POTASH NUTRITION OF RICE WITH REGARD TO THE EFFECT OF CALCIUM, MAGNESIUM AND SILICON

By

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THESIS

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CERTIFICATE

This is to certify that the thesis herewith submitted contains the results of bonafide research work carried out by Miss. C. Usha 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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C O N T E N T S

INTRODUCTION

At the present day, the outstanding problem for the whole world in general and for India in particular, is the inadequacy of food supplies. Now we are hardly in a position to feed the rapidly growing population. Lack of many-sided development in agriculture is the reason for this pitiable situation. In the long run, the situation can be remedied only by increasing agricultural productivity.

Since the principal food of nearly half the world's population is Rice, it is very necessary that at this time maximum attention should be given to its cultivation. This is particularly so in India where rice is the major food crop and about three-fourths of the people subsist on it.

One of the important and well established methods of raising rice yields is optimum fertilization of the rice fields. Extensive fertilizer trials have been conducted under different soil and climatic conditions by the Agricultural Departments of various States. Along with these, fundamental studies have been undertaken on the growth and nutrient uptake of the crop. From the manurial experiments conducted it became clear that rice is a fairly heavy feeder on nitrogen and that relatively large amounts of this plant food help in maximisation of production. Phosphates are also usually applied in large quantities. On the other hand, comparatively little attention has been paid to the use of potash, the third major plant food.

There are several reasons why potash has not received proper consideration in rice production.

FIRST:- Soil analysis often shows that the total potash content of the soils is comparatively high and this has led to the general belief and tacit assumption that potash manuring is not required for Indian Soils.

SECOND:- The fact that only a very small part of this "total potash" content is actually available to the rice plants during the growing seasons, is left out of consideration.

THIRD:- The number of exact potash experiments with rice is relatively small and in many cases, these trials have been conducted at experimental stations where the soil conditions are special and not typical of average farm conditions. Further, the tests that have been carried out on average farm soils or cultivator's fields have not been conducted for sufficiently long periods to give conclusive results.

FOURTH:- The effect of potash is not as easily observed by the primitive farmer, as the spectacular growth obtained with increased doses of nitrogen.

For these reasons, the role of potash in rice produc- ction for maximum economic yields and high quality of grain and straw has been somewhat neglected. Moreover, little attention has been paid to the dangers which arise from one-sided fertilization of rice where the farmer continues to include little, if any, potash in his fertilization programme. The use of potash in rice production has made remarkable progress in Japan in recent years. Many Japanese farmers have accepted the results of scientific research and practical field tests with potash and have put into practice a balanced fertilizer programme for rice, which includes adequate amounts of the three principal plant foods--nitrogen, phosphoric acid and potash. The need for all the three of these plant nutrients is generally recognized in Japan and now in India.

But sufficient data are not yet available with regard to the need for potash manuring in the rice soils of Kerala. At the same time, it is well known that rice soils of Kerala are highly deficient in calcium and magnesium. For these reasons, the Kerala Department of Agriculture has planned an extensive liming programme for the rice growing soils of the State. It is known that liming the soil,affects the available potash contents in the soils,sometimes increasing it and sometimes decreasing it. This is essentially decided by the clay mineralogical composition. Moreover, the presence of divalent ions like calcium and magnesium beyond a certain ratio may adversely affect the potash uptake by rice plants even if potash is present in large amounts in the available form.

It was therefore considered worthwhile to study the potash nutrition of rice with special reference to the effect of calcium, magnesium and silicon on the fixation and/or release of soil and fertiliser potassium and its utilization by the rice plant grown in an acid paddy soil.

REVIEW OF LITERATURE

Although much work has been done and much has been written regarding the use of potassium in agriculture, the importance of this nutrient in rice production has been recognised only very recently. The efforts made by previous workers to throw light on the different aspects of potash nutrition of plants with special reference to rice are briefly reviewed in this chapter.

A. Effect of Potash on plant growth and yield.

As an essential element for plant growth, potassium presents a challenge to workers who wish to establish its role and exact functions in plants since potash plays no apparent structural role. It appears inter alia to be of importance in the synthesis of polymeric carbohydrates and proteins, assimilation, the reduction of nitrates, in cell devision and in the water economy of plants.

Early studies by Helliriegal (1898) and Wilfarth and Wimmer (1902) demonstrated a close relationship between carbohydrate content and Potassium level. Hibbard and Grigsby (1934) found that garden peas growing in minus potassium solutions produced simple sugars, starches, sucrose, hemicelluloses and proteins but in less quantity than plants grown in complete nutrient solution. They concluded that a lack of potassium retarded protoplasmic mechanisms, which in turn retarded carbohydrate accumulation and other processes. Miller (1938) and Hoffer (1938) found that potassium is essential for various metabolic activities of living cells.

Aiyer (1948) observed that a moderate deficiency of potassium caused no serious disturbances in the rice plant whereas an acute deficiency resulted in stunted plant with short, soft stem, reduction in effective tillers, short stiff leaves with ends bent like hooks, or nearly horizontal, change of colour to yellow in early stages followed by change to blue green colour, which later on persisted throughout the growth period.

In 1952 Noguchi and Sugawara published "Studies on the Effect of Potassium on the Rice Plant" and they reported results of their investigations on the effect of potash on growth, health and productivity of rice plants. They observed that the number of tillers was smaller for plots without potash. According to them yields of grain and straw decreased with progressing potash deficiency.

Singh (1953) from his various research studies on cereal crops found that potassium gave better stand and yield. He concluded that Indian Soils generally require also phosphate and potash in addition to nitrogen and he recommended the use of potash for cereals like dry and wet-land paddy, bajra, jowar and wheat. Mukerjee, et.al. (1955) obtained positive response to potash in five out of nine soils containing even 0.01 per cent citric acid soluble potassium. Mukerjee (1955) suggested that the failure to obtain potash response has been due to unsuitable technique of experimentation followed for such work. According to him, the view that Indian Soils are well supplied with potash reserves is also not tenable. In 1957, the results of Potaschemes N.P.K. trials proved that (1) potash increased the yield of crops in the presence of N.P. when compared to N.P. alone and (2) that potash not only increased the yield in the year of application but also left a good residual effect. Mitra et.al. (1958) observed that response of rice to potassium fertilizers was related more to the availability based on the geological origin of the soil than to a single chemical test which does not take seasonal variations in potassium availability into account. Cuthbertson's (1960) water culture studies with rice revealed that potassium applied to rice 35-45 days before heading increased the 1000 grain weight where as potassium applied after that period had little effect. Ray Chaudhari and Landy (1960) showed the effect of soil reaction on the availability of potassium.

According to them, the available potassium generally decreases with decreasing pH in the case of alluvial sandy soil (Rajasthan) and laterite soil (Kerala) whilst in the other cases, the available potassium is maximum at a definite pH value. According to Mortland (1961), the rate of fixation should be inversely related to the initial potassium content of the soil clays. The amount of reactive potassium is proportional to the total potassium content of soils. Clays with lower initial potassium contents have a greater rate of fixation.

Thakazhi (1961) found by experiment that during the course of the growth, the rice plant requires a lot of sugar as the source of energy and sugar is formed in the leaves from carbon dioxide and water through the function of chlorophyll, sunlight and a number of essential elements among which potassium plays an important role. According to Harikawa and Kawaguchi (1963) the increased absorption of potassium under submergence was directly attributable to soil reduction which is mostly associated with the specific nature of 2:1 clay minerals and the dyanamic status of other soil constituents. Shey, Su, Lin and others (1964) found that correlation between soil exchangeable potassium before transplanting and potassium content of rice straw at harvest and at full ear elongation were highly significant on reddish brown latosols.

B. Effect of other nutrients on the uptake of potassium.

1. Nitrogen.

According to Richard (1938), plants growing in solutions high in ammonium salts and low in potassium fail to form ear or die on account of ammonium accumulation. It was observed in the case of cereal crops, that the full utilisation of nitrogen is possible in the presence of potassium. Anon (1956) and Sircar and Datta (1957) found that potassium when applied with ammonium salts, the one great theoretical consideration is the rate at which the ammonium ion is metabolized to organic nitrogen as otherwise its accumulation will lead to toxicity. It has been suggested that potassium plays an important role in the synthesis of amino acids and proteins. Van Gontard (1959) suggested that potassium operates as an antagonist to nitrogen. Excess of nitrogen causes certain physiological disorders. But these undesirable results from too high dressings with nitrogen can often be corrected if the plant received sufficient potash. A balanced ratio of nitrogen and potassium has therefore to be maintained if one aims at the production of quality crops. Govind and Tilak R Chadha (1959) summarised the results of their experiments on rice as follows:-

(1) Higher dose of nitrogen gave good responses at all the centres for the second crop of paddy.

(2) The increased dose of nitrogen generally gave the highest profit when applied with higher dose of potassium.

2. <u>Phosphate.</u>

A large number of fertilizer experiments on paddy have been conducted by the Agriculture Departments in various States, under different soil and climatic conditions. Reviewing 52 experiments on paddy conducted upto 1931, Vydianathan (1933) suggested that potash gave a negative response. Coowie (1942) noted that addition of both phosphorus and nitrogen enhanced potassium deficiency in potatoes. Lawton et.al. (1952) found that the per cent potassium in legume hay was reduced from 1.52 to 1.35 when super phosphate was applied to soils already treated with potash. Digar (1960) suggested from the results of manurial experiments on paddy conducted at Sreenikethan Farm, that the combinations of 30 lbs. of Nitrogen with 60 lbs. of P_2O_5 appears to be the best for higher production. Daji (1965) made the following recommendations for the manuring of rice:-

(1) The optimum dose of nitrogen is found to vary between 20 and 60 lbs. per acre.

(2) The optimum dose of phosphoric acid varies between 20 and 40 lbs. per acre when applied in combination with nitrogen.

(3) The optimum dose of potash varies between 20 and 40 lbs. per acre. Both muriate and sulphate of potash are equally effective, but the former is cheaper to use. It should be applied before the crop is transplanted.

3. Potash.

Many investigators have reported increases in potassium content of cereal straw, legume and grass hay, vegetable and root crops and foliage of fruit trees upon the application of potash fertiliser to soils. Boynton and Burrell (1944) found that potash fertilization of apple trees consistently raised the per cent potassium in the leaves. Bear and Prince (1945) reported excessive absorption of potassium by alfalfa and recommended application at frequent intervals during the life of alfalfa stands. Nelson et.al. (1945) suggested that use of increasing amounts of potash fertilizer greatly increased the potassium content of one variety of soybean seed. According to Snyder (1947), the use of potassiumfor four Illinois soils relatively low in available potassium increased the potassium content of wheat and oat straw on an average by 100 per cent. In a comparison of potash and phosphate mixtures with phosphate alone Dunn and Rost (1948) showed that applied potash increased the potassium content of potato.

According to Russel (1950), the average increases in potassium content of grass hay grown at the Rothamstead Station during an 18 year period for PK–P and NPK—NP treatments was 1.45 and 1.60 per cent. Again Aldrich and Coony (1952) found that potassium content of leaves was significantly increased by soil application of potash fertilizer. In a green house study Tucker and Smith (1952) noted that addition of potash fertilizer to soil always resulted in an increase in the potassium content of red clover.

From various experiments conducted it was suggested in 1959 (Anon) that in the Community Project areas of Pusa and Rameshwar (Bihar), Chalakudy (Kerala) and Raipur (M.P.) application of 20 lbs. of K_2O per acre increased paddy yields by two to three maunds per acre. Raji (1965) suggested that application of fertilizers increased yields ranging from two to nine per cent in the case of N P treatment and from 12 to 22 per cent for N.P.K. treatment. These trials emphasised the necessity of applying potash in addition to nitrogen and phosphoric acid to obtain higher yield of rice.

4. Calcium.

Numerous workers have studied the influence of calcium compounds on soil reaction, nutrient availability and plant growth. Considerable attention by a large number of workers has been concentrated on the effects of calcium on the behaviour and availability of soil potassium. Liming has been shown to bring about changes in the water soluble, exchangeable and fixed potassium content of soils, including fixation of available potassium and its release under suitable conditions.

Troug (1918) et.al. attributed the beneficial role of calcium in crop production to its effect in reducing soil acidity. Ehrenberg (1919) presented the idea of decreased uptake of potassium and low yields on limed soils to an "antagonistic effect" between calcium and potassium.

Hester and Shelton (1936) grew lima beans on three soils limed to various levels and measured the quantities of potassium absorbed and that leachable by water. He found that water soluble potassium decreased with increasing calcium saturation. Total potassium uptake increased with increasing pH and was even higher in presence of excess lime than at the lower lime level.

It has also been definitely established that alkalinity and liming increase the tendency of soils and clays to fix potassium in forms not immediately exchangeable. Gilligan (1938) treated electrodialysed Chesterloam and Sassafras silt loam with $Ca(OH)_2$ to provide calcium saturation of 0, 50, 75, 100 and 200 per cent. The extent of fixation of potassium of 0.4 m.e. of Kcl when dried at 85°C, increased almost linearly as the degree of calcium saturation. But according to Viet (1942) calcium ions can increase the permeability of plant tissues to potassium ions. This view was supported by many other workers. Stanford et.al. (1942) observed that more potassium fertilizer is generally required for crops grown on nearly neutral or alkaline soils. Darls ~ (1945) observed that either lime or potash applied alone to a soil might be of no value and some times actually cause reduced yields, but when the two nutrients were applied in the proper balance highly beneficial results could be achieved. Joffe and Levine (1947) showed that potassium fixation was reduced when potassium ions had to compete with calcium ions for exchangeable positions and that potassium fixation increased in proportion to the quantity of potassium ions entering the exchange complex.

According to York and Rogers (1947) it would be extremely difficult to make generalisations regarding the influence of lime on the availability of potassium in the soil because it was dependent upon the nature of soil and many other factors. Lucas and Davis (1961) suggested that soil pH has less influence on potassium. According to them very acid soils usually have less than 0.1 per cent potassium while those of well limed average about 0.15 per cent.

The question of the effect of lime on fixation or release of soil potassium is still an open one. Liming has however been a common practice in rice culture. Abichandani and Patnaik (1961) have reported that extensive trials on lime application to rice soils conducted in India have shown significant increase in yield of grain due to lime application at 2000 lbs. per acre. According to them lime response in combination with nitrogen fertilizer tended to decrease with increase in nitrogen supply. On the other hand, lime response was higher with phosphate fertilizer than without it. Money and Varghese (1965) showed that calcium tended to increase available K_2O in the soil.

5. Magnesium.

Troug et.al. (1947) noticed that by increasing concentrations of magnesium, the nitrogen content of peas went up slightly. But there was only very negligible increase in the potassium content with additions of this element in an available form. Cooper et.al. (1947) observed that crops containing a relatively large quantity of magnesium such as potatoes, cotton, tobacco, buck wheat and some vegetables often gave a marked response to applications of magnesium in mixed fertilizers as indicated by their yields. It would appear that potassium has a favourable influence on the uptake of magnesium. The beneficial effect of magnesium on potash nutrition. has also been reported. Thus Walsh and Lamb (1955) found that fruit trees infected with magnesium eliminated potash deficiency, the effect of this application being due among other things to the increase in the mobility of potash.

6. Silicon.

The discovery of silica in plant ash by De Sassure (1904) paved the way for a series of investigations on the role of silicon. Okawa and Kinsaku (1936) conducted water culture experiments with rice and barley to study the physiological action of silicic acid on plants. They observed that plants grown in culture solutions with silica produced ear-head with higher percentage of potassium than the control plants. According to Fritz (1940) investigating the importance of silicic acid in plant nutrition, recorded an accumulation and better utilisation of potassium when applied along with it. Okamato (1959) reported that plants from silica deficient plots had low potassium content. Utagawa and Kashima (1963) studied the physiological functions of silicic acid applied to rice and wheat. They observed that potash contents of leaf sheath increased with silica treatments. Padmaja and Verghese (1964) obtained increased potash contents in grains and straw of rice on the application of silica either alone or in combination with calcium or magnesium. These results have been confirmed by subsequent work (Sadanandan and Verghese (1965).

C. Physiological role of potash.

Data presented by Nightingale (1930) and James and Penston (1933) emphasised that the fact that high potassium concentrations are associated with actively growing plant tissues. Gregory and Sen (1937) reported decreased carbon dioxide assimilation and increased respiration in potassium deficient barley plants. According to Thomas and Mack (1941), certain infections were associated with a low level of potash nutrition especially characterised by high levels of nitrogen.

A number of investigations have shown that potassium fertilizer increased the oil content of certain crops. Nelson et.al. (1945) reported that liberal application of potash fertilizer to a soil low in potassium increased the oil content of two varieties of soybeans by an average of 1.5 per cent. Stewart (1947) has reviewed more recent experiments and mentions positive responses to potash on wheat and groundnut. Brown and Potter (1949) found significant increases in yield and oil content of fruit from tung trees fertilized with potassium. Govindarajan (1955) in his recommendations advised the use of potash on paddy "when grain setting appears affected and empties appear through poor grain formation or filling". He also suggested the use of potash as a N,P,K mixture, in the cultivation of crops like ragi, cotton, maize, jowar, tobacco, potatoes, chillies, onions, ginger and other vegetable and plantation crops. According to Satyanarayana (1957), the results of a large number of experiments carried out in cultivators' fields in North Bihar have shown that potash considerably increased the yield and higher the dose, the higher was the response.

D. Deficiency symptoms.

Potassium deficiency symptoms are characterized by a sharp contrast between the yellow and green areas of the leaves of many crops. In the later stages of potassium starvation, leaf edges become necrotic and the tissue disintegrates, giving the leaf a ragged appearance. Excellent reviews of potassium deficiency symptoms of the common crops have been presented by Eckstein <u>et.al</u>. (1937). According to Hester (1941 a), tomato fruits grown on soils low in available potassium are commonly low in sugars and ascorbic acid. Foliage is rapidly lost on potassium--deficient plants, exposing the fruit. Chapman <u>et.al</u>.(1947) found that slight potassium deficiency in orange trees was indicated first by a low content of leaf potassium. A slightly more serious deficiency was manifested by a slight reduction in the size of the fruit. Mulder (1949) found an inverse relationship between potassium supply to potato plants and the content of free tyrosine in the tuber. According to Nelson (1949), the use of potassium fertilizer produced marked increases in boll weight, mean fibre length and weight and per cent of mature fibres in cotton. The most striking symptom of potassium deficiency in the cotton plant is known as "Cotton rust".

Wallace (1951) suggested that a shortage of potassium in the cereal grains may result in a bluish-green colour of young leaves, excessive tillering, shrivelled and immature grain. The excessive tillering may be due to an excess of phosphorus over potassium. In 1956 some workers reported that in cereals potash increases starch production and the grains become heavy. It guards against lodging of plants and shedding of grains. It is observed that full utilisation of nitrogen is possible in the presence of potash. According to Thakazhi (1961), potassium is and indispensable element for the growth of a plant. Potash deficiency is known to effect adversely the formation of carbohydrates and proteins, the action of various enzyme systems like coenzyme, particularly coenzyme A, pyruvic acid phospherase, lactase, enzymes connected with carbohydrate metabolism etc. and for the translocation of produced substances. The plant's water relationships are also adversely affected---a larger quantity of water being necessary for the production of unit weight of dry matter. The rate of transpiration is higher in potash starved plants. This leads to wilting of the plants when the roots are not able to supply enough water to cope up with the transpirational loss. At a later stage this leads to marginal scorching of the leaves. It is also well known that potassium increases resistance against lodging. Thakazhi (1961) also suggested that when potassium is constained abundantly in the plant body, it decreases the bad effects of weather conditions upon the growth of the plant. The relationship between potash deficiency and parasitism has been reported by Schaffnit and Volk (1930).

MATERIALS AND METHODS

The present work was undertaken with a view to study the potash nutrition of rice with and without Calcium, Magnesium, Calcium and Magnesium and Silicate. To facilitate the investigation, a field experiment with split plot in Randomised Block Design was laid out. Sufficient number of replications were given to enable chemical analysis of the plants during their growth periods.

A. Field Experiments

1. Site selected for the Experiments and soil analysis.

The experiment was conducted at the Kayal land of Agricultural College Farm, Vellayani, usually cropped with wet land paddy. The site selected had uniform soil conditions.

2. Lay out of the experiment.

A split plot in Randomised Block Design was laid out with fifteen treatments---three major and five sub treatments---with four replications. Details of treatments are given at the end of this Chapter and the lay out is illustrated in figure 1.

3. Preparation of land.

The site selected for the study was ploughed four times and then the experimental area was devided into four blocks of uniform size. Between the four blocks channels of about one foot width were made for irrigating the crop. Each block was then devided into three sub blocks each containing five plots of uniform size (14' x 14'). Firm bunds were laid out in between the plots as well as blocks. Provision was also made for irrigating the plots by means of channels.

4. Manures.

Ammonium sulphate, 40 lbs. per acre and superphosphate at the rate of 30 lbs. per acre were applied as basal dressing.

The potash was applied as muriate of potash 0, 30 and 60 lbs. K_2O per acre.

Magnesium and calcium were applied on the basis of one fourth lime requirement of the soil estimated previously. Silicate added was in the form of calcium magnesium silicates. It was prepared in the laboratory as a mechanical mixture of calcium carbonate and Magnesium silicate.

These manures and calcium magnesium silicates were applied before transplanting.

5. Seedlings and planting.

Paddy strain selected for the experiment was PTB.4. 35 days old seedlings were transplanted in the plots in line, with 9" spacing. Altogether there were 20 x 20 seedlings with in a plot.

6. Irrigation.

The seedlings were irrigated on alternate days so as to maintain a constant level of one and a half inches of water over the surface of the soil.

7. Observations.

Observations on plant height and tiller counts were made at monthly intervals in order to study the effect of different treatments on plant performance. The measurements were made on plants selected at random according to the method described below and illustrated in figure 2.

In each plot four rows of plants on left side were left out to avoid border effects. In one case the plants in the 5th, 6th, 7th and 8th row and 9th, 10th, 11th and 12th column totalling 16 plants were selected. In the other case, the plants in the 12th, 13th, 14th and 15th row and 12th, 13th, 14th and 15th column (total 16 plants) were selected. Each sub-plot thus contained two small 'observation' plots each with 16 plants.

a) Plant Height.

This was recorded on 8 plants—the corner plants of the observation plots—at monthly intervals from the date of transplanting. The measurement was taken from the surface of the soil to the tip of the last leaf of the selected plants.

b) Total number of tillers.

The tiller counts were made at monthly intervals on all the 32 plants of the observation plots. A total of 3840 counts were recorded during the course of the study.

8. Plant samples.

One plant adjacent to one of the observation plots was collected as sample for analysis.

At each sampling, there was a total of sixty samples. The first set of samples was collected on 7—10—1965. and the second set on 7—11—1965. Finally 60 samples of straw and 60 samples of grain were collected after harvest.

B. Analysis of Soil

Procedure adopted for taking samples.

Soil samples were collected from 6" surface layers of four representative sites in each of the 15 plots in a block. This was repeated for all the four blocks. The 60 samples thus obtained for each block were separately air dried, crushed with a wooden hammer, thoroughly mixed and reduced in bulk by cone and quartering. The soil was then passed through a 2 m.m sieve and a representative sample was collected for analysis. The four samples were analysed for chemical constituents, physical properties and mechanical composition by standard methods described below.

Chemical constituents.

1. Moisture.

5 gm. of soil were dried in an oven at 105°C. for eight hours and the percentage of weight reported as moisture.

2. Loss on ignition.

A weighed quantity of soil was ignited to constant weight in a silica basin at dull red heat over a roso head burner. The loss in weight on ignition was calculated on oven dry basis after deducing the moisture content.

Preparation of Hydrochloric Acid Extract.

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

3. Sesquioxides.

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

4. Iron oxides.

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

5. Aluminium.

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

6. Calcium.

Calcium was estimated volumetrically in the filtrate of iron and alumina estimation by oxalate method in ammoniacal medium.

7. Magnesium.

Magnesium content was determined gravimetrically in the filtrate from calcium by precipitation as magnesium ammonium phosphate.

8. Total phosphoric acid.

The ammonium phosphomolybdate volumetric method was followed for the estimation of total phosphorus (Piper 1950).

9. Acid soluble silica.

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

10. Total Nitrogen.

Total nitrogen was estimated by Salicylic acid method (A.O.A.C.).

11. pH.

A photovolt pH meter with glass electrode was used for measurement of pH using 1:2 soil water ratio.

C. Analytical procedure for plant material.

180 plant samples and 60 samples of grain collected during the study were dried to constant weight in an air oven at 60°C. The samples were then powdered to completely pass through 0.3—0.5 m.m. sieve. The samples thus obtained were analysed as follows:

1. Nitrogen.

This was estimated in 2 gm. of plant material by Kjeldhal method.

Preparation of Triple acid Extract.

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

2. Phosphorus.

This was done by the ammonium molybdate method of estimation and the phosphoric content was determined volumetrically (Piper).

3. Potassium.

This was estimated by the sodium cobaltinitrite method (Piper 1950).

4. Calcium and Magnesium.

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

5. Calcium.

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

6. Magnesium.

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

D. Statistical Studies.

The data obtained in the present study viz. analytical data of nutrient content of plant and grain samples for N,P,K,Ca,Mg and Si were statistically analysed.

E. Yield.

The straw and grain obtained from each of the sixty plots at the final harvest were air dried and weighed and the data subjected to statistical analysis.

Treatments

T_1	K_0	-	No potash
T_2	K_1	-	K_2O - 30 lb./acre
T_3	K_2	-	K_2O - 60 "
T_4	$CaO+K_0$	- CaO	+No potash.
T_5	$CaO+K_1$	- CaO	$+K_2O$ - 30 lb./acre.
T_6	$CaO+K_2$	- CaO	$+K_2O$ - 60 "
T_7	$MgO+K_0$	- MgO	+No potash
T_8	$MgO+K_1$	- MgO	$+K_2O$ - 30 lb./acre.
T_9	$MgO+K_2$	-MgO	$+K_2O$ - 60 lb./acre.
T_{10}	$CaO+MgO+K_0$	- CaO+MgO	+No potash
T_{11}	$CaO+MgO+K_1$	- CaO+MgO	$+K_2O$ - 30 lb./acre.
T_{12}	$CaO+MgO+K_2$	- CaO+MgO	$+K_2O$ - 60 "
T_{13}	$CaO+MgO+SiO_3+K_0$	- $CaO+MgO+SiO_3$	+No potash
T_{14}	$CaO+MgO+SiO_3+K_1$	- $CaO+MgO+SiO_3$	$+K_2O$ - 30 lb./acre
T_{15}	$CaO+MgO+SiO_3+K_2$	- $CaO+MgO+SiO_3$	$+K_2O$ - 60 "

RESULTS

The results obtained in the study are given below:

A. Analysis of the soil

1. Chemical analysis.

All the four samples collected from the experimental plots were analysed and the average figures obtained are given in Table I. The soil used for the experiment is acidic in nature having a pH of 4.6. The sesquioxides recorded the maximum value containing 29.51 per cent. Calcium and magnesium oxides are present in very low amounts containing 0.0372 and 0.035 per cent respectively. The total content of major nutrients are nitrogen 0.14 per cent, P_2O_5 0.034 per cent, and potassium oxide 0.16 per cent. Acid soluble silica recorded a value of 4.6 while water soluble silica is present only in traces.

2. Mechanical composition (Table I).

Mechanical analysis revealed that the soil has a coarse fraction of 44.92 per cent. As high as 70.89 per cent of this fraction exists as coarse sand and the rest as fine sand. The per cent of clay found to be 33.5. It is seen from the figures that the soil belongs to the textural class Sandy Clay Loam.

Table I

Analysis of Soil
(Percent on moisture free basis)

A.	Chemical analysis.			
1.	Moisture	..	..	1.30
2.	Loss on ignition	..	..	8.32
3.	Sesquioxides (T_2O_3)	..	..	29.51
4.	Iron oxide (Fe_2O_3)	..	..	13.86
5.	Aluminium oxide (Al_2O_3)	..	..	15.65
6.	Calcium oxide (CaO)	..	..	0.037
7.	Magnesium oxide (MgO)	..	..	0.035
8.	Phosphorus (total)(P_2O_5)	..	..	0.034
9.	Potassium (total) (K_2O)	..	..	0.16
10.	Acid soluble silica	..	..	4.60
11.	Water soluble silica	..	..	Trace
12.	Nitrogen (total)	..	..	0.14
13.	pH	..	..	4.60
B.	Mechanical analysis.			
1.	Coarse sand	..	..	31.84
2.	Fine sand	..	..	13.08
3.	Silt	..	..	16.24
4.	Clay	..	..	33.50

Textural class = Sandy clay loam.

B. Plant observations

Data on vegetative characters relating to growth of the plants are presented in Table II. The measurement recorded in the table is the average for 32 plants (eight plants per replicate) for height measurements and the average of 128 plants (32 plants per replicate) for tiller counts per treatment at two stages of growth. It is seen:-

1. Height.

In the initial stage the plants under treatment T_2 have the maximum average height followed by T_3, T_{12} and T_{15}. Though the latter three have the same values to start with T_{12} and T_{15} showed better performance than T_3 during the second stage. It is interesting to note that treatments T_6, T_7, T_8, T_9, T_{11}, T_{13} and T_{14} have the same average height of 68 cm, 30 days after transplantation. Of these treatments T_{11} alone gains very considerably in growth during the second stage attaining equality with T_{15}. T_{11}, T_{12} and T_{15} follow very closely T_2 which is the most efficient. T_4 gives the lowest values in both stages.

2. Tiller counts.

In both stages treatment 1 recorded the lowest tiller counts. In the initial stage maximum number of tillers is observed in treatment 3 with 12.6 tillers. But in the second stage maximum tillering is found in treatment 2.

Table II

Growth characters
Height and tiller counts at two stages

Treatments	Height in cm*		Tiller counts (Nos)**	
	30 days	60 days	30 days	60 days
T_1	64	106	9.0	12.0
T_2	72	120	12.2	14.5
T_3	70	110	12.6	14.0
T_4	62	104	12.0	13.2
T_5	66	112	11.5	13.6
T_6	68	112	10.4	13.2
T_7	68	108	9.7	12.0
T_8	68	109	11.0	12.0
T_9	68	114	10.4	12.8
T_{10}	66	115	10.4	12.4
T_{11}	68	118	10.0	12.6
T_{12}	70	118	10.0	12.6
T_{13}	68	110	10.5	13.4
T_{14}	68	115	12.0	13.8
T_{15}	70	118	12.0	13.6

* Average for thirty two plants (eight plants per replicate)
** Average for 128 plants (32 plants per replicate).

The second rank goes to treatment 3. Silicate treated plots are also found giving better results. All the treatments are better than control.

C. Yield.

The data on yield of straw and grain obtained in the final harvest are presented in Table III. A perusal of the data reveals:-

1. Straw.

The maximum yield of straw is obtained from the plots treated with potassium and magnesium (T_9). T_{15} which is, potassium + calcium magnesium silicate treated plot is second in rank. Much lower yields are recorded in no potash treatments viz. T_1, T_4 and T_7. All the other treatments which contain the nutrients studied, singly or in combinations, showed better performance. From the statistical analysis for yield data (Appendix 2) it is concluded that major treatments are significant. It is also seen that potassium applied at the level of 60 lbs. per acre ranks first.

2. Grain.

The maximum yield is obtained from treatment 9 which contains potassium at the rate of 60 lbs. per acre

Table III

Yield in Kg. per plot
(final harvest)

Treatments	Straw	Grain
T_1	4.25	1.36
T_2	5.40	1.53
T_3	5.44	1.36
T_4	4.60	1.49
T_5	5.50	1.53
T_6	6.00	1.53
T_7	4.13	1.42
T_8	5.60	1.55
T_9	6.72	1.79
T_{10}	5.20	1.41
T_{11}	5.90	1.63
T_{12}	5.60	1.63
T_{13}	5.40	1.42
T_{14}	5.60	1.64
T_{15}	6.12	1.76

together with calcium and magnesium. The minimum yield is found in the case of control plot. From the statistical analysis (Appendix 1) it is observed that the major treatments are highly significant. Potassium applied at the rate of 60 lb. per acre is more efficient than all other treatments.

D. Nutrient uptake by straw and grins.

1. Nitrogen (Table IV).

Straw:- Plants from T_6 recorded the maximum N content on the 30th day. Treatment 9, which is a combination of calcium magnesium and 60 lb. K_2O has the second place. The straw of the final harvest contains the maximum nitrogen in treatment 2 which consists of only 30 lb. of K_2O over 40 lb. of N and 30 lb. of P_2O_5. T_1 and T_4 which do not contain potash showed the minimum values. The nitrogen content decreases with progress in plant growth. Thus in the ripe straw the nitrogen is less by 47 per cent compared to that of plants of 30 days' growth.

Analysis of variance Table (Appendix-8) show that major and minor treatments are significant.

Grain:- Maximum nitrogen content is for the grain of treatment 3 which consists of 60 lb. K_2O per acre over

Table IV

Percentage Nutrient Uptake by straw and grain

(Nitrogen)

(N)

Treatments	30th day straw	After harvesting	
		Straw	Grain
T_1	1.16	0.55	1.15
T_2	1.28	0.77	1.27
T_3	1.23	0.73	1.35
T_4	1.20	0.55	1.18
T_5	1.26	0.65	1.18
T_6	1.40	0.69	1.22
T_7	1.25	0.66	1.18
T_8	1.20	0.64	1.11
T_9	1.32	0.62	1.18
T_{10}	1.21	0.61	1.14
T_{11}	1.13	0.57	1.10
T_{12}	1.21	0.61	1.14
T_{13}	1.20	0.62	1.18
T_{14}	1.19	0.64	1.26
T_{15}	1.21	0.64	1.20

the basal dressing. T_{11} recorded the minimum value. Statistical analysis of the data has revealed that the major treatments are highly significant. It is also seen that the higher level of potash--K_2(K_2O, 60 lb. per acre) is superior to K_1 (K_2O-30 lb. per acre) and 'no potash' (K_0) treatments. It is further observed that K_0 is the least efficient with regard to nitrogen uptake by grain. Analysis of variance Table (Appendix 13) has also shown that the minor treatments are significant.

2. Phosphorus (Table V).

Straw:- In the initial phase the maximum phosphorus content is obtained in T_2 (Potassium at the rate of 30 lb. per acre over basal dressing). T_3 ranked second with T_1 and T_5 showing low values. In the subsequent stage of growth T_6 and T_{14} show the maximum values with T_2 and T_3 closely following. From statistical analysis, it is observed that both major and minor treatments are significant. Among the major treatments K_1 and K_2 are superior to K_0. But K_1 ranks first.

In the mature straw the maximum phosphorus content is recorded for treatments T_6 and T_{10}. Calcium magnesium silicate treatment (T_{15}) with 60 lb. of P_2O per acre ranks second. Control (T_1) has the minimum uptake of phosphorus. It is pertinent to observe that T_{15} which has a minimum

Table V

Percentage Nutrient Uptake by Straw and Grain (Phosphorus)

(P_2O_5)

Treatments.	30th day	60th day	After harvesting	
	Straw.	Straw.	Straw.	Grain.
T_1	0.51	0.54	0.26	0.59
T_2	0.63	0.60	0.32	0.67
T_3	0.61	0.60	0.30	0.69
T_4	0.50	0.56	0.31	0.68
T_5	0.54	0.58	0.33	0.69
T_6	0.56	0.63	0.38	0.69
T_7	0.50	0.58	0.33	0.70
T_8	0.59	0.56	0.31	0.67
T_9	0.58	0.56	0.31	0.72
T_{10}	0.54	0.54	0.38	0.69
T_{11}	0.51	0.55	0.33	0.68
T_{12}	0.56	0.53	0.35	0.68
T_{13}	0.52	0.53	0.31	0.68
T_{14}	0.55	0.63	0.30	0.68
T_{15}	0.49	0.56	0.36	0.67

phosphoric acid content in the early stages of growth has a very much increased uptake of this nutrient during the later stages approximating to that of T_3 the most efficient.

It is also seen that as in the case of nitrogen phosphoric acid also decreases as ripening sets in. The straw of the final harvest contain less phosphoric acid, on an average by 33 per cent compared to the young plants of 30 days duration. Statistical analysis show that major treatments are significant at 1 per cent level.

Grain:- Maximum value is recorded by T_1. All the treatments contain more P_2O_5 than control. In statistical analysis both major and minor treatments are found to be significant. Among the major treatments K_2 is superior to K_1 and K_0. K_0 is the least efficient. Among minor treatments T_5 ranks first. All other treatments are found superior to control treatment (T_1).

3. Potassium (Table VI).

Straw:- The maximum values are recorded by treatments T_2 and T_3 in 30th and 60th day. The performance of plants treated with calcium magnesium silicate is also fairly good. In the final samples, the maximum value is found for T_5 (Calcium + K_2O at 30 lbs. per acre). As plant growth

Table VI

Percentage Nutrient Uptake by Straw and Grain.

(Potassium)

(K_2O)

Treatments.	30th day	60th day	After harvesting.	
	Straw.	Straw.	Straw.	Grain.
T_1	1.39	2.02	1.17	2.02
T_2	2.13	2.89	1.29	2.56
T_3	2.22	2.99	1.42	2.67
T_4	1.37	2.27	1.39	2.02
T_5	1.96	2.52	1.53	2.50
T_6	1.85	2.54	1.48	2.70
T_7	1.35	2.60	1.16	2.40
T_8	1.88	2.81	1.34	2.40
T_9	1.78	2.60	1.37	2.16
T_{10}	1.68	2.43	1.30	2.07
T_{11}	1.77	2.68	1.34	2.22
T_{12}	1.81	2.55	1.52	2.30
T_{13}	1.70	2.49	1.39	2.05
T_{14}	1.91	2.75	1.49	2.46
T_{15}	1.86	2.85	1.48	2.12

advances there is an increased uptake of potassium. Plants of 60 days growth contain 46 per cent more of potassium than 30 days old ones. Subsequently the potash content decreases by an equal amount.

The data obtained, on statistical scrutiny have shown that the major treatments are significant. It is also seen that the major treatments are also significant at the final round of analysis. It is also revealed from the study that the potassium content of the plant tends to decrease with the onset of grain formation and maturity.

Grain:- Maximum values are found in the case of T_6, T_2 and T_3. Potassium content of grain was found to be more than that of the straw. Minor treatments are found to be significant from statistical analysis.

4. Calcium (Table VII).

Straw:- The uptake of calcium is maximum in treatment 11 during the initial stage. The minimum values are recorded by T_7, T_{10} and T_{12}. In the second stage T_7 has the maximum values. T_3 ranks second. The minimum values are noted in the case of T_{14}. As in the case of potassium, the calcium uptake is low in the early stages. Thus the straw of the second round of analysis is found to contain 65 per cent more of calcium than that of the first stage.

Table VII

Percentage Nutrient Uptake by Straw and Grain.

(Calcium)

Treatments	30th day.	60th day.	After harvesting.	
	Straw.	Straw.	Straw.	Grain.
T_1	0.42	0.72	0.52	0.19
T_2	0.50	0.68	0.57	0.22
T_3	0.50	0.81	0.65	0.24
T_4	0.42	0.77	0.60	0.23
T_5	0.50	0.67	0.60	0.22
T_6	0.50	0.67	0.62	0.22
T_7	0.33	0.84	0.55	0.13
T_8	0.42	0.74	0.52	0.22
T_9	0.50	0.78	0.52	0.23
T_{10}	0.33	0.76	0.55	0.21
T_{11}	0.55	0.71	0.53	0.22
T_{12}	0.33	0.69	0.55	0.21
T_{13}	0.42	0.69	0.61	0.21
T_{14}	0.42	0.65	0.62	0.24
T_{15}	0.42	0.64	0.66	0.21

As ripening sets in the Calcium content falls on an average by 12 per cent.

From statistical analysis of the data it is found that both major and minor treatments are significant. Among major treatments, K_0 is observed to be superior to K_2 and K_2 more efficient than K_1. Among minor treatments T_3 is more efficient.

In the analysis of straw of the final harvest maximum values are recorded by T_{15} with T_3, T_6 and T_{14} closely following. Major treatments are significant in this case also. The data have also revealed the very interesting fact that, in the mature straw, the uptake of calcium by plants treated with the higher doses of potash (K_1 and K_2 is superior to those of the K_0 treatment) a reversal of the position obtained in the second stage of growth.

<u>Grain:-</u> When grain analysis was done maximum values were recorded by T_3. T_1 recorded the minimum values. From statistical analysis major treatments are found significant. In this case also K_2 is superior to K_1 and K_0.

5. <u>Magnesium (Table VIII).</u>

<u>Straw:-</u> In the initial stage of analysis T_2, T_3, T_6 and T_7 are found to contain more magnesium than other treatment

Table VIII.

Percentage Nutrient Uptake by Straw and Grain.

(Magnesium.)

Treatments	30th day.	60th day.	After harvesting.	
	Straw.	Straw.	Straw.	Grain.
T_1	0.10	0.33	0.29	0.14
T_2	0.20	0.39	0.34	0.15
T_3	0.20	0.45	0.32	0.15
T_4	0.10	0.33	0.37	0.13
T_5	0.15	0.38	0.35	0.14
T_6	0.12	0.43	0.35	0.14
T_7	0.20	0.29	0.32	0.16
T_8	0.10	0.50	0.33	0.15
T_9	0.12	0.46	0.34	0.15
T_{10}	0.12	0.35	0.33	0.13
T_{11}	0.12	0.49	0.36	0.11
T_{12}	0.12	0.49	0.30	0.13
T_{13}	0.10	0.425	0.31	0.12
T_{14}	0.15	0.45	0.34	0.14
T_{15}	0.10	0.40	0.38	0.16

But in the second stage plants from treatment 8 have recorded the maximum and treatment T_7 the minimum values. Major treatments alone are statistically significant, K_1 ranking first.

In the final stage, treatment 15 recorded the maximum values. T_4 ranking second. All the treatments contain more MgO than the control. Both major and minor treatments are found significant. Calcium appears to have a beneficial effect on the absorption of magnesium. The calcium treated plant has a higher uptake of magnesium-- as revealed by statistical analysis.

Grain:- Maximum values are given by T_7 and T_{15} where as T_{11} records the minimum values. In the case of grain major treatments alone are found to be significant. Among the major treatments K_2 ranks first where as K_0 is found least efficient and K_1 coming in between.

6. Silica (Table IX).

Straw:- Both in the initial and second stage of analysis T_9 has recorded the highest value. Though in the initial stage T_4 gives the lowest silica content, in the second stage all the treatments were superior to control (T_1). In the mature straw (final analysis) the silica content

Table IX.

Percentage Nutrient Uptake by Straw and Grain.

(Silica)

Treatments	30th day.	60th day.	After harvesting.	
	Straw.	Straw.	Straw.	Grain.
T_1	6.00	6.60	7.10	2.85
T_2	5.95	8.24	8.00	3.80
T_3	5.90	7.48	8.10	3.20
T_4	5.60	8.10	7.88	3.10
T_5	7.00	8.09	8.10	3.40
T_6	7.00	7.91	8.60	3.55
T_7	5.85	7.15	8.25	3.20
T_8	7.05	7.55	8.30	3.15
T_9	7.80	8.26	7.90	2.95
T_{10}	6.10	8.13	7.90	2.70
T_{11}	6.60	7.75	8.20	3.30
T_{12}	5.82	8.40	8.10	3.30
T_{13}	7.00	8.15	8.05	2.50
T_{14}	7.17	7.50	8.65	2.84
T_{15}	7.17	7.90	8.80	2.84

is maximum in plants receiving a higher level of potash nutrition along with silica (T_{15}). In no potash plots with or without silica, the uptake of silica is found to be less. The values are not however statistically significant. It is however noted that just as in the case of potassium and calcium there is increased uptake of silica in the early stages with a slight fall with the onset of ripening. All the treatments contain more SiO_2 than T_1 which is the control.

<u>Grain:-</u> In the case of grain maximum values are recorded by T_2 where as minimum values were given by T_{13}. Statistical analysis showed that none of the treatments are significant.

DISCUSSION

The fundamental importance of Potassium in plant nutrition, particularly its role in cell division, assimilation, nitrate reduction, production and translocation of carbohydrates and proteins, enzyme action, water economy, utilisation of other plant foods, prevention of pest and disease infection and counteracting bad effects of adverse weather conditions has been outlined under the review of literature. It is needless to emphasize that a proper supply under suitable conditions of a nutrient element of such far reaching and varied physiological functions of great agronomic importance, will greatly help maximisation of production of agricultural crops. With regard to rice, high yields of quality grain and straw have been obtained in Japan and other countries and also in some of the Indian States, by fertilizing with higher doses of Potassium. The problem of Potash manuring of rice in the Kerala State which is deficient in this major food crop, thus assumes great practical significance. The all-important question is whether potash applied to the acid paddy soils of the State is utilized by the crop for better growth and yield or whether the added potash will have no effect and be of no practical value or even permanently lost by "fixing". The problem is discussed below in the light of the results obtained in the present investigation, which show that potash has many beneficial effects on the growth, nutrient uptake and yield of the rice plant.

A. Vegetative characters relating to growth

1. Height.

The beneficial effect of potash is clear from the increased height of plants grown with treatments containing potash compared to treatments devoid of this nutrient. This may be due to the fact that potash plays an important role in the formation of carbohydrates and proteins in the plant body as suggested by Hellriegal (1898), Wilfarth and Wimmer (1902) and Thakazhi (1961).

2. Tiller production.

Just as height increase, better tiller production is an important measure of plant performance. Data on tiller counts at different stages of growth shows that T_1--the 'no potash' plot--recorded the minimum values. Addition of potash confers on the plant better tillering capacity. The results are in accordance with the findings of Noguchi and Sugawara (1952) who observed that the number of tillers was smaller for plots without potash. The present study confirms their findings and further goes to show that potassium applied along with silicate produces better results. Thakazhi (1961) Mitsui and Tahahashi (1963) and Sadanandan (1965) reported better tiller production due to silicon application. The increased tiller production may be the result of beneficial soil conditions brought about by potash.

B. Yield.

Better vegetative growth as evidenced by the increase in height and production of tillers in the plant will naturally be reflected in increased yields. Potash nutrition brings about this very desirable quality as shown below:

1. Straw.

The maximum yield of straw is obtained from the plots treated with potassium and magnesium. According to Noguchi and Sugawara (1952) yields of grain and straw decreased with decreasing levels of potash nutrition. Singh (1953), Mukerjee (1955) and Potascheme experiments (1957) showed better yield of both grain and straw in the presence of potassium. The present study confirms their findings. The increase in straw yield observed may be due to the better utilisation of nitrogen in the presence of potash and better utilisation of phosphorus in the presence of magnesium.

2. Grain.

The results have shown that maximum yield of grain is in the case of plots treated with potassium at the rate of 60 lbs. per acre together with calcium and magnesium. Thakazhi (1961) reported increased yield of grain in presence of potassium. The results of the present investigation also supports his view. The increase in yield due to the presence of potassium may be attributed to the fact that it plays an important role for carbon assimilation, formation of protein and translocation of the formed substances. During the course of the growth of rice plant, it requires a lot of sugar as the source of the energy and sugar is formed from carbon dioxide and water in the leaves through the functions of chlorophyll, sunlight and a number of essential elements of which potassium plays an important role.

C. <u>Plant Analysis--Nutrient Uptake and Inter-relationship.</u>

It may be noted in this context that the growth and yield of plants are in fact controlled by the nutrients contained in the soil and the plant and their availability and inter-relationship. Numerous laboratories devote their time to soil analysis in order to assess fertilizer response. Soil analytical methods, however, are largely empirical and we have yet no absolute fundamental measure which can give a precise quantitative definition of nutrient availability to all soil types and hence it is often difficult to decide fertility norms from these analyses. The chemical composition of the plants has therefore been considered a better guide. Increasing use of this method has of late been resorted to provide quantitative information on how much nutrients should be added to the soil to meet the demands of the plant. The nutrient content of the plant will thus be a measure of its uptake by plant roots and consequently a reliable index of its availability.

As stated already, potash manuring considerably increases the growth and yield of the rice plant. This goes well with increased uptake of nutrients. This aspect of the problem and the uptake of potassium in relation to nitrogen, phosphorus, calcium, magnesium and silicon are briefly discussed below.

1. <u>Nitrogen.</u>

It is observed that treatment 6 and treatment 9 occupy the 1st and 2nd rank in the initial stages. But in the last stage treatment 2 which contains potassium alone has recorded the maximum value. T_1 and T_4 which do not contain potash show the minimum values.

The results obtained in the present study are in accordance with the work of Richard (1938). He reported that the full utilisation of nitrogen is possible only in the presence of potassium. Further, it is seen that with progress of maturity the nitrogen content decreases. This may be due to the utilisation of nitrogen for the formation of grain.

The maximum uptake of nitrogen in grain is found in the case of treatment 3 which contains only potassium at the rate of 60 lbs. per acre. Statistical analysis has revealed that both major and minor treatments are significant and among major treatments K_2—(Potassium—60 lbs. per acre) is superior to K_1 and K_0.

2. Phosphorus.

The straw obtained from potassium included treatments contain more phosphorus than the no potash treatment. Though T_2 excelled in the initial stage, the lead is taken over by T_6 and T_{14} in the second stage. But in the mature straw, the maximum phosphorus content is in T_6 and T_{10}. These results prove the fact that potash has a beneficial effect on the uptake of phosphorus.

3. Potassium.

The potassium uptake of straw is found to be increased by potassium application as evidenced from the better results exhibited by potassium treated plants. Among the treatments, potassium applied singly at the rate of 30 lbs. K_2O per acre and 60 lbs. K_2O per acre, T_2 and T_3 respectively, are better in the first two stages. These results are in accordance with the findings of Burrell (1944), Nelson et.al. (1945), Aldrich and Coony (1952) and Tucker and Smith (1952). But in the final stage the maximum value is obtained in T_5 (Calcium + K_1). This may be due to the fact that calcium ions can increase the permeability of plant tissues to potassium ions. Increase in uptake of potassium due to the presence of calcium ions was obtained by Viet (1942) and Mongy and Verghese (1964).

It is also observed that the uptake of potassium during the later stages of growth increases. But with the onset of grain formation the potassium content of straw decreases. A possible explanation for this may be the translocation of potassium from the vegetative parts to the grain. The analysis of grain for nutrient uptake has revealed that potassium uptake followed the same trend as straw ie. potassium treated plants T_1, T_2 and T_6 show the maximum values. The results reveal the fact that potash manuring of rice soils of Kerala State is a beneficial practice. The added potash is actually available to the plant for greater production of better quality grain and straw.

4. Calcium.

The important fact brought out in the present investigation is that there is no regular pattern in calcium uptake of the straw. Statistical analysis has revealed that major treatments are significant with regard to calcium uptake. Further, K_0 is superior to K_2 and K_1. This is the case in the initial stages of growth only. But in the mature straw the position is reversed, plants treated with higher doses of potash producing plants of higher calcium content. Judging from the overall final result, the present study does not show any evidence for the "Calcium-Potash antagonism" theory postulated by Ehrenberg (1919) and York and Rogers (1947).

The straw of the final harvest contains maximum calcium in treatment 15 which is calcium-magnesium-silicate+ K_2O 60 lbs. per acre. This additional beneficial effect may be due to the presence of silicate. Increased uptake of calcium in straw with silicic acid application was reported by Otagawa and Kashima (1963) and Sadanandan (1965).

The potassium included treatments produce grain with maximum calcium content where as no potash treatments produce the lowest. From this it is clear that potassium is not lost through fixation but utilised at the time of grain setting. It may be noted however that analysis of grain could be undertaken only at the time of final harvest. Whether there is an initial lag in calcium uptake during the early stages of grain formation as observed in the case of straw, only further work can show.

5. <u>Magnesium.</u>

Potassium included treatments are found to produce straw with higher magnesium content. These results are supported by the findings of Walsh and Hamb (1955). A possible explanation for this is that magnesium ions can increase the mobility of potash.

Among the potash carriers, calcium-magnesium-silicate has proved to be the best in the final harvest. This result is well correlated with the finding of Sadanandan (1965). Both major and minor treatments are significant. Among the minor treatments calcium appears to have a beneficial effect on the absorption of magnesium as revealed by statistical analysis.

The calcium magnesium silicate with higher dose of potassium and calcium is predominent in the case of grain also with regard the magnesium uptake. Among the major treatments K_2, is found to be the most superior.

6. Silicon.

Both in the initial and second stage of analysis magnesium application has effectively increased silicon uptake by straw. But in the final stage, the silica content of straw is maximum in plants receiving a higher level of potash along with silica. In no potash plots with or without silica, the uptake of silica is found to be less.

Results of a similar nature were presented by Utagawa and Kashima (1963), Padmaja and Verghese (1964) and Sadanandan (1965) and many others.

It may also be noted that silicon percentage of straw increases with maturity. Statistical analysis however showed that none of the treatments are significant.

The results discussed above may now be considered in relation to the Chemistry of soil potash.

Soil Potash.

The Chemistry and mineralogy of soil potash is even now a controversial subject. Since the clay fraction is the seat of mineral fertility of the soil, the potassium supplying power of soils is essentially a function of the soil colloid. According to recent work, the clay minerals chiefly concerned in this consist of the Kaolinitic "Type" (1:1 Lattice type represented by Kaolinite and Halloysite), the Hydrated Mica type (2:1 Lattice Type represented by Illite) and Montmorillonite or Expanding Lattice type (2:1 Lattice Type, represented by Montmorillonite and Biedellite). Potassium occupies a graded series of positions in these minerals resulting in a gradient in relative ease of removal.

At the more flexible end of this series potassium is attached to the clay mineral in a form which is well known as "Exchangeable" or "replaceable" potassium. In this form potassium is bound up loose in the outer kernel of the clay minerals and can be easily taken up by the plants by its conversion to water soluble potash which forms the soil solution feeding the plant roots. If potassic manures are added to the soil, the K ion enters the clay by replacing the "exchangeable" calcium and replenishes the stock of "exchangeable" potash to supply the potash in the soil solution as and when the plant needs. The water soluble and exchangeable potash are reversibly convertible and their relationship forms the key to potash availability and potash response. If the original reserves of exchangeable potash are high, the plants may not respond to additional potash.

At the less flexible extreme end of the potash Series, the potassium occupies a stable position deeply burried in the colloid particle (eg. Illite which is allied to the primary rock mineral muscovite) and it is dislodged with great difficulty under field conditions. Added potassium which reacts with the clay fraction and enters into exchangeable form by chemical reaction may revert to non-exchangeable or "fixed form". This is called "potash fixation". However, its firmness of attachment lies midway between that of exchangeable and lattice potassium. It is considerably more available than the difficulty available form and may be considered to be moderately available. The transformation of exchangeable potassium to the fixed form and back again is a balanced equilibrium reaction. Further, the fixation of potassium is a characterestic of clays of the Montmorillonite and Illite groups and is absent from that of the Kaolinite group. Fixation is also slight in acid soil.

It is evident from the above that the essence of potash fertility and the phenomenon of response to potash manuring is dependent primarily on the more or less flexible equilibrium of the different forms of potassium in the colloidal clay, the nature of the clay and the soil reaction.

Koshi (1962) from his investigations on Vellayani soils has established the Kaolinitic nature of these soils. The soil used in the present study is distinctly acidic, having a pH of 4.6. These facts considered along with the various beneficial effects discussed in the fore-going pages would show that potash fixation is not a serious problem here. The evidence would further support the view that in an acid Kaolinitic soil, the phenomenon of potash fixation, if at all present, is only a beneficial mechanism and the trend of the balanced reactions of the different forms of potassium in the soil is more towards the release of potassium readily available to the plant. The results also show that the use of soil amendments like lime or calcium magnesium compounds will not in any way adversely affect the efficient utilisation of the potash of the added fertilizer.

The present study would thus make much more stronger the case of potash manuring of rice in Kerala State and probably elsewhere in India.

SUMMARY AND CONCLUSIONS

SUMMARY.

The study of potash nutrition of rice for maximum economic yields of grain and straw of high quality has not so far received adequate attention.

In recent years, however, the use of potash in rice production has made remarkable progress in Japan and in India. But sufficient data are not yet available with regard to the need for potash manuring of Rice in Kerala. It is well known that rice soils of Kerala are very poor in lime status due to high rainfall obtained in the State. It has been found that liming affects the available potash contents in the soils.

With the above picture of rice nutrition with particular reference to the Kerala State in view, a field experiment was laid out with split plot in Randomised Block Design to assess the effect of calcium, magnesium and silicon on the fixation, release and utilization of potash with regard to rice crop.

The treatments were three levels of potassium singly and in combination with calcium, magnesium, calcium + magnesium and calcium + magnesium + silicon. Nitrogen and

phosphoric acid at the rate of 40 and 30 lbs. respectively were applied as the basal dressing.

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

Periodical observations on plant behaviour, such as height measurements and tiller counts were made. Chemical analysis of various parts of rice plant were carried out at three stages corresponding to the vegetative phase, flowering stage and final stage of maturity. From the analytical values obtained, the uptake of nitrogen, phosphoric acid, potash, calcium, magnesium and silicon in the different plant parts were computed.

Statistical analysis was done for the nutrient content in the last two stages of growth for both grain and straw and for the yield data.

CONCLUSIONS

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

1. The height measurements recorded reveal the beneficial influence of potash in promoting growth.

2. The tillering capacity of the rice plant is maximum in potash treated plots. Silicate along with potash also fares well.

3. The straw yields of the potassium treated plots are higher than those of no potash plots, thereby establishing the influence of potash in promoting straw yield. Higher levels of potash have better effect.

4. Potassium at higher levels along with calcium and magnesium have recorded maximum grain yield.

5. The application of potash promotes the availability of nitrogen manifested in the increased uptake of nitrogen by the plants.

6. The maximum uptake of phosphorus is obtained with potash at 60 lbs. per acre. Calcium magnesium silicate along with potassium ranks second.

7. The observed increasing uptake of potash by straw is followed by a proportionate increase in growth of the plant. The potash uptake however decreases with the grain formation.

8. The potassium promotes the uptake of calcium as evidenced by the straw analysis at the final stage.

9. Magnesium and silicon uptake are proportional to the potash application.

Practical implications.

1. The present investigation shows that potash manuring has many beneficial effects which are ultimately manifested in the increased production of grain and straw of high quality.

2. The programme of intensive cultivation of rice by increased use of fertilizers including potash can work harmoniously with the drive for the liberal use of soil amendments like lime or dolomite lime in acid soil tracts. These soil amendments will not in any way adversely affect the uptake and efficient utilisation of potash.

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Appendix 1

Analysis of variance table for Grain yield.

Source	Sum of squares	d.f.	Variance	F
Total	3.4	59		
Blocks	0.4	3	0.1333	13.3**
Major treatments	0.3	2	0.150	15.5**
Whole plot error	0.1	6	0.16	
Minor treatments	0.2916	4	0.0729	1.73
Interaction	0.89	8	0.111	2.8*
Sub plot error	1.42	36	0.04	

Critical difference 0.1028

Conclusion: $\overline{K_2 \; K_1} \; K_0$

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 2.

Analysis of Variance Table for Straw yield.

Source	S.S.	d.f.	Variance	F
Total	99.813	59		
Block	65.6	3	21.8667	240.2**
Major treatments	11.05	2	5.525	60.73**
Whole plot error	0.55	6	0.091	
Minor treatments	6.0833	4	1.5208	3.305*
Interaction	11.27	8	1.41	3.06*
Sub plot error	5.26	36	0.46	

Conclusion: $\overline{K_2 \quad K_1} \quad K_0$

$T_5 - T_3 - T_4 - T_2 - T_1$

Appendix 3

Analysis of variance Table for Nutrient Uptake in the Second Stage (Phosphorus)

Source	S.S.	d.f.	Variance	F
Total	0.0900	59		
Block	0.0046	3	0.00153	2.35
Major treatments	0.0100	2	0.00500	7.70**
Whole plot error	0.0039	6	0.00065	
Minor treatments	0.0188	4	0.00470	6.7**
Interaction	0.0272	8	0.00340	5.0**
Sub plot error	0.0255	36	0.00070	

Conclusion: $\overline{K_1 \quad K_2} \quad K_0$

$\overline{T_2 \ T_1 \ T_5 \ T_3} \ T_4$

Appendix 4

Analysis of variance Table for Nutrient Uptake in the Second Stage (Potassium.)

Source	S.S.	d.f.	Variance	F
Total	4.0350	59		
Block	0.0560	3	0.0153	0.744
Major treatments	1.5620	2	0.7810	38.180**
Whole plot error	0.1229	6	0.0205	
Minor treatments	0.2160	4	0.0540	2.36
Interaction	1.2190	8	0.1523	6.65**
Sub plot error	0.8241	36	0.0229	

Conclusion: K_1 K_2 K_0

Appendix 5

Analysis of variance Table for Nutrient Uptake in the Second Stage (Calcium)

Source	S.S	d.f	Variance	F.
Total	0.3229	59		
Blocks	0.0277	3	0.0092	
Major treatments	0.0336	2	0.0168	8.36**
Whole plot error	0.0067	6	0.0011	15.27**
Minor treatments	0.0896	4	0.0224	30.00**
Interaction	0.1380	8	0.0172	23.00**
Sub plot error	0.0272	36	0.00075	

Conclusion: K_0 K_2 K_1

$\underline{T_3 \quad T_1}$ T_4 T_2 T_5

Appendix 6

Analysis of variance Table for Nutrient Uptake in the Second Stage (Magnesium)

Source	S.S	d.f	Variance	F
Total	0.9043	59		
Block	0.0018	3	0.0006	0.265
Major treatments	0.1102	2	0.0551	24.380**
Whole plot error	0.0136	6	0.00226	
Minor treatments	0.0652	4	0.0163	0.930
Interaction	0.0799	8	0.0098	0.500
Sub plot error	0.6336	36	0.176	

Conclusion: $\underline{K_1 \quad K_2} \quad K_0$

Appendix 7

Analysis of variance Table for Nutrient Uptake in the Second Stage (Silica).

Source	S.S.	d.f	Variance	F.
Total	26.0804	59		
Blocks	0.1618	3	0.5236	2.56
Major treatments	0.9521	2	0.4760	2.33
Whole plot error	1.2244	6	0.2041	
Minor treatments	2.8799	4	0.7199	2.25
Interaction	6.9125	8	0.8641	2.71*
Sub plot error	13.9497	36	0.3188	

Appendix 8

Analysis of variance Table for Nutrient Content of Straw in the final stage Nitrogen (N).

Source	S.S.	d.f.	Variance	F.
Total	0.2707	59		
Block	0.009	3	0.003	1.2
Major treatments	0.05	2	0.025	10.2**
Whole plot error	0.015	6	0.0025	
Minor treatments	0.04	4	0.0100	5.5**
Interaction	0.15	8	0.0187	10.38**
Sub plot error	0.0067	36	0.0018	

Conclusion: K_2 K_1 K_0

T_4 T_3 T_5 T_2 T_1

Appendix 9

Analysis of variance Table for Nutrient content of Straw in the final stage

Phosphorus (K_2O)

Source.	S.S.	d.f.	Variance	F.
Total	0.1888	59		
Blocks	0.03	3	0.0100	6.66*
Major treatments	0.031	2	0.0155	10.3**
Whole plot error	0.009	6	0.0015	
Minor treatments	0.04	4	0.0100	8.07*
Interaction	0.037	8	0.0046	4.0*
Sub plot error	0.0418	36	0.00115	

Conclusion: K_1 K_2 K_0

T_5 T_2 T_1 T_3 T_4

Appendix 10

Analysis of variance Table for Nutrient content of Straw in the final stage

(Potassium)

K_2O

Source	S.S.	d.f	Variance	F
Total	0.95	59		
Blocks	0	3	0	-
Major	0.18	2	0.90	6*
Whole plot error	0.09	6	0.015	
Minor treatments	0.33	4	0.082	2.4*
Interaction	0.227	8	0.028	0.82
Error	0.123	36	0.034	

Conclusion: K_2 K_1 K_0

T_2 T_5 T_4 T_1 T_3

Appendix 11

Analysis of variance Table for Nutrient content of Straw in the final stage

(Calcium)

CaO

Source	S.S	d.f	Variance	F.
Total	0.393	59		
Blocks	0.10	3	0.0330	19.4
Major treatments	0.131	2	0.0655	38.5**
Whole plot error	0.01	6	0.0017	
Minor treatments	0.14	4	0.0350	43.75**
Interaction	0.009	8	0.00011	1.375
Sub plot error	0.003	36	0.0008	

Conclusion: K_2 K_1 K_0

T_5 T_2 T_1 T_4 T_3

Appendix 12

Analysis of variance Table for Nutrient content of Straw in the final stage

Magnesium (M_gO)

Source	S.S.	d.f.	Variance	F
Total	0.0667	59		
Blocks	0.015	3	0.005	15.15**
Major treatments	0.016	2	0.008	24.24**
Whole plot error	0.002	6	0.00033	
Minor treatments	0.02	4	0.005	2.63*
Interaction	0.007	8	0.00081	0.463
Sub plot error	0.0067	36	0.0019	

Conclusion: K_1 K_2 K_0

T_5 T_2 T_4 T_3 T_1

Appendix 13.

Analysis of variance Table for Nutrient uptake of Grains.

(Nitrogen)

Source	S.S.	d.f	Variance	F.
Total	0.2839	59		
Block	0.0059	3	0.00196	98**
Major treatments	0.0243	2	0.01215	602**
Whole plot error	0.0001	6	0.00002	
Minor treatments	0.214	4	0.0534	6.43**
Interaction	0.0095	8	0.00019	1.69
Sub plot error	0.0301	36	0.00083	

Conclusion: K_2 K_1 K_0

T_1 T_5 T_2 T_3 T_4

Appendix 14

Analysis of variance Table for the Nutrient Uptake of Grains

Phosphorus.

Source	S.S.	d.f	Variance	F.
Total	0.0698	59		
Block	0.001	3	0.0003	3.00
Major treatments	0.0018	2	0.0009	9.00*
Whole plot error	0.0008	6	0.0001	
Minor treatments	0.0151	4	0.0038	6.8**
Interaction	0.0305	8	0.0038	6.8
Sub plot error	0.0206	36	0.00056	

Conclusion: K_2 K_1 K_0

T_3 T_4 T_2 T_5 T_1

Appendix 15

Analysis of variance Table for the Nutrient content of Grains

(Potassium)

Source	S.S.	d.f	Variance	F.
Total	6.0917	59		
Blocks	0.7206	3	0.2402	0.5218
Major treatments	0.9643	2	0.4821	1.0470
Whole plot error	2.7619	6	0.4603	
Minor treatments	0.2861	4	0.7150	37.6**
Interaction	0.66	8	0.0825	4.3*
Sub plot error	0.6988	36	0.019	

Conclusion: T_3 T_1 T_5 T_2 T_4

Appendix 16

Analysis of variance Table for the Nutrient content of Grains.
(Calcium).

Source	S.S.	d.f.	Variance	F.
Total	0.0310	59		
Blocks	0.0045	3	0.0015	3.1
Major treatments	0.0031	2	0.00155	3.1*
While plot error	0.0029	6	0.00048	
Minor treatments	0.0011	4	0.000275	0.86
Interaction	0.0078	8	0.000975	3.04*
Sub plot error	0.0116	36	0.00032	

Conclusion: K_2 K_1 K_0

Appendix 17

Analysis of variance Table for Nutrient content of Grains.

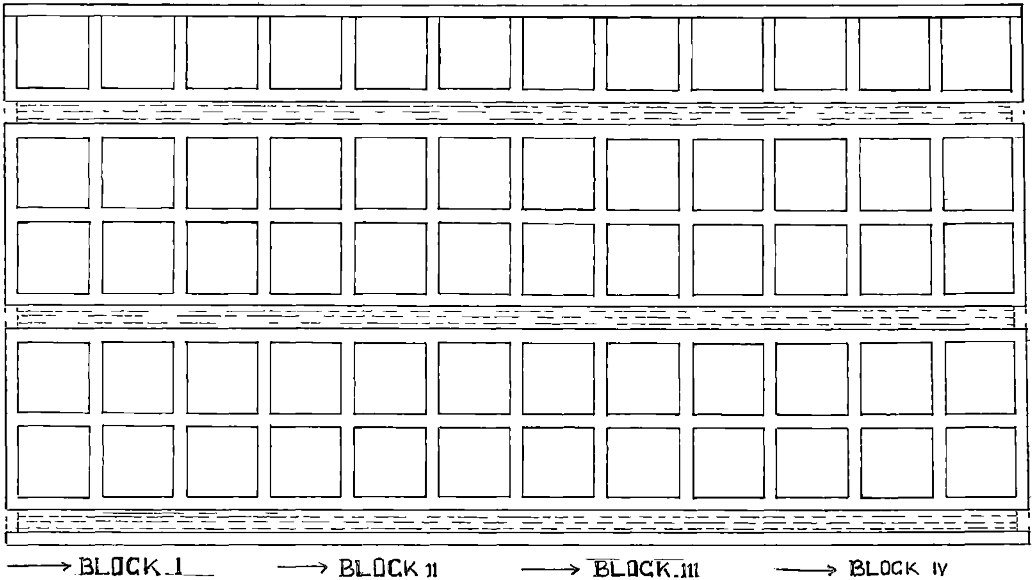
Magnesium (MgO)

Source	S.S.	d.f.	Variance	F
Total	0.0396	59		
Blocks	0.0253	3	0.0084	9.3*
Major treatments	0.0011	2	0.0005	5.5*
Whole plot error	0.000542	6	0.00009	
Minor treatments	0.0061	4	0.0015	1.9
Interaction	0.0038	8	0.0005	
Sub plot error	0.0028	36	0.00079	0.63

Conclusion: K_2 K_1 K_0

FIG 1

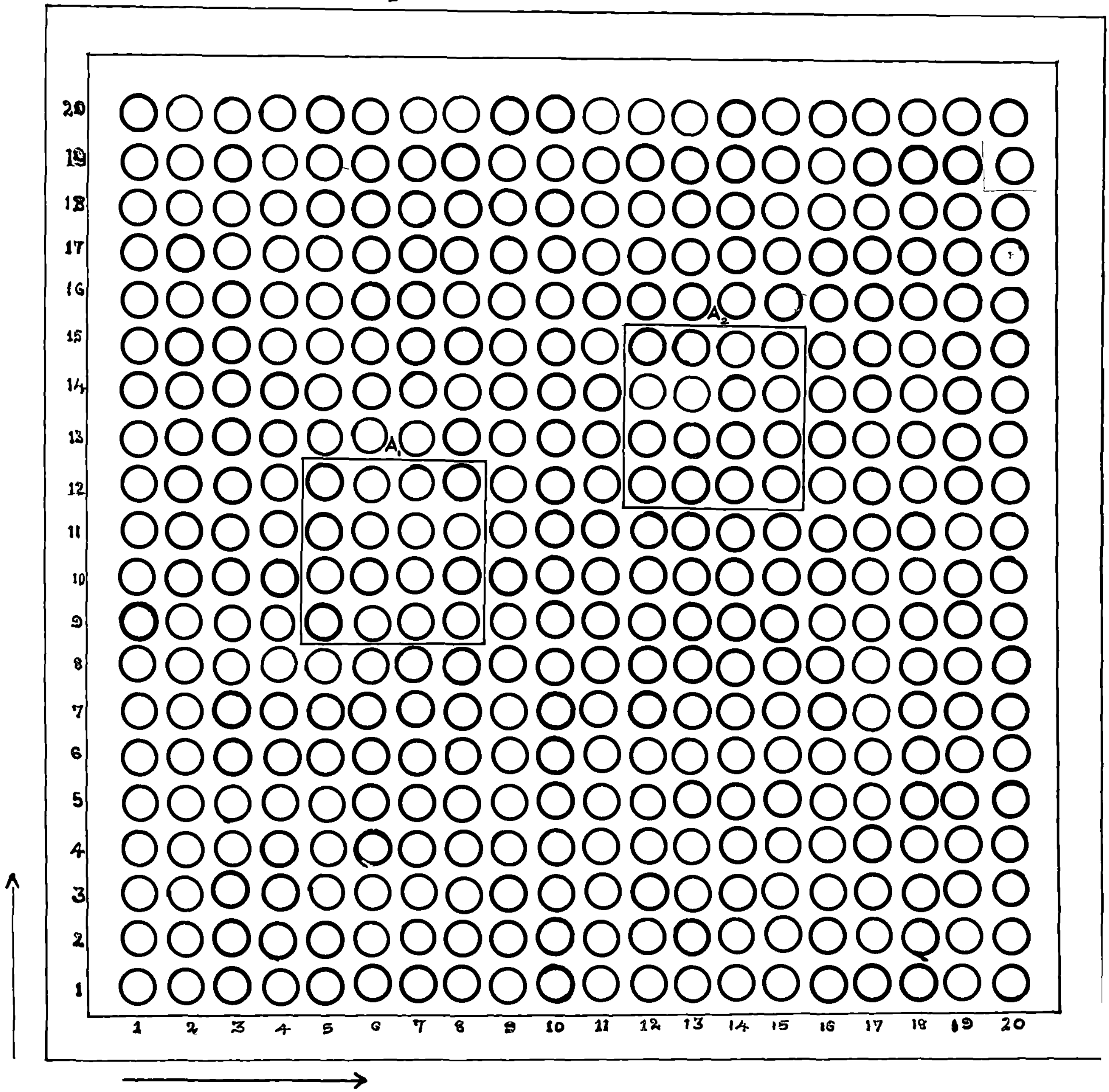
LAYOUT OF THE EXPERIMENT



METHOD OF TAKING SAMPLES —

RANDOM NUMBERS FOR A_1 = 8, 9

RANDOM NUMBERS FOR A_2 = 12 12



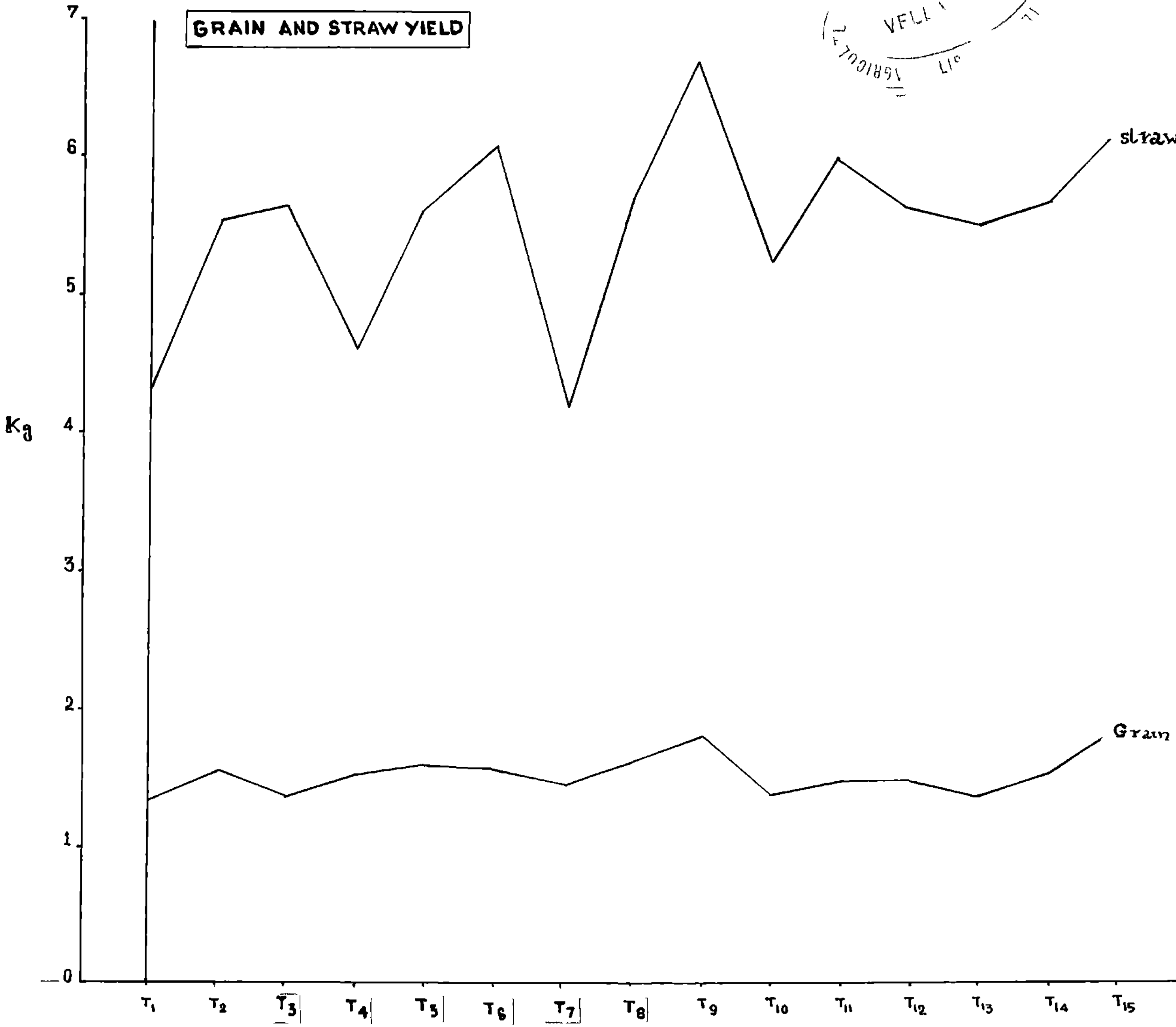

GRAIN AND STRAW YIELD
Kg
0
1
2
3
4
5
6
7
straw
Grain
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15

FIG 3