported from the International Rice Research Institute, Phillippines, that the removal of silica may be as high as 830 kg per hectare per crop. (Tech.Bull. No.3, 1964 of the I.R.R.I., Phillippines).

For low yielding strains of rice, it would thus appear that silicate application may not substantially contribute to their nutrition, as the soils contain more than the required amounts of available silica in addition to the amounts supplied by irrigation waters. The results further show that application of soluble silicates above 50 to 100 kg per hectare may not appreciably increase the available silica status as they react with the sesquioxides of the soil. However, response to silicate application has been recorded by a number of workers in the 'degraded' soils of Japan (Yoshida et al 1959, Izawa & Kume 1959, Kyogoto 1960) and also by Padmaja and Verghese (1966) for the laterite soils of Kerala. The increased yields obtained by Japanese workers are for the 'degraded' soils which are notorious for their low available silica status. Padmaja and Varghese (1966) in their pot culture studies have grown plants in upland red loam low in available silica status (Table I and V). Perhaps, the low status of available silica of those soils might explain the significant response recorded by them.

The results of the present investigation on the available silica status of Kerala soils emphasise the need for plant response studies under field conditions.

SUMMARY AND CONCLUSION

The distribution and status of soluble silica in the surface soils of low land rice tracts and uplands distributed over the important soil types of Kerala were assessed employing different extractants, viz., water, 0.5 N sodium bicarbonate, 0.2 N hydrochloric acid and 0.025 M citric acid. Correlation studies were made between available silica in soil and uptake by rice plants. Irrigation waters from different sources were also analysed for silica content. Soil characteristics like, texture, moisture regime, pH, organic carbon, iron and aluminium content, that are likely to influence the availability of soluble silica, were also investigated. The availability of four levels of added soluble silicate in the laterite soil and *kari* soil, as well as their influence on the availability of native phosphorus under different moisture regimes during different periods were studied under laboratory conditions. The effect of iron and aluminium on the availability of added silicate was also examined.

The following conclusions could be drawn from the results.

1. Among the four different extractants used for assessing available silica status, it is found that 0.025 M citric acid is the most reliable.

2. Citric acid extractable silica is positively correlated with the fine fraction of the soil ($r = 0.748$) and with the silica content of the rice plant ($r = 0.723$).

3. Water soluble silica content varies from 8 to 10 ppm in the sandy soils of Onattukara, 20 to 30 ppm in the low land laterite soils, 50 to 70 ppm in the black soils, and 75 to 100 ppm in the <u>kari</u> and <u>kayal</u> soils of Kerala, while the citric acid soluble (available) silica in the soils are 90 ppm, 330 ppm, 395 ppm and 675 ppm respectively.
4. The low land rice soils in general have a higher available silica status than the upland soils.
5. Drying a wet land soil increases the water soluble silica by approximately 15 per cent.
6. For a given soil type the available silica is maintained at a fairly steady concentration.
7. Application of soluble silicates to soils enhance the availability of silica upto 20 days,beyond which it is maintained at the steady concentration specific to the soil.
8. The interaction between added soluble silica and iron and aluminium in soils is evident.
9. Though with the increasing levels of added silicates there is an increase in total amounts of silica extracted the percentage availability of added silica decreases with the increasing doses. This is more pronounced in the organic matter rich <u>kari</u> soil.
10. Application of soluble silica above the level of 100 kg per hectare does not appreciably increase the soluble silica status of the soil.

11. In the kari soil even the highest dose of added silicate does not increase the availability of native phosphorus, while in the case of laterite soil only the highest dose of added silicate, 500 kg per hectare registers a significant increase in the available phosphorus.

12. The silica content of the rice plant is found to be quite independent of the variety but is dependent on the available silica status of the soil. It varies from 4 to 12 per cent and 8 per cent silica content appears to be sufficient for high yields.

13. The ratio of silica content of the straw and grain is maintained at 2:1 irrespective of the varietal differences and soil variations.

14. No correlation could be established between silica content of plants and rice yields under local manurial and cultural practices.

15. A low content of silica in the rice plant is associated with high values of phosphorus. Nevertheless, a higher percentage of silica does not seem to influence the phosphorus content. However, a high value is invariably associated with low values of metallic cations viz., iron, aluminium and manganese.

16. On the average the Kerala soils contain 600 to 700 kg available silica per hectare and irrigation waters contribute about 30 kg per hectare per crop of rice.

17. An average rice crop in Kerala removes about 250 kg of silica per hectare.

It would appear from the results of the present investigation that for the low yielding varieties of rice soluble silicate application may not substantially contribute to their nutrition because the soils contain more than the required amounts of available silica in addition to the contribution made by the irrigation waters. The results further show that application of soluble silicate above 50 to 100 kg per hectare may not appreciably increase the available silica status as they react with the sesqui oxides of the soil and is rendered unavailable.

The results of the present study on the available silica status of Kerala soils, thus emphasise the need for plant response studies under field conditions.

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* Originals not seen.

APPENDIX

APPENDIX

I

ANALYSIS OF VARIANCE FOR THE SILICA EXTRACTED FROM SOILS INCUBATED WITH SOLUBLE SILICATE UNDER LABORATORY CONDITION.

Source	S S	df	Variance	F ratio
S	849783	1	849783	304.00**
M	71913	1	71913	25.80**
S M	18354	1	18354	6.58*
L	89101	3	29700	10.64**
S L	4590	3	1530	1
M L	418	3	139	1
P	267346	2	133673	47.89**
S P	5554	2	2777	1
M P	100148	2	50074	17.94**
L P	1732	6	289	1
E	8428888	2	4214444	1510.01**
S E	688229	2	344115	123.29**
M E	30346	2	15173	54.36**
L E	30648	6	5108	18.30**
P E	113437	4	28359	10.16**
Error	287507	103	2791	

* Significant @ 5% level

** Significant @ 1% level

S_2, M_2, L_4, P_3 & E_2 are the best.

APPENDIX

II

ANALYSIS OF VARIANCE FOR THE PHOSPHORUS EXTRACTED FROM SOILS INCUBATED WITH SOLUBLE SILICATE UNDER LABORATORY CONDITION.

Source	S S	df	Variance	F ratio
S	0.30	1	0.30	1
M	46.15	1	46.15	8.88**
S M	0.09	1	0.09	1
L	20.90	3	6.97	1.34
S L	9.74	3	3.25	1
M L	6.93	3	2.31	1
P	544.22	2	272.11	52.33
S P	5.42	2	2.71	1
M P	1.73	2	0.86	1
L P	15.29	6	2.55	1
E	1103.89	2	551.95	106.14**
S E	2.76	2	1.38	1
M E	209.00	2	104.50	20.10**
L E	11.21	6	1.87	1
P E	549.76	4	137.44	27.49**
Error	535.34	103	5.20	

* Significant @ 5% level.

** Significant @ 1% level.

M_2, P_2 & E_2 are the best.

APPENDIX
III

ANALYSIS OF VARIANCE FOR ALUMINIUM EXTRACTED FROM SOILS INCUBATED WITH SOLUBLE SILICATE UNDER LABORATORY CONDITION.

Source	S S	df	Variance	F ratio
S	2028607	1	2028607	126.88**
M	12538	1	12538	1
S M	56688	1	56688	3.55
L	7510	3	2503	1
S L	85	3	28	1
M L	9095	3	3032	1
P	5893929	2	2946965	184.32**
S P	773360	2	386680	24.31**
M P	320994	2	160497	10.04**
L P	402	6	67	1
E	14911292	2	7455646	466.33**
S E	1070755	2	535378	33.49**
M E	91242	2	45621	2.85
L E	21550	6	3592	1
PE	3747431	4	936858	58.60**
Error	1646764	103	15988	

** Significant @ 1% level. S_2, P_2 & E_2 are the best.

APPENDIX
IV

ANALYSIS OF VARIANCE FOR IRON EXTRACTED FROM SOILS INCUBATED WITH SOLUBLE SILICATE UNDER LABORATORY CONDITION.

Source	S S	df	Variance	F ratio
S	92997414	1	92997414	655.45**
M	615414	1	615414	4.34*
S M	813484	1	813484	5.73*
L	990760	3	330253	2.33
S L	949030	3	316343	2.23
M L	675414	3	225138	1.59
P	10123543	2	5061772	35.68**
S P	1745234	2	581745	4.10*
M P	636428	2	318214	2.24
L P	1030526	6	171754	1.21
E	148484408	2	74242204	523.26**
S E	45002761	2	22501381	158.59**
M E	17709170	2	8854585	62.41**
L E	1535322	6	255887	1.80
P E	11262271	4	2815568	19.84**
Error	14613943	103	141883	

* Significant @ 5% level
** Significant @ 1% level

S_2, M_1, P_3 & E_2 are the best.