STUDIES ON THE RESPONSE OF N, P, AND K IN CONJUNCTION WITH Ca ON THE GROWTH, YIELD AND QUALITY OF TAPIOCA (*Manihot utilissima* Pohl) VAR - "MALAYAN-4"

BY

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CERTIFICATE

This is to certify that the thesis herewith submitted contains the results of bonafide research work carried out by Shri. K. Gopala krishna Pillai, under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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INTRODUCTION

INTRODUCTION

Tapioca (*Manihot utilissima* Pohl.) otherwise known as 'Manioc' or 'cassava', is extensively grown as a subsidiary food crop in Kerala State, with about 2,09, 371 hectares under cultivation and producing about 27,63,000 tons of tubers per annum. The total area under its cultivation in India is nearly 2,30,200 hectares, with a total annual production of 29,42,967 tons of tubers. In 1962-1963, the world acreage under tapioca was 83,00,000 hectares producing about 7,55,00,000 tons of tubers (Minkevich 1966).

The importance of tapioca, as a subsidiary food crop and its use as a raw material for the manufacture of starch is being increasingly realised and appreciated in several countries and there has been, of late, perceptible signs of significant increase in the demand for tapioca for the above purposes.

Next only to rice it is one of the most important subsidiary food crops in Kerala. Considering the gravity of the present food situation, and the importance of extension of food habits of our people, it is essential to step up the total annual production of tapioca in our state. It is a rich source of carbohydrates and hence a bold and patriotic approach on the part of every family in Kerala by reassorting the menu in such a way as to permit tapioca to contribute towards the carbohydrate requirements substantially, can be of immense help to cripple the threat of undernourishment our country faces today. Tapioca also contains nearly 2.0 per cent proteins, 0.4 per cent fats and 2.1 per cent mineral matter, on a dry basis. Thus it can be seen that the deep-rooted misconception, branding tapioca as a "poor-man's food" is baseless. (Magoon and Appan 1966)

Tapioca is a tropical crop which thrives under a warm humid climate with a moderate rainfall of about 150 cm. The gravelly laterite and the red loam soils of Kerala are ideally suited for this crop. These soils are however, generally deficient in nitrogen, available phosphoric acid and potash, whereas the nutrient requirements of the crop are very high.

Till recently very few studies have been conducted in India, on the agronomic aspects of the cultivation of tapioca. In 1945, a Tapioca Research Station was started at Trivandrum, and the results of the manurial trials conducted at the station have shown the immense potentialities of raising the yield of tapioca with balanced NPK fertilization. On the basis of a manurial-cum-spacing trial on tapioca, conducted continuously for a period of five years, at the Tapioca Research Stations, Trivandrum, Thiruvalla and Ollukkara it was concluded that an optimum manurial dose for tapioca will be 112 Kg of nitrogen and 135 Kg to 180 Kg potash per hectare, over a basal dose of 5-8 tons of the farm yard manure. The response due to phosphatic fertilization was found to be erratic and hence, it was recommended only for soils poor in available phosphorus (Anonymous 1963).

Based on the above trials the original fertiliser recommendation of N, P and K for tapioca in Kerala was 90:90:180 Kg per hectare. But this was subsequently brought down to 56:56:112 Kg per hectare, mainly because of a fall in price of tapioca, in the year 1962-1963. However, the original dose is still being recommended for this crop, in the I.A.D.P. areas of the State.

Most of the studies conducted hitherto, on fertiliser application for tapioca and other tuber crops in general, revealed the relative importance of nitrogen and potash application in increasing the yield. Application of phosphatic fertilizers failed to show any consistent response, probably because of the chances for more of fixation in the acidic soils of Kerala, where tapioca is mostly grown.

Laterite soils in general and Kerala soils in particular are deficient in lime status. Practically no work has been conducted to study the response of calcium on a root crop like tapioca, grown in the predominantly acidic soils of Kerala. Calcium, in addition to its effects on the soil as an ameleorant, also acts as an important plant nutrient, and the beneficial effects of liming by way of increased utilization of nitrogenous and phosphatic fertilizers have been reported in other tuber crops, like potato (Moriakulandai 1955). The beneficial effects of the major plant nutrients, applied in conjunction with calcium, on the growth, yield potential and quality of tapioca have not been studied so far, under Kerala conditions.

The present investigation was therefore undertaken with a view to study the response to graded doses of nitrogen, phosphorus, potash and calcium in factorial combinations, on the growth, yield and quality of a popular improved variety of tapioca, "Malayan-4", and to determine the optimum as well as an economic dose of these nutrients, under the agro-climatic conditions of Vellayani, by fitting response curves.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The nutrient requirements of tapioca, like all rapidly growing plants yielding carbohydrates, are reported to be very high. Hajholt (1935) as quoted by Jacob and Uexkull (1960) have shown the nutrient removal of tapioca at Buitenzorg as follows:

Nutrient	Amount removed (in kg per hectare)
Nitrogen	124
Phosphoric acid	104
Potash	584
Calcium oxide	217
Magnesium oxide	71

The quantity of N, P, K, Ca and Mg, removed by a crop of tapioca yielding 42 tons of tubers per hectare, from a fertile alluvial soil, at Madagascar as reported by Jacob and Uexkull (1960) was 255, 28, 250, 42 and 29 Kg per hectare respectively. They have also reported the amount of N, P, K, Ca and Mg removal from a laterite clay soil, by a crop of tapioca yielding 36 tons per hectare as 285, 36, 122, 56 and 12 Kg per hectare respectively.

Results of manurial trials on tapioca in Kerala conducted by " Potaschemie " have shown that a crop yielding 20,000 lb of raw tubers per acre removes 54 lb of nitrogen, 45 lb of phosphoric acid and 230 lb of potash per acre.

The above findings clearly show that tapioca can utilise large quantities of nutrients and that it responds well to fertilizer application.

Response of tapioca towards Nitrogen, Phosphorus & Potash fertilization:

The results of manurial experiments conducted at the Tapioca Research Station, Trivandrum as reported by Abraham (1956) have shown the immense potentialities of raising the yield of tapioca tubers with the application of balanced N, P & K fertilizers.

Manurial-cum-spacing trials on tapioca, with three levels each of nitrogen, phosphoric acid and potash and three levels of spacing in factorial combinations, conducted at the Tapioca Research Stations at Trivandrum, Thiruvalla and Ollukara in Kerala, for a period of five years consecutively, has conclusively proved that there is steady response to yield, due to nitrogen and potash. There was no significant response to phosphoric acid in the form of superphosphate. Based on the above trials it has been concluded that 100 lb of nitrogen in the form of ammonium sulphate and 120-160 lb of potash per acre in the form of muriate of potash is the optimum requirement of fertilizers for tapioca. Only if the organic manure supplied or the soil itself is deficient in available phosphorus, application of 20-40 lb phosphorus is necessary (Anonymous, 1963).

Chadha (1958) in a statistical examination of the results of fertilizer experiments on tapioca in Kerala State, has reported that plants in plots receiving fertilizers had better growth and development of tubers. A highly significant interaction of nitrogen and potash, on the yield of tapioca also has been reported by him. The results of simple fertilizer trials on tapioca in cultivators' fields in Kerala State, carried out by " Potaschome ", have shown that the application of N, P & K fertilizers increases the yield by 32-92 per cent as compared to the cultivators' usual practice which is taken as the control (Anonymous, 1961).

Greenstreet and Limbourne (1928) as quoted by Jacob and Uexkull (1960) have reported that treatments with calcium, nitrogen, phosphate and potash showed an increased yield especially of the second crop in Federated Malay States.

Cours (1952, 53) in fertilizer experiments at Madagascar with PK and NPK fertilizers on tapioca obtained considerable increase in yield whose value far exceeded the cost of fertilizers.

Acosta and Perez (1954) in Coasta Rica showed a close interaction between N and K, and N and P, on the yield of tapioca.

Malavolta et al. (1955) reporting on the physiological basis for the nutrition of tapioca, observed that effect of mineral elements N, P and K on the composition of roots. They have concluded that phosphates and nitrogen under the experimental conditions proved to be the most important nutrients for tapioca.

Cours et al. (1961) in Marovitisika on a piolet investigation of the main elements and trace elements useful to tapioca, have reported a significant positive effect of the combined application of N, P, K, Ca and Mg on the yield and density of tapioca tubers.

Effects of Nitrogen on plant growth and yield of tubers:

Manurial experiments on tapioca conducted at Thiruvalla and Trivandrum have revealed that the effect of nitrogen on plant growth and yield of tubers was highly significant (Anonymous 1954, 1955, 1957).

Malavolta et al. (1955) have shown that highest tuber yield in tapioca could be obtained by doubling the dose of nitrogen, thereby enhacing shoot and root growth.

In a statistical examination of the results of certain manurial trials on tapioca, conducted in Kerala state, Chadha (1958) has reported that the mean response to nitrogen varied from 1.02 to 2.75 tons for 40 lb nitrogen per acre and from 1.17 to 4.00 tons for 80 lb nitrogen per acre. The mean response from individual experiments due to doses of nitrogen varied from 23-79 per cent for 80 lb nitrogen per acre.

The economic optimum dose of nitrogen for tapioca recommended by " Potascheme " in 1961, on the basis of the manurial trials conducted by them for over a period of 5 years in Kerala was 96 lb/acre.

Manurial trials on tapioca conducted at the Central farm, Coimbatore for over a period of three years using 3 levels each of different organic manures, nitrogen and potash and two levels of phosphorus have shown that the main effects of nitrogen, potash and the interactions NPK, N x P x K, N x N x Px K, were significant during the second year of the experiment. (Anonymous 1962). The beneficial effects of nitrogen on plant growth and the final yield of tubers have been conclusively proved as a result of the manurial-cum-spacing trials conducted for five years consecutively in the Tapioca Research Stations Trivandrum, Thiruvalla and Ollukara in Kerala State. 100 lbs of nitrogen per acre (112 kg per hectare) applied in the form of Ammonium sulphate was found to be the optimum dose for tapioca (Anonymous 1963).

Results of manurial trials conducted recently at the Central Tuber Crops Research Institute, at Sreekaryam in Kerala State during the year 1966-1967 are also in agreement with these findings. (Anonymous, 1967)

<u>Effect of nitrogen on the growth and yield of certain other tuber crops:</u>

In sweet potato, Johnson and Ware (1948) observed that on Decatur soils the increase in vine production was highly significant for each additional increment of nitrogen applied from 0 to 120 lb per acre. There was a corresponding increase in the yield of roots also for each nitrogen increment.

Landrau and Samuels (1951) found that 82 lb nitrogen per acre was the optimum dose for raising the yield of sweet potato considerably, while 165 lb nitrogen per acre was found to be an excessive dose causing heavy vine growth leading to low yield of poor quality tubers.

Kunjan (1957) reported that the optimum dose of nitrogen for sweet potato at Mannuthy was 50 lb per acre and that further additions of nitrogen did not significantly increase the yield of tubers.

Isava and Odamoto (1959) found that nitrogen increased the growth of all plant parts and promoted the formation and translocation of sugars and production of nitrogen compounds in sweet potato.

Increase in vine length, weight and number of shoots in sweet potato with nitrogen application and early planting has been reported by Purewaland Dargan (1959).

Fujise and Tsuno (1962) in Japan noted that the rate of photosynthesis in sweet potato increased with increase in leaf nitrogen.

The results of manurial trials on sweet potato, conducted at Coimbatore has recorded that the main effects of nitrogen and organic manures were highly significant in raising the yield. 50 lb nitrogen per acre was found to be optimum (Anonymous 1962).

Peterson and Speights (1964) obtained highly significant results in the total and first grade tubers of sweet potato as rates of nitrogen were increased from 0 to 50 and from 50 to 100 lb per acre.

Narasimha Rao and Narasinga Rao (1954) observed that as the level of nitrogen was increased from 0 to 50 and 100 lb per acre, only long and slender tubers were obtained, in sweet potato.

Reporting on investigations in potato, Singh (1952) observed that application of nitrogenous fertilizers increased the leaf weight ratio, tuber size, yield and ware proportion.

Odland and Sheehan (1956) have recorded a consistent increase in the yield of potato from increased nitrogen application upto 120 lb per acre.

A linear increase in yield of potatoes upto 210 lb nitrogen per acre has been reported by Sawyer and Dallyn (1958).

Kanwar (1962) has reported that in acid loamy soils of Punjab the greatest response in potato was obtained at 100 lb nitrogen per acre.

Gruner (1963) has opined that a large mass of leaves and consequently large areas of assimilation are created by the action of nitrogen, which are pre-requisites for a good development, of tubers and a high production of starch in potatoes.

Pushkarnath and Sardana (1964) calculating the economics of nitrogen fertilisation in potatoes, have shown that a second degree parabola is found to be a satisfactory fit to the underlying relationship between the amount of nitrogen applied and the corresponding yield. 140-150 lb nitrogen per acre was found to be the optimum economic dose for giving the maximum yield of potatoes.

Valentin (1964) has reported that application of nitrogen at 70, 140 and 210 Kg per hectare, resulted in significant increase in the yield of potatoes between the levels tried.

Chapman (1965) in his experiments with Irish potatoes has observed that nitrogen fertilizer increased the yield from 17.8 to 22.9 and 26.4 tons per hectare, mainly because the leaf area decreased at a slower rate, in plots receiving nitrogen than it did in plots without nitrogen.

Sinha et al. (1966) has reported that nitrogenous fertilization plays an important role in increasing the potato production, and the fertilizer dose may vary due to various edaphic factors. Maximum number of leaves, branches and maximum yield was obtained at 135 Kg nitrogen per hectare, which have synthesized more amount of photosynthate.

Sommerfeldt and Knutson (1965) in South east Idaho found in field and glass house trials using Russet Burbank potatoes, that excess nitrogen reduced tuber size and number of tuber set.

In colocasia, Purewal and Dargon (1957) have shown that plant height, leaf area and yield of tubers were increased significantly with the application of nitrogen in doses ranging from 50 to 100 lb per acre. Nitrogen was not found to have any effect on the number of leaves formed at various stages of growth.

Mathur et al. (1966) have observed that the yield of colocasia can be increased with increasing levels of nitrogen upto 224 kg per hectare. But the economic optimum dose was fixed at 200 kg nitrogen per hectare in the form of Ammonium sulphate.

In sugar beet, Tolman and Johnson (1958) have reported that maximum sugar recovery was obtained with 120 lb nitrogen per acre and the optimum dose was 100 lb nitrogen per acre.

Russel (1959) found that highest yield and sugar content was obtained from sugar beet, with 150-180 lb nitrogen per acre.

Takegami (1962) observed that the development of branching roots in sugar beets was greatly enhanced in the presence of nitrogen.

Baldwin and Davis (1966) in a Brookston clay loam, have found that maximum recovery of sugar was obtained when nitrogen was applied as a pre-plant at 90-120 lb per acre.

In carrots, Dhesi et al (1964) at Ludhiana, have reported that application of nitrogen at 25, 50, and 75 lb per acre levels has significantly increased the leaf number, height of plants root length and yield.

Verma and Bajpai (1965) have found that nitrogen application at the rate of 22.5 Kg per hectare increased root yield of carrots by 20.1 and 40.75 quintals per hectare, in the first and second years of trial.

Investigations conducted by Chapman (1965) on Lisbon Yams under Trinidad conditions have shown that the yield was increased from an average of 6.4 to 8.3 tons per acre by applying six cwts of Ammonium sulphate per acre, applied 3 months after planting over a basal dose of P and K given at planting.

Effect of phosphorus on plant growth and yield of tubers: Miller (1938) has opined that in the absence of phosphorus, root crops like turnips, and mangolds do not enlarge but remain permanently dwarfed.

Black (1958) has observed that if a root crop is deficient in phosphorus, phosphorus fertilization usually increased the yield of roots more than that of the above ground parts. He has stressed the role of P in attaining maximum leaf weight at an early date for phosphorus fertilized plants and thereby helping in carbohydrate translocation to the storage tissues for a much longer period in the case of phosphorus fertilized plants than in phosphorus deficient plants.

Gruner (1963) has opined that phosphates are not only an important constituent of numerous substance but play an essential part in the process of transformation of substances and energy. High energy phosphates regulate the carbohydrate metabolism within the plant. Phosphoric acid has an important share in the formation of sugar and starch and to a large extent determines the quality of starch in potatoes.

In incremental phosphate nutrition experiments on tapioca, Doop and Den (1937) observed that 74 Kg per hectare of P_2O_5 over a basal dose of 74 Kg per hectare of nitrogen and 186 Kg per hectare of potash gave the maximum yield. Malavolta et al.(1955) have stressed the importance of phosphorus in increasing the yield and starch content of tapioca tubers. They were of opinion that requirement of this element for the phosphorylation of the starch reserves necessary to carry on vegetative growth during the early stages of development probably accounts for this high phosphate requirement.

Chadha (1958) has reported that the mean response due to P_2O_5 on the yield of tapioca varied from 4 to 12% for 40 lbs P_2O_5 per acre and from 3 to 25% for 80 lb P_2O_5 per acre.

The mean response of tapioca to phosphoric acid as reported by Potascheme in 1961 varied from 0.28 to 0.64 tons for 40 lb P_2O_5 per acre and from 0.23 to 1.27 tons for 80 lb P_2O_5 per acre. The application of phosphoric acid has given, significant response in the second and third season, but not in the first season, there by showing a cumulative effect due to its application. The economic optimum dose of P_2O_5 for tapioca was estimated by Potascheme, as 60 lb per acre.

The results of manurial trials conducted at the Tapioca Research Stations at Trivandrum, Thiruvalla and Ollukara in Kerala for over a number of years have shown that the response of tapioca to phosphoric acid was erratic in nature. There was a fall in response beyond 60 lb P_2O_5 per acre (Anonymous 1957, 1962).

<u>Effect of phosphorus on other tuber crops:</u> In sweet potato Morgan (1939) has observed that addition of Superphosphate gave significant increase

in tuber yield.

Rao and Rao (1954) found that application of phosphates increased the size of tubers considerably, in sweet potato.

Landrau and Samuels (1954) and Poorewal and Dargon (1959) found no response to phosphates on vine length, weight of vines, number of shoots and yield of sweet potato, except on acid lateritic soils.

Raju *et al.*(1954) has reported that a reduction of phosphorus below 200 lb per acre, caused significant reduction in yield of potatoes, at Nilgiris.

Hougland (1960) observed that an abundant supply of available phosphorus was necessary for potato during the early phases of its development for optimum growth and tuber formation.

Jaisinghani *et al.*(1964) had shown that application of phosphorus upto 90 lb per acre did not show any response on the yield of potato.

In colocasia, Purewal and Dargon (1957) have found that application of phosphates had no effect on germination, height of plants, leaf area or number of leaves produced. A general increase in yield however, was noticed.

Hodnet (1958) has reported that there was no response to phosphates in raising the yield of colocasia in Trinidad.

Irving (1956) in Eastern Nigeria found no overall general response to phosphatic fertilizer application on the yield of yams.

Verma and Bajpai (1965) found no response to phosphates either in root yield or foliage in the case of carrots.

Effect of potash on plant growth and yield of tubers: White (1928) as quoted by Jacob and Uexkull (1960) had shown the importance of K in increasing the yield of tapioca in Java.

Grossman and de Assis (1951) in Brazil have found significant increase in yield and quality of tapioca due to potash fertilization. Bolhuis (1954) has shown that the " linamerin " content was markedly increased by drought and potash deficiency.

Malavolta et al.(1955) in their studies on mineral nutrition of cassava have opined that the effect of K on root yields was much less marked than that of either Nitrogen or Phosphorus. In the absence of potash, the weight of roots decreased where as that of the shoots increased.

Chadha (1958) has reported that mean response due to potash varies from 19-43% for 80 lb K_2O per acre and from 23-75% for 160 lb K_2O per acre.

Cours et al.(1961) at Marovitsika have correlated the potassium content of the phelloderm with the yield of tubers and also with the density of tapioca tubers. Application of potassic fertilizers increased the total nutrient contents of N, P and K and the yield and density of tubers.

The mean response of tapioca to potash, as reported by " Potascheme " in 1961, varied from 1.22 to 2.55 tons for 80 lb potash per acre and from 1.48 to 3.13 tons for 160 lb potash per acre. The economic optimum level of potash for tapioca fixed by Potascheme was 167 lb per acre (188 Kg per hectare).

Nutrient uptake studies of potash, conducted at Tapioca Research Station, Trivandrum has revealed that maximum absorption of potash is after 3 to 4 months of planting and hence it was regarded as the best period of applying potash to tapioca. A total quantity of 110 lb K_2O per acre was found to have been removed by a crop of tapioca. (Anonymous, 1954, 1962).

Manurial trials conducted at the Tapioca Research Stations in Kerala have conclusively proved the beneficial effect of potash in increasing the yield and starch content of tapioca. 120-160 lbs K_2O per acre (135 to 180 Kg per hectare) has been recommended as the optimum dose for tapioca. (Anonymous 1963).

Effect of Potash on the yield of other tuber crops: In sweet potato Rao and Rao (1954) have found that application of potash produced napiform and spherical shaped tubers.

Duncun et al (1958) have reported that increasing doses of potash upto 480 lb/acre are beneficial in promoting the yield of sweet potato. A larger percentage of oversized roots were noted at higher levels of potash.

Jackson and Thomas (1960) have found that the uptake of potash by sweet potato was closely correlated with the growth of enlarged roots, more than 300 lbs of potash per acre was taken with a linear increase in yield.

Tsuno and Fujise (1965) have found that heavy potash application increased tuber weight, net assimilation rate and water content of tubers in sweet potato. Photosynthetic activity may be promoted by the accelerated translocation of photosynthates from the leaves to tubers.

Ho (1965) found that potash had no effect on the yield of leaves and vines while increasing the yield of tubers in sweet potato by 12-27% when potash at the rate of 120-180 Kg per hectare was applied. Rates higher than this adversely affected the yield of tubers.

In potatoes, Johnson (1958) found 200 lb of potash per acre as the optimum dose. Ward (1959) found an increase in vegetative growth and the number and size of tubers in potatoes with increasing doses of potash.

Gruner (1963) has reported that a higher proportion of larger tubers is produced as a result of potash application.

Mackay (1964) found 150 Kg of potash per acre as the optimum dose for potato.

Pushkernath and Sardana (1965) have observed, 125 Kg of potash per hectare as an enonomic dose for potatoes.

Carpenter and Murphy (1965) have reported that an elimination of potash from the fertilizer, reduced the yield of potatoes by 55 bushels per acre.

In calocasia, Purewal and Dargon (1957) have found that plant height, leaf area and yield were increased significantly by the application of potash at 50 lb per acre. Potash had no effect on the number of leaves formed at different stages of growth of the calocasia plant.

Effect of Calcium on plant growth and yield of tubers: Black (1957) has concluded that the beneficial effects observed on liming were mainly due to the nutrient effect of calcium.

Hoslop (1951) and others indicated that the beneficial influence on crop production obtained by liming was not due to the nutritional effect of calcium, but was associated with changes in soil reactions.

Parker and Troug (1927) have reported that calcium is intimately associated with nitrogen assimilation.

Blue and Eno (1957) have also obtained similar results and they found that liming resulted in better and efficient utilisation of nitrogenous fertilizers.

Hilgard (1907); Davis and Brewer (1940), Dunn (1947) and Troug (1948) claimed that liming increased the availability of phosphates.

Mariakulandai (1955) has reported that liming the acid soils of Nanjanad in Nilgiris increased the availability and uptake of phosphorus by potato.

Ehrenberg (1919) as quoted by York and Rogers (1947) pointed out the antagonistic effect between calcium and potassium in the soil.

In cassava, Stephens (1956) has reported that addition of lime with fertilizers improved the yield of tubers, considerably.

Coure et al (1961) have observed that the treatment including 2 tons per hectare of lime along with N, P, K has given the maximum yield of cassava at Mnrovitisika.

Effect of Calcium on the yield of other tuber crops: August Mehr et al.(1964) have reported that liming is important in successful potato production in most humid regions.

Hugh Murphy et al.(1965) found that liming increases the supply of available potash for potential use, by the potato plants.

Liming investigations conducted for over a period of 16 years at 12 different sites by Boekema (1964) have shown that maximum yield of turnips was obtained at a pH of 5.0.

Camargo (1960) found yield increase in carrot ranging from 16-99% over control due to the application of lime in an acid soil having a pH of 5.0, at the rate of 250 or 500 g of 48% CaO per sq.metre.

Maynard et al.(1961) attributed calcium deficiency as a reason for the carrot cavity spot.

In yams, Girardot (1956) found that addition of lime with fertilizers improved the yield, and that lime may be preferred because of the beneficial residual effect on the succeeding crop.

Nicleon et al.(1958) found that liming increased the yield of sugar beet.

Landrau and Samuels (1951) in Peurto Rico have observed that calcium treatment raised the yield of sweet potato tubers on lateritic clay soils having a pH of 4.5

Lucas and De Freitas (1960) studying the nutritional deficiencies of major and minor elements in Radish, have observed that tap root development was practically nil without N, K or calcium. Plant growth was checked most severely by nitrogen and calcium.

Effect of Interaction N x K on plant growth and yield of tubers: Acosta and Perez (1954) in Cossta Rica have observed a close interaction between Nitrogen and Potash on the yield of tapioca. Maximum yield was obtained by an application of 50 Kg nitrogen and 100 Kg potash per hectare.

Chadha (1958) has reported that there is a highly significant interaction between doses of N and K on the yield of tapioca. The productivity due to one of these elements was limited by the amount of other with which it was combined. The data indicated that greatest yields can be obtained from use of nitrogen and potash in 1:1.75 ratio.

In sweet potato, Tsuno and Fugise (1965) indicated a close relationship between weight and K/N ratio of tubers. Increasing the K/N ratio in the fertilizer, increased tuber weight and net assimilation rate in sweet potato.

In potatoes, Dhesi and Padda (1964) have found that application of 50 lb nitrogen and 50 lb potash per acre significantly increased the leaf number, height of plants and final yield of tubers, and improved root length and diameter in potatoes.

Effect of interaction N x P on plant growth and yield of tubers:

Acosta and Perez (1954) have also shown a close interation between N and P in increasing the yield of tapioca. Phosphates only increased the yield in the case of a simultaneous dressing of 100 Kg nitrogen per hectare.

In potatoes, Sommerfeldt and Knutson (1965) found that a proper balance of nitrogen and phosphorus was required, excess nitrogen reducing tuber size and number of tuber set, while excess phosphate delayed emergence. Rate of top growth was accelerated by both the minerals. The manurial trials conducted on sweet potato at Ollukara, in Kerala have also shown a highly significant interaction between N and P, on the yield (Anonymous 1962).

Effect of organic manures on plant growth and yield of tubers:

Abraham (1956) has reported the beneficial effects of application of organic manures in increasing the yield of tapioca.

Briant (1959) found that application of 10 tons of farm yard manure per acre produced 16.11 tons per acre of tapioca compared to no manure treatments.

Manurial experiments conducted at the Tapioca Research Stations in Kerala, have conclusively proved the beneficial effects of application of organic manures in increasing the yield of tapioca. (Anonymous 1963).

Similar results were also reported from Coimbatore. The main effect of organic manures, and its interaction with N K, PK and NPK were also reported to be significant at Coimbatore (Anonymous 1962).

Caesar and Ganesan (1965) in Ceylon demonstrated that yield responses in potatoes to 12.5 tons of cattle manure per hectare was higher than those to a fertilizer mixture providing 67 Kg nitrogen, 146 Kg phosphates and 56 Kg potash per hectare.

In carrots, Haworth and Cleaver (1963) observed that seedlings from farm yard manure treated plots contained more potash than carrots from plots which had received only mineral fertilizers. They found that this greater uptake was responsible for more rapid growth in such plants.

<u>Influence of Nitrogen, Phosphorus, Potash and Calcium on the quality of tubers:</u> Mudaliyar (1951) has given the food and vitamin value of tapioca as compared to rice. The per acre production of carbohydrates is the highest from this crop, giving four to five times as many calories as rice, from the same area.

Schery (1947) referred to it as a starch rich food for millions, a true " staff of life " among many ill-nourished tropical populations.

Irvine (1953) opined that tapioca produced from unit area, six times as much food as wheat.

Cassava leaf protein was suggested as a useful supplement to cereal diets by Rogers (1959), and Rogers and Milner (1963).

The chemical composition of cassava has been given by Johnson and Raymond (1965).

A scrutiny of the comparative nutritive value of tapioca and other food crops, as reported by Magoon and Appan (1966) indicate that there is no justification, whatsoever to brand tapioca as an inferior food. Tapioca is unrivalled as an indigenous raw material for starch production due to its low cost, high productivity and simple inexpensive methods of extraction.

(1) <u>Dry matter content:</u> Investigations carried out at the Tapioca Research Station, Trivandrum have shown that the percentage of rind varies from 10-22% depending on the variety and period of growth and nutrient supply. In varieties with high percentage of starch the moisture content was comparatively less at all stages of growth of tapioca ranging from 51.0 to 73.0% (Anonymous 1955).

In potatoes, Terman (1953) has found that the dry matter content of tubers grown without potash in the fertilizer increased upto levels 200-300 lb per acre of exchangeable K in the soil and decreased at higher levels. The dry matter content of tubers grown with 180 lb potash per acre as potassium chloride in the fertilizer, decreased in all years with increase inexchangeable-K per acre. The yield of dry matter per acre of tubers grown withfertilizers containing potash, increased only slightly above a level of 200-400 lbs exchangeable-K in the soil. Sheard and Johnson (1958) have reported that the dry matter content of Katahdin potato was sometimes increased by phosphate, consistently decreased by potash and slightly decreased by nitrogen.

Mourst and Tayel (1957) have shown that in corms of Egyptian colocasia dry matter content and starch increased from the rose end to the heel end and hence he suggested the best sampling technique to find dry matter is to take a diagnal core.

Duncan *et al.* (1958) have shown that dry matter content of roots in sweet potatodcereased with increased potash supply.

Application of nitrogen and to a lesser extent potash has been found by Baerug (1961) to reduce tuber dry matter in potato.

Murphy and Goven (1966) have also reported that application of higher rates of potash resulted in lower specific gravity in potato.

Improved methods of drying to bring about improvement in quality of tapioca has been suggested by Lavigne (1966).

(2) Crude-protein content: Mudaliyar (1951) and Magoon and Appan (1966) have reported that the crude protein content of tapioca, on an average,

ranges from 1.20 to 1.75% though varieties having upto 10.0% have also been reported.

Investigations conducted at the Tapioca Research Station, Trivandrum have shown that application of nitrogen as Ammonium sulphate increased the nitrogen content of tapioca tubers, whereas, application of potash in the form of Muriate of potash decreased the nitrogen content. The period of harvest also was found to be important. (Anonymous 1960)

In potatoes, Mulder and Bakema (1956) have found that the amino acid composition of the protein was independent of the supply of nitrogen, phosphorus and potash, although the total protein may vary considerably with varying supplies of N, P and K. Non-limiting amounts of nitrogen on deficiencies of phosphorus or potash increased the nitrogen content and protein fractions.

Murtin (1957) has found that the protein content of potatoes was increased considerably by a single application of 80 lb nitrogen per acre at planting.

3. <u>Starch content</u>: Reuter (1955) has reported that application of 400-500 Kg per hectare of Ammonium sulphate produced an increase in starch yield from tapioca by about 1500-1600 Kg per hectare, which worked out to 16-18 Kg starch for every Kg of nitrogen applied.

Malavolta <u>et al</u>.(1955) have stressed the importance of phosphorus and nitrogen on the starch content of roots in tapioca.

In the Annual Report of the scheme of Research on Tapioca and other tuber crops in Kerala for the year 1956-1957, it has been reported that higher doses of potash produce significant increase in starch content of tubers, upto the highest level of potash tried viz; 150 lb per acre. Further investigations have shown that the application of nitrogen as Ammonium sulphate decreased the starch content of tapioca tubers, the average rate of decrease in percentage of starch content of tubers for every addition of 50 lb of nitrogen per acre was found to be 1.94. The effect of potash and that of the interaction between nitrogen and potash, on starch content of tubers were not significant.

In potato, Lucas et al. (1954) found that a fertilizer with a 1:3 phosphate potash ratio, gave the highest yield, but they contained 2% less starch than did those fertilized with a 2:1, 1:1 or 1:2 rates of the same fertilizers.

Eastwood et al. (1955) have reported that both lower and higher levels of nitrogen application raised slightly the specific gravity of potatoes, while the medium dose had only very little influence.

Rajat De (1960) has shown that the starch content of potato tubers was significantly increased by potash application, but the reducing sugars and total sugars remained unaffected.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation was undertaken to study the effect of three levels each of Nitrogen, Phosphoric acid, Potash and Calcium in factorial combinations, on the yield and quality of a popular improved variety of tapioca viz: " Malayan-4 ".

I. Experimental site: The investigations were carried out in the red loam soils, at the central farm attached to the Agricultural College & Research Institute, Vellayani. Chemical analysis of the soil was carried out and the analytical data are given below:

Total nitrogen.	0.056%
Total phosphoric acid.	0.032%
Total potash.	0.069%
Available phosphoric acid.	0.0021%
Available potash.	0.00066%
pH.	5.1

II. Season: The experiment was conducted from June, 1966 to April 1967. The meteorological observations recorded during this period are given in Appendix XIV.

III. Materials:

(i) Planting material: ' Malayan-4', the variety chosen is an improved exotic variety introduced from Malaya, which is becoming very popular with the cultivators in Kerala. Abraham (1956) has described it as a tall growing, scarcely branching and high yielding variety with a duration of 9-10 months. Ram Raj (1966) has reported it to be comparatively resistant to cassava-mosaic disease, which has become a problem with most of the indigenous varieties of tapioca which are now being grown in our state.

Mature stems of this variety harvested and preserved for one month before the commencement of the present investigation, was used as the planting material. Cuttings, 8-9" in length were taken, from stems having more or less uniform thickness. The top and basal portions of the stems were rejected, since the middle portion of the stems are reported to be the best for planting (Anonymous, 1951).

(ii) Manures and Fertilizers: A uniform dose of well rotted cattle manure, at the rate of 6000 Kg per hectare was applied uniformly in all the plots. Nitrogen, Phosphoric acid and Potash were applied in the form of Ammonium Sulphate, Superphosphate and Muriate of potash respectively, and Calcium was applied in the form of calcium hydroxide. The chemical analysis of the manures and fertilizers used are given below:

Ammonium sulphate	20.6% N
Super phosphate	16.1% P_2O_5
Muriate of potash	59.1% K_2O
Lime	54.3% CaO
Cattle manure:	
	0.51% N
	0.29% P_2O_5
	0.46% K_2O

IV. Methods:

(i) Lay out: The experiment was laid out in a 3^4 confounded factorial experiment in Randomized Block Design with 81 treatments, grouped into 9 blocks of 9 plots each. The higher order interactions of " N P K ", " N K^2 Ca", N P^2 Ca^2", and P$K^2$$Ca^2$" were confounded. The procedure followed in allocating the various treatments into blocks and plots was in accordance with the procedure given by Yates (1937).

(ii) Treatments: The levels of individual nutrients were fixed, based on the results of previous trials and also based upon the fertilizer recommendations for the crop in Kerala. The original recommended dose of N P and K for tapioca were 80:80:160 lbs/acre respectively (90:90:180 Kg/hectare). But this was subsequently brought down to 50:50: 100 lbs/acre (56:56:112 Kg/hectare), mainly because of a fall in price of tapioca in the year 1963. However, the original dose of 90:90: 180/hectare of N, P and K is still being recommended for this crop in the I.A.D.P. areas of the State.

In the light of the above recommendations, and also after considering the present high cost and demandfor tapioca, three graded dose of N, P, K and calcium were fixed for carrying out the present investigation, with a view to fitting response curves and to determine the optimum as well as economic dose of these nutrients for tapioca.

A zero level was given for Phosphoric acid, since the response due to P_2O_5 has not yet been conclusively proved and the response in many cases were reported to be erratic.

Three levels of calcium viz: zero level with no lime, a middle dose supplying half the lime requirement of the soil and a third dose supplying the full lime requirement of the soil were included, in order to find out the response of a tuber crop like tapioca, grown in naturally acidic soils of this region towards the application of calcium, which in itself is a secondary plant nutrient element as well as an amelioront to the soil. The treatments comprised of all possible factorial combinations of the following levels of nutrients, involving 81 treatments:

<u>Nitrogen:</u>

(1) N_0 = 50 Kg/hectare.

(2) N_1 = 100 Kg/hectare.

(3) N_2 = 150 Kg/hectare.

<u>Phosphoric acid:</u>

(1) P_0 = 0 Kg/hectare.

(2) P_1 = 50 Kg/hectare.

(3) P_2 = 100 Kg/hectare.

<u>Potash:</u>

(1) K_0 = 100 Kg/hectare.

(2) K_1 = 150 Kg/hectare.

(3) K_2 = 200 Kg/hectare.

<u>Calcium:</u>

(1) Ca_0 = 0 Kg/hectare.

(2) Ca_1 = 600 Kg/hectare.

(3) Ca_2 = 1200 Kg/hectare.

(iii) Other details of the layout:

Number of replication	One
Number of plots	81
Gross plot size	5.4 m x 5.4 m.
Net plot size	3.6 m x 3.6 m
Number of plants in the gross plot	36
Number of plants in the net plot	16

(iv) Spacing: A spacing of 90 cm. eitherway, between plants and between rows was adopted.

V. Field culture:

(i) Preparatory cultivation: The experimental site was given two deep ploughings with tractor. Plots of size 5.4 m x 5.4 m were laid out in nine blocks, the plots being separated by bunds having a breadth of 30 cm., and the blocks being seperated by bunds having a breadth of 50 cm. The plots were given a digging and levelled. Mounds were taken in lines 90 cm. apart.

(ii) Manuring: The entire dose of calcium hydroxide as per the treatments were applied as a basal dose, on 20—6—1966 immediately after the lay out was completed. Cattle manure at the rate of 6000 Kg per hectare, was applied uniformly in all the plots, nine days after the application of lime. Both lime and cattle manure were spread uniformly in the plots and were incorporated into the soil by light diggings.

The entire dose of superphosphate as per the treatments were also applied as a basal dose along with the cattle manure and incorporated into the soil.

Nitrogen and potash were applied as Ammonium sulphate and Muriate of potash respectively, in 2 split doses. The first dose was given at the time of first inter cultivation on 2nd September 1966, and the second dose was applied at the time of the next intercultivation, done on 7th November, 1966. The fertilizers were applied in basins farmed around the base of the plants and were covered properly.

(iii) Planting: Planting was done on 3rd July 1966. Tapioca cuttings were planted vertically at the centre of the maunds at the rate of one cutting per maund. (Jayaseelan, 1951, and Anonymous 1952).

(iii) General condition of the crop: Pot watering was done on the fifth day after planting to get the cuttings sprouted uniformly. A soaking rainwas obtained on the seventh day after planting and cent per cent germination of cuttings were obtained. The sprouts were healthy, and vigorous. Sprouts in excess of two per plant were removed a week after their emergence.

The general stand of the crop was excellent throughout the growth period.

(v) Interculitivation and weeding: A light raking and weeding was given on 9—8—1966. First intercultivation was done on 2—8—1966 and the second intercultivation on 7—11—1966. Earthing up was conducted twice, first earthing up was done on 7—11—1966 and the final earthing up on 11—1—1967.

(vi) Plant protection: There was no incidence of attack of any major pest or disease. The variety chosen was free of any serious disease or pest.

(vii) Harvest: The maturity of the crop was indicated by the falling of leaves, stem colour, and also by the cracking of soil around the base of plants. The plants selected for biometric studies were harvested on 10—4—1967 from all the plots, and the necessary observations were recorded. The remaining plants from the net plots were harvested on 11—4—1967 and the weights were recorded. Samples of tubers for chemical analysis were collected on that day. The boarder plants were harvested on the next day and their yield was also recorded.

VI. Observations recorded:

(i) Sampling technique for biometric studies: Four plants from the net plot standing in a diagonal line in the same direction were selected from all the plots for studying the biometrical characters.

(ii) <u>Pre and post-harvest observations:</u> The following characters were studied during the growth phase of the crop and after the harvest.

<u>Pre-harvest observations:</u>

1. Germination
2. Number of leaves per plants
3. Height of plants
4. Branching

<u>Post-harvest observations:</u>

1. Yield of tubers from the observation plants
2. Number of tubers in the observation plants
3. Number of unproductive roots in the observation plants
4. Mean length of tubers in the observation plants
5. Mean girth of tubers in the observation plants
6. Weight of vegetative parts in the observation plants
7. Total yield of tubers from the net plot
8. Weight of rind and flesh in tubers collected from each plot, and their relative proportion.
9. Estimation of dry matter percentage in tubers
10. Estimation of starch content of tubers
11. Estimation of nitrogen and crudeprotein content of tubers.

(iii) <u>Technique adopted for recording observations:</u>

(1) <u>Germination:</u> Three observations were taken at an interval of three days viz; on the 9th, 12th and 15th day after planting. Cent per cent

germination was noted in all the plots.

(2) Height of plants: Height was measured from the base of the sprouts to the tip of the plant, correct to a centimetre; at an interval of 30 days upto the 150th day after planting. The final height at the time of harvest also was recorded.

(3) Number of leaves per plant: The first observation was taken on the 30th day after planting and the subsequent observations were taken at an interval of 30 days, upto the 150th day. The total number of leaves formed per plant, till the time of harvest was noted by counting the total number of leaf scars from the base to the tip of the stems, on the day of harvest.

(4) Branching: Branching was observed in some of the plots four months after planting, though the variety used was reported to be a tall growing and non-branching type. Observations on branching was recorded at an interval of 15 days till harvest.

(5) Number of tubers per plant: The total number of tubers from each of the four observation plants were counted and the average was recorded as number of tubers per plant.

(6) Number of unproductive roots per plant: The total number of roots which were unproductive, from each of the four observation plants was counted and the average recorded.

7. Average length of tubers: Length of 4 average sized tubers taken at random was measure , correct to a centimetre and the average recorded.

8. Average girth of tubers: Girth also was measured, from the tubers selected for recording the length, and the average girth was recorded.

9. Weight of tubers from the net plot: The total weight of tubers obtained from the plants in the net plot was recorded in Kg as the yield from the net plot.

10. Weight of vegetative parts: The total weight of stems and the leaves which remained on the four observation plants at the time of harvest, was noted and the average was recorded.

(11) Weight of the rind and flesh and their relative proportion in tubers:

A random sample of 1000 gms of tubers was weighed out from each plot and the weight of the rind and the fleshy edible portions was taken separately, after peeling, and the percentages were calculated and recorded.

(12) Percentage of dry matter: A known weight viz: 500 Kg of the fleshy portion of tubers from individual plots were chipped diagonally into pieces and dried in the sun for three days. The sundried material was kept in the air oven for about 6 hours at 105°C and the final weight was noted. This was expressed as a percentage of dry matter content of tubers and recorded.

13. Crude protein: The total nitrogen content of the oven dried samples from individual plots were estimated by the Kjeldahls' method given by Piper (1948). The crude protein content was calculated from this and was recorded.

14. Starch content: The percentage of starch contained in the oven dried samples from individual plots were estimated by the A.O.A.C. method (1956).

RESULTS

RESULTS

The data relating to various biometric, yield and qualitative characters of tapioca, under the present investigation were analysed statistically and the results are presented in the tables furnished below:

A. Growth characters:

i. Height of plants: The analysis of variance for the mean height of plants at harvest is given in Appendix I. It is seen that the height of plants is increased significantly due to the application of potash. Nitrogen, phosphorus and calcium had no significant, effect on plant height. The combined effect of nitrogen and calcium at various levels are also found to be significant.

Application of the highest level of potash (k_2) has significantly increased the height of plants over the other two levels. But there was no significant difference between k_0 and k_1.

The combined effect of n_1 Ca_2 significantly depressed the height to a minimum of 436.7 cm, as compared to the maximum height of 595.9 cm recorded by the treatment n_2 Ca_0.

ii. Branching in plants: Appendix II presents the analysis of variance, for the effect of various levels of nutrients on branching of tapioca plants. The combined effect of nitrogen and calcium alone is found to have significantly increased branching. None of the direct

Table I

Height of plants at harvest (in cms)

	N_0	N_1	N_2	Mean
P_0	496.1	444.3	474.2	471.5
P_1	496.7	520.9	482.9	500.2
P_2	428.8	540.4	491.0	486.0
K_0	442.1	475.6	487.1	468.3
K_1	481.7	483.7	436.0	467.2
K_2	497.7	546.3	525.1	523.0
Ca_0	459.2	595.9	455.5	503.5
Ca_1	512.9	472.9	497.3	494.4
Ca_2	449.5	436.7	495.4	460.5
Mean	473.9	501.8	482.7	

	P_0	P_1	P_2	Mean
K_0	438.2	514.1	452.5	468.3
K_1	419.6	477.1	504.8	467.2
K_2	556.7	509.4	502.9	523.0
Ca_0	489.4	511.1	510.0	503.5
Ca_1	466.9	495.9	520.3	494.4
Ca_2	458.3	493.5	429.8	460.6
Mean	471.5	500.2	486.7	

	K_0	K_1	K_2	Mean
Ca_0	454.5	484.2	571.8	503.5
Ca_1	506.1	469.0	508.0	494.4
Ca_2	444.1	448.3	489.2	460.5
Mean	468.3	467.2	523.0	

C.D. (5%) for comparison between marginal means = 46.05

,, combinations = 79.92

Table II

Percentage of plants branched

	N_0	N_1	N_2	Mean
P_0	59.00	62.00	66.33	62.44
P_1	59.45	62.55	61.67	61.22
P_2	71.00	66.33	77.22	71.52
K_0	67.11	65.33	70.44	67.63
K_1	60.44	67.11	72.00	66.52
K_2	61.89	58.44	62.78	61.04
Ca_0	67.44	43.33	67.22	59.33
Ca_1	53.11	73.55	70.33	65.66
Ca_2	68.89	74.00	67.67	70.18
Mean	63.15	63.63	68.41	

	P_0	P_1	P_2	Mean
K_0	64.67	64.11	74.11	67.63
K_1	63.67	67.67	68.22	66.52
K_2	59.00	51.89	72.22	61.04
Ca_0	58.78	58.33	60.89	59.33
Ca_1	59.67	63.44	73.89	65.66
Ca_2	68.88	61.89	79.78	70.18
Mean	62.44	61.22	71.52	

	K_0	K_1	K_2	Mean
Ca_0	68.44	57.11	52.44	59.33
Ca_1	61.78	70.11	65.11	65.66
Ca_2	72.67	72.33	65.55	70.18
Mean	67.63	66.52	61.04	

C.D.(5%) for comparison between marginal means = 8.63

" " combinations = 14.95

effects of nutrients or their interactions, excepting the one already mentioned is found significant.

It is evident from Table 11, that incremental doses of nitrogen are increasing the percentage of plants branched per plot, but the rate of increase is not statistically significant. The highest level of phosphorus (p_2) has significantly increased branching, over the p_0 and p_1 levels.

Application of potash is showing a depressing effect on branching in tapioca, as the levels are increased. However, the effect is not found statistically significant.

The highest level of calcium (Ca_2) significantly increased branching when compared to the treatments receiving no calcium (Ca_0). However, the differences between Ca_0 and Ca_1, and Ca_1 and Ca_2 are not statistically significant.

It is also evident from the above table that the combined effect of nitrogen and calcium on branching in tapioca is showing a significant positive trend. Minimum percentage of branching per plot is noticed under the combination n_1 Ca_0 and maximum at n_1 Ca_2., among the N x Ca combinations.

Considering all the effects of combinations, a maximum percentage of branching viz; 79.78 per cent is noticed under the treatment p_2 Ca_2 .

Table III

Number of leaves per plant

	N_0	N_1	N_2	Mean
P_0	315.6	303.5	344.6	321.2
P_1	318.2	315.2	300.8	311.4
P_2	314.0	345.0	325.8	328.3
K_0	323.2	330.9	330.9	328.3
K_1	316.1	312.5	326.0	318.2
K_2	314.0	320.3	314.4	314.4
Ca_0	315.5	325.8	302.6	314.6
Ca_1	315.3	332.9	334.3	327.5
Ca_2	316.9	305.1	334.3	318.8
Mean	315.9	321.2	323.7	

	P_0	P_1	P_2	Mean
K_0	302.6	327.8	354.6	328.3
K_1	326.0	301.3	327.3	318.2
K_2	335.0	305.1	302.9	314.4
Ca_0	318.4	316.3	309.2	314.6
Ca_1	308.5	320.7	353.3	327.5
Ca_2	336.8	297.3	322.3	318.8
Mean	321.2	311.4	328.3	

	K_0	K_1	K_2	Mean
Ca_0	302.4	320.2	321.2	314.6
Ca_1	341.6	320.9	320.1	327.5
Ca_2	341.0	313.5	301.8	318.8
Mean	328.3	318.2	314.4	

C.D. (5%) for comparison between marginal means = 35.08
,, ,, combinations = 60.74

iii. Number of leaves per plant: The analysis of variance for the total number of leaves produced per plant, as influenced by the factorial combination of different levels of nutrients, is presented in Appendix III. None of the treatments had any significant effect on the total number of leaves produced per plant.

However, it is evident from Table III, that increased levels of nitrogen show an increasing trend in the total number of leaves produced per plant. But, in the case of potash the effect was just the reverse.

iv. Weight of vegetative parts: It is evident from Appendix IV and and Table IV, that only nitrogen and potash have significant effect in increasing the weight of vegetative parts.

The higher levels of nitrogen (n_1 and n_2) significantly increased the weight of vegetative parts over the n_0 level, but there is no significant difference between n_1 and n_2. It is also seen that the highest level of potash (k_2) is found to be significantly superior over the lowest level of potash (k_0) but the difference in response between k_0 and k_1, and k_1 and k_2 are not significant.

Eventhough none of the interactions are found significant the combination of n_1 k_2 recorded the maximum mean weight of 2.472 kg per plant, while n_0 p_2 combination recorded the minimum mean weight of 1.500 kg per plant.

Table IV

Weight of vegetative parts(in kg per plants)

	N_0	N_1	N_2	Mean
P_0	1.833	1.847	2.041	1.907
P_1	1.791	2.166	2.250	2.069
P_2	1.500	2.263	2.263	2.009
K_0	1.597	1.819	2.083	1.833
K_1	1.819	1.986	2.153	1.986
K_2	1.708	2.472	2.319	2.166
Ca_0	1.652	2.250	1.944	1.949
Ca_1	1.661	1.889	2.236	1.995
Ca_2	1.611	2.138	2.375	2.041
Mean	1.708	2.092	2.185	

	P_0	P_1	P_2	Mean
K_0	1.694	1.986	1.819	1.833
K_1	1.875	2.069	2.013	1.986
K_2	2.152	2.152	2.194	2.166
Ca_0	1.847	2.013	1.987	1.949
Ca_1	2.000	1.987	2.000	1.995
Ca_2	1.875	2.208	2.041	2.041
Mean	1.907	2.069	2.009	

	K_0	K_1	K_2	Mean
Ca_0	1.638	1.972	2.236	1.949
Ca_1	1.903	2.000	2.083	1.995
Ca_2	1.958	1.986	2.180	2.041
Mean	1.8333	1.986	2.166	

C.D.(5%) for comparison between marginal means = 0.230

,, ,, combinations = 0.399

B. Yield components and final yield of tubers in tapioca:

1. Yield of tubers: The analysis of variance for the yield of tubers, as influenced by the various combinations of different levels of nutrients is furnished in Appendix V.

It is seen that the effect of nitrogen, phosphorus, potash, calcium and the combined effect of nitrogen and potash are significant in increasing the yield of tubers in tapioca.

Table V summarises the mean yield of tubers, as influenced by the various treatment combinations.

Application of higher levels of nitrogen (n_1 and n_2) significantly increased the yield of tubers, over the application of the lowest level of nitrogen (n_0) while there is no significant difference between the higher levels tried. Similar trends are also noticed in the case of phosphorus and calcium.

In the case of potash, the highest level (k_2) has significantly increased the yield of tubers over the lowest level (k_0), while there is no significant difference between k_0 and k_1 and k_1 and k_2.

Application of higher levels of calcium (Ca_1 and Ca_2) also has significantly increased the yield over their control (Ca_0). However, the difference in response between the higher levels is not significant.

Table V

Yield of tubers
(Tonnes per Hectare)

	N_0	N_1	N_2	Mean
P_0	29.83	32.79	32.88	31.83
P_1	31.16	35.02	35.62	33.93
P_2	31.97	35.18	38.02	35.05
K_0	31.84	32.14	33.90	32.64
K_1	30.13	36.09	34.93	33.72
K_2	30.99	34.72	37.67	34.46
Ca_0	30.17	30.99	33.13	31.43
Ca_1	30.86	35.79	36.30	34.32
Ca_2	31.93	36.18	37.07	35.06
Mean	30.99	34.32	35.50	

	P_0	P_1	P_2	Mean
K_0	30.82	33.31	33.78	32.64
K_1	30.99	34.93	35.23	33.72
K_2	33.69	33.56	36.13	34.46
Ca_0	29.53	32.10	32.66	31.43
Ca_1	32.02	35.15	35.79	34.32
Ca_2	33.95	34.55	36.69	35.06
Mean	31.83	33.93	35.05	

	K_0	K_1	K_2	Mean
Ca_0	31.16	31.89	31.25	31.43
Ca_1	33.13	34.68	35.15	34.32
Ca_2	33.61	34.59	36.99	35.06
Mean	32.63	33.72	34.46	

C.D. (5%) for comparison between marginal means = 1.35
" " combinations = 2.34

Among the combined effects, only the interaction of nitrogen and potash is found to have significantly increased the yield. Between $n_0 k_0$, $n_0 k_1$ and $n_0 k_2$ there is no significant difference. The combined effects of $n_1 k_1$ and $n_1 k_2$ are found to be superior over $n_1 k_0$, but there is no significant difference between $n_1 k_1$ and $n_1 k_2$. The combined effect of $n_2 k_2$ is significantly superior over $n_2 k_0$ and $n_2 k_1$, but there is no significant difference between $n_2 k_0$ and $n_2 k_1$.

Within the various levels of nitrogen and potash, the combination $n_2 k_2$ gave the maximum yield of 36.67 tonnes per hectare, while $n_0 k_1$ gave the lowest mean yield of 30.13 tonnes of tubers per hectare.

A maximum mean yield of 38.02 tonnes of tubers per hectare is recorded by the combined application of $n_2 p_2$ and the minimum mean yield of 29.53 tonnes per hectare is recorded by the combination $p_0 Ca_0$.

ii. <u>Number of tubers per plant</u>: Appendix VI presents the analysis of variance for the number of tuber per plant. Different levels of nitrogen and calcium alone are found to be significant in increasing the number of tubers per plant.

Table VI summarises the mean effect of factorial combinations of the different levels of nutrients on the number of tubers per plant.

It is evident that the number of tubers per plant is increasing significantly with increasing doses of nitrogen and calcium.

Table VI

Number of tubers per plant

	N_0	N_1	N_2	Mean
P_0	8.92	9.94	11.33	10.06
P_1	8.69	11.89	11.42	11.08
P_2	9,08	11.53	12.75	11.12
K_0	9.56	9.61	10.30	9.82
K_1	8.47	12.25	12.52	11.08
K_2	8.67	11.50	12.67	10.94
Ca_0	8.44	10.33	10.58	9.79
Ca_1	9.39	11.28	12.56	11.07
Ca_2	8.86	11.75	12.36	10.99
Mean	8.90	11.12	11.83	

	P_0	P_1	P_2	Mean
K_0	9.42	10.33	9.72	9.82
K_1	10.17	10.94	12.14	11.08
K_2	10.61	10.72	11.50	10.94
Ca_0	9.08	10.28	10.00	9.79
Ca_1	10.53	10.94	11.75	11.07
Ca_2	10.58	10.78	11.61	10.99
Mean	10.06	10.67	11.12	

	K_0	K_1	K_2	Mean
Ca_0	9.06	10.33	9.97	9.79
Ca_1	10.36	11.42	11.44	11.07
Ca_2	10.06	11.50	11.42	10.99
Mean	9.82	11.08	10.94	

C.D.(5%) for comparison between marginal means = 1.06

,, ,, combinations = 1.83

In the case of phosphorus there is no significant difference between p_0 and p_1, and p_1 and p_2, while the highest level of phosphorus (p_2) increased the number of tubers significantly over the lowest level (p_0) tried.

Even though there is no significant difference between the higher levels of potash, it is found that these two levels significantly increased the number of tubers per plant over the lowest level of potash (k_0).

Of all the combinations tried, n_0 k_1 recorded the minimum mean number of tubers per plant (8.47), while a maximum of 12.75 tubers per plant is recorded by the combination n_2 p_2 .

iii. Number of unproductive roots per plant : The analysis of variance for the mean number of unproductive roots per plant is given in Appendix VII. It is evident that none of the direct effect of nutrients or their interactions is having any significant effect on the mean number of unproductive roots produced per plant.

It is seen from Tables VII that the higher levels of nitrogen are having a depressing effect on the number of unproductive roots, even though its effect is statistically not significant. Levels of calcium did not exert any significant difference on the number of unproductive roots per plant.

The combined effect of n_2 p_2 produced a minimum of 7.36 unproductive roots per plant, while the maximum number of 9.92 such

Table VII

Number of Unproductive roots per plant

	N_0	N_1	N_2	Mean
P_0	8.92	8.08	8.39	8.46
P_1	8.69	9.25	8.39	8.94
P_2	8.58	7.92	7.36	7.95
K_0	8.83	8.19	8.25	8.43
K_1	8.11	7.45	8.36	7.97
K_2	9.25	9.61	8.03	8.96
Ca_0	9.17	7.75	8.39	8.43
Ca_1	9.14	8.36	7.89	8.46
Ca_2	7.89	9.14	8.36	8.46
Mean	8.73	8.42	8.21	

	P_0	P_1	P_2	Mean
K_0	8.28	9.39	7.61	8.43
K_1	8.00	7.53	8.39	7.97
K_2	9.11	9.92	7.86	8.96
Ca_0	8.05	9.53	7.72	8.43
Ca_1	8.39	8.97	8.03	8.46
Ca_2	8.95	8.33	8.11	8.46
Mean	8.46	8.94	7.95	

	K_0	K_1	K_2	Mean
Ca_0	8.45	8.33	8.53	8.43
Ca_1	8.11	8.00	9.28	8.46
Ca_2	8.72	7.58	9.08	8.46
Mean	8.43	7.97	8.96	

C.D. (5%) for comparison betwe-n marginal means = 1.31

,, ,, combinations = 2.27

roots is produced by the combination p_1 k_2.

iv. <u>Mean length of tubers</u>: Appendix VIII presents the analysis of variance for the mean length of tubers. The main effect of nutrients and their interactions failed to show any significant effect on the mean length of tubers in tapioca.

The mean length of tubers under the different treatment combinations are presented in Table VIII. A slight increase in mean length of tubers is noticed with increasing levels of all the nutrients, but none of these differences is significant.

v. <u>Mean girth of tubers</u>: The analysis of variance for the mean girth of tubers as influenced by the factorial combinations of different levels of nutrients are presented in Appendix IX.

It is evident that the direct effects of nitrogen, potash and calcium alone are significant in increasing the mean girth of tubers. None of the interactions shows any significant effect on the girth of tubers.

Table IX summarises the effect of different levels of nutrients and their combinations on the mean girth of tubers.

It can be seen from the Table that the girth of tubers is increased with incremental doses of nitrogen. A significant increase in mean girth is noticed due to the application of the highest level of nitrogen (n_2). There is no significant difference between n_0

Table VIII

Mean length of tubers (in cm)

	N_0	N_1	N_2	Mean
P_0	52.67	54.22	54.11	53.66
P_1	55.11	52.11	53.67	53.63
P_2	55.22	55.55	55.33	55.37
K_0	52.78	53.67	54.11	53.52
K_1	54.44	54.44	53.89	54.26
K_2	55.78	53.78	55.11	54.89
Ca_0	53.12	54.89	55.11	54.37
Ca_1	54.33	53.11	53.89	53.78
Ca_2	55.55	53.89	54.11	54.52
Mean	54.33	53.96	54.37	

	P_0	P_1	P_2	Mean
K_0	53.22	53.11	54.22	53.52
K_1	53.33	53.00	56.44	54.26
K_2	54.44	54.78	55.44	54.89
Ca_0	53.44	51.89	57.78	54.37
Ca_1	53.44	53.78	54.11	53.78
Ca_2	54.11	55.22	54.22	54.52
Mean	53.66	53.63	55.37	

	K_0	K_1	K_2	Mean
Ca_0	53.67	54.55	54.89	54.37
Ca_1	52.22	54.00	55.11	53.78
Ca_2	54.67	54.22	54.67	54.52
Mean	53.52	54.26	54.89	

C.D.(5%) for comparison between marginal means = 2.49

" " combinations = 4.30

Table IX

Mean girth of tubers (in cm)

	N_0	N_1	N_2	Mean
P_0	19.00	19.67	20.89	19.85
P_1	20.22	19.78	22.67	20.89
P_2	18.66	20.89	21.78	20.44
K_0	18.33	19.67	20.33	19.44
K_1	19.67	20.78	21.89	20.78
K_2	19.89	19.89	23.11	20.96
Ca_0	19.11	18.78	20.00	19.29
Ca_1	19.44	21.44	22.55	21.15
Ca_2	19.33	20.12	22.78	20.74
Mean	19.29	20.11	20.78	

	P_0	P_1	P_2	Mean
K_0	18.55	20.67	19.11	19.44
K_1	20.33	20.56	21.44	20.78
K_2	20.67	21.44	20.78	20.96
Ca_0	18.89	20.11	18.89	19.21
Ca_1	20.11	21.78	21.55	21.15
Ca_2	20.55	20.78	20.89	20.74
Mean	19.85	20.89	20.44	

	K_0	K_1	K_2	Mean
Ca_0	18.55	18.78	20.55	19.29
Ca_1	19.89	21.78	21.78	21.15
Ca_2	19.89	21.78	20.55	20.74
Mean	19.44	20.78	20.96	

C.D.(5%) for comparison between marginal means = 0.91

,, ,, ,, combinations = 1.57

and n_1, and n_1 and n_2 in influencing the mean girth of tubers.

Application of higher levels of potash (k_1 and k_2) also have significantly increased the mean girth of tubers, over the minimum level of potash (k_0) applied, but the difference in response between the higher levels, k_1 and k_2 are not statistically significant.

A more or less similar trend is noticed with the application of different levels of calcium, over the zero level tried (Ca_0). The highest level (Ca_2) had a depressing effect on the mean girth of tubers though not significant. However, the difference between the higher levels (Ca_1 and Ca_2) are not found to be significant.

Though the effect of phosphorus application on the mean girth of tubers is not statistically significant, the middle dose of phosphorus application tendsto increase the mean girth of tubers.

Among the various combinations a minimum girth of tubers (18.33 cm) is recorded by the treatment combination n_0 k_0 and a maximum girth of 23.11 cm is recorded by n_2 k_2.

<u>Correlation studies</u>: Correlationsworked out between the various biometric and yield characters of the plant,with the final yield of tubers have shown the following results:

a) <u>Correlation between weight of vegetative parts and yield of tubers</u>: A highly significant correlation (r = 0.5023) is obtained between these two characters, indicating the positive relationship between them.

Table X

Percentage of edible portion of tubers after removing the rind

	N_0	N_1	N_2	Mean
P_0	85.55	84.44	83.78	84.59
P_1	85.00	85.33	84.17	84.83
P_2	85.22	85.05	84.22	84.83
K_0	84.78	84.44	83.28	84.16
K_1	85.55	85.00	84.05	84.87
K_2	85.44	85.38	84.84	85.22
Ca_0	85.22	84.72	83.78	84.57
Ca_1	85.33	85.05	84.11	84.83
Ca_2	85.22	85.05	84.28	84.85
Mean	85.26	84.94	84.06	

	P_0	P_1	P_2	Mean
K_0	84.05	83.94	84.50	84.16
K_1	84.67	85.06	84.89	84.87
K_2	85.05	85.50	85.11	85.22
Ca_0	84.39	84.61	84.72	84.57
Ca_1	84.78	84.78	84.94	84.83
Ca_2	84.60	85.11	84.84	84.85
Mean	84.59	84.83	84.83	

	K_0	K_1	K_2	Mean
Ca_0	84.11	84.72	84.89	84.57
Ca_1	84.22	85.00	85.28	84.85
Ca_2	84.17	84.89	85.50	84.85
Mean	84.16	84.87	85.22	

C.D.(5%) for comparison between marginal means = 0.44

" " " combinations = 0.75

(b) Correlation between height of plants and yield of tubers: The correlation coefficient (r = 0.1006) obtained in this case is found to be not significant.

(c) Correlation between total number of leaves produced per plant and yield of tubers: The correlation coefficient (r = 0.0168) obtained between these two characters also was found to be not significant.

(d) Correlation between percentage of plants branched per plot and yield of tubers: A significant positive correlation of r = 0.265 is obtained between these two characters.

(e) Correlation between number of tubers and yield: A highly significant correlation (r = 0.711) is obtained, showing the positive relationship between these two characters.

C. Quality:

1. Percentage of edible portion of tubers, after removing the rind: The analysis of variance is presented in appendix, X and the mean percentage by weight of edible portion of tubers, as influenced by the various treatment combinations is furnished in Table X.

It is evident that nitrogen and potash alone exert significant influence on the percentage of edible portion of tubers in tapioca.

Table X shows that there is a significant reduction in the percentage of edible portion, due to incremental doses of nitrogen

Table XI

Per-centage of dry matter in tubers
(on oven-dry basis)

	N_0	N_1	N_2	Mean
P_0	33.34	33.82	34.00	33.72
P_1	33.39	34.67	35.05	34.37
P_2	33.55	35.17	35.00	34.57
K_0	32.78	32.61	33.17	32.85
K_1	33.50	35.50	35.50	34.83
K_2	34.00	35.55	35.39	34.98
Ca_0	33.33	34.11	34.05	33.83
Ca_1	33.28	34.67	35.00	34.32
Ca_2	33.67	34.88	35.00	34.52
Mean	33.43	34.55	34.68	

	P_0	P_1	P_2	Mean
K_0	32.78	32.72	33.05	32.85
K_1	34.22	34.89	35.39	34.83
K_2	34.17	35.50	35.28	34.98
Ca_0	33.39	33.78	34.33	33.83
Ca_1	33.89	34.44	34.61	34.32
Ca_2	33.89	34.89	34.78	34.52
Mean	33.72	34.37	34.57	

	K_0	K_1	K_2	Mean
Ca_0	32.55	34.33	34.61	33.83
Ca_1	32.78	35.05	35.11	34.32
Ca_2	33.22	35.11	35.22	34.52
Mean	32.85	34.83	34.98	

C.D.(5%) for comparison between marginal means = 0.47

,, ,, combinations = 0.82

application, thereby showing an increase in the percentage of rind. However, the difference between n_0 and n_1 is not significant.

Application of higher levels of potash (k_1 and k_2)shows just the reverse effect which also is significant. The percentage of edible portion is increased due to each incremental dose of potash. The difference between the k_1 and k_2 levels, however, is not found significant.

Eventhough phosphorus does not exert any significant influence, there is an increasing trend in the percentage of edible portion of tubers, due to the application of higher levels of phosphorus. A similar trend is also seen in the case of calcium.

Among the combinations a minimum of 83.28% of edible portion is recorded under $n_2\ k_0$, and a maximum of 85.55% is recorded under the treatment combinations $n_0\ p_0$ and $n_0\ k_1$.

ii. Dry matter content in tubers: The data regarding the influence of different levels of nutrients and their combinations on the dry matter content of tapioca tubers, were analysed statistically and the analysis of variance is presented in Appendix XI.

It is evident that the direct effects of nitrogen, phosphorus, potash, calcium and the combined effect of nitrogen and potash, in increasing the percentage of dry matter content, are statistically significant. None of the other interactions are found to be significant.

Table XI summarises the effects and interactions of factorial combinations of different nutrients on the percentage of dry matter content in tapioca tubers.

It is seen that higher levels of nitrogen (n_1 and n_2) significantly increased the percentage of dry matter content in tubers, over the n_0 level. However, the difference in response between n_1 and n_2 is not statistically significant.

Similar trends are also seen in the case of phosphorus, potash and calcium. Higher levels of all these nutrients significantly increased the percentage of dry matter.

Among the interactions, only the combined effect of nitrogen and potash recorded a significant increase in the dry matter content. The combination $n_1 k_0$ recorded the minimum mean percentage of dry matter (32.61 %), as compared to a maximum of 35.55% recorded under the treatment $n_1 k_2$. Among the various other combinations of nitrogen and potash $n_0 k_2$, $n_1 k_2$ and $n_2 k_2$ recorded significant increase in dry matter content, as compared to $n_0 k_0$, $n_1 k_0$ and $n_2 k_0$ respectively.

However, the difference in response due to $n_0 k_0$ and $n_0 k_1$, $n_1 k_1$ and $n_1 k_2$ and those due to $n_2 k_1$ and $n_2 k_2$ are not statistically significant.

A minimum mean percentage of dry matter content (32.55) is recorded under the treatment combination k_0 Ca_0, while a maximum of 35.55% is recorded under the combination $n_1 k_2$.

Table XII

Percentage of starch content of tubers (on oven dry basis)

	N_0	N_1	N_2	Mean
P_0	76.46	77.99	79.09	77.83
P_1	77.97	79.94	79.96	79.29
P_2	78.07	80.07	80.04	79.39
K_0	76.38	77.26	77.95	77.20
K_1	77.85	80.15	80.46	79.49
K_2	78.27	80.59	80.68	79.85
Ca_0	77.36	78.89	79.42	78.56
Ca_1	77.38	79.46	79.75	78.86
Ca_2	77.77	79.65	79.93	79.12
Mean	77.50	79.33	80.81	

	P_0	P_1	P_2	Mean
K_0	76.18	77.66	77.76	77.20
K_1	78.47	79.94	80.04	79.49
K_2	78.89	80.27	80.38	79.85
Ca_0	77.86	78.88	78.91	78.56
Ca_1	77.49	79.45	79.64	78.86
Ca_2	78.08	79.52	79.63	79.12
Mean	77.83	79.28	79.39	

	K_0	K_1	K_2	Mean
Ca_0	77.36	78.99	79.32	78.56
Ca_1	76.78	79.63	80.18	78.66
Ca_2	77.46	79.84	80.05	79.12
Mean	77.20	79.49	79.85	

C.D. (at 5%) for comparison between marginal means = 0.444

" " combinations = 0.763

iii. <u>Starch content of tubers</u>: Appendix XII presents the analysis of variance for the percentage of starch content in the edible portion of tubers in tapioca.

The individual effects of different levels of nitrogen, phosphorus and potash alone are found to have significant effect in increasing the starch content. The second and third degree interactions failed to show any significant effect.

Table XII summarises the mean percentage of starch content in tubers, as influenced by the various treatments.

It is evident from the above table that each incremental level of nitrogen, significantly increased the starch content of tubers over the next lower level, the difference in response produced by all the three levels being statistically significant.

In the case of phosphorus application, the p_1 and p_2 levels significantly increased the starch content of tubers, over the p_0 level. However, the difference in response between p_1 and p_2 levels is not significant.

A similar trend is also noticed in the case of application of higher doses of potash.

The highest level of calcium (Ca_2) also is found to increase the percentage of starch content in tubers over the lowest level of calcium (Ca_0), eventhough the effect of calcium is not found to be significant.

Table XIII

Percentage of crude protein content of tubers
(on oven dry basis)

	N_0	N_1	N_2	Mean
P_0	1.92	2.27	2.26	2.15
P_1	1.92	2.30	2.38	2.19
P_2	1.94	2.36	2.43	2.24
K_0	1.97	2.31	2.39	2.22
K_1	1.95	2.35	2.41	2.24
K_2	1.86	2.27	2.26	2.13
Ca_0	1.93	2.26	2.31	2.17
Ca_1	1.89	2.31	2.39	2.20
Ca_2	1.96	2.36	2.37	2.23
Mean	1.93	2.31	2.36	

	P_0	P_1	P_2	Mean
K_0	2.18	2.21	2.29	2.22
K_1	2.25	2.22	2.25	2.24
K_2	2.03	2.17	2.19	2.13
Ca_0	2.11	2.16	2.23	2.17
Ca_1	2.17	2.19	2.22	2.20
Ca_2	2.18	2.21	2.28	2.23
Mean	2.15	2.19	2.24	

	K_0	K_1	K_2	Mean
Ca_0	2.17	2.19	2.14	2.17
Ca_1	2.24	2.20	2.15	2.20
Ca_2	2.26	2.33	2.11	2.23
Mean	2.22	2.24	2.13	

C.D. (5%) for comparison between marginal means = 0.059

" " = 0.104

Among the combined effects, the combination $p_0 k_0$ recorded a minimum of 76.18 per cent starch content of tubers, while the maximum percentage of starch content (80.68) was recorded under the combination $n_2 k_2$.

iv. Crude protein content of tubers: It is evident from Appendix XIII, that nitrogen, phosphorus and potash are significantly influencing the crude protein content of tubers.

It is also evident from Appendix XIII that incremental doses of nitrogen and phosphorus have significantly increased the crude protein content, the effect being more pronounced with the application of increasing doses of nitrogen.

Application of higher levels of nitrogen (n_1 and n_2) has recorded a crude protein content of 2.31 and 2.36 per cent respectively in tubers of tapioca, while the n_0 level recorded a crude protein content of 1.93 per cent. The difference in response between n_1 and n_2 is not significant.

Application of the highest dose of potash (k_2) has caused a significant reduction in crude protein content, as compared to its lower levels. However, the middle dose of potash (k_1) showed an increasing trend, though not significantly.

A maximum mean of 2.43 per cent crude protein content is recorded in treatments receiving a combination of highest levels of nitrogen and phosphorus ($n_2 p_2$), while a minimum of 1.86% is recorded by the treatment receiving a combination of the lowest level of

Table XIV

Economics of application of different levels of N, P, K & Ca for tapioca

Levels of nutrients in kg per hectare	Yield of tubers in tonnes per hectare.	Value of produce Rs.	Ps.	Increase or decrease over the lowest level Rs.	Ps	Cost of fertilizer. Rs.	Ps.	Extra cost of fertilizer over that of the lowest level.		Profit due to fertilizer application over the lowest level Rs.	Ps
I Nitrogen											
50 Kg/Hectare	30.99	6,198	00	..	..	101	00	..		..	
100 Kg/Hectare.	34.32	6,864	00	666	00	202	00	101	00	565	00
130 Kg/Hectare.	35.30	7,060	00	862	00	262	60	161	60	700	40 *
150 Kg/Hectare.	35.50	7,100	00	904	00	303	00	202	00	700	00
II Phosphorus											
0 Kg/Hectare.	31.83	6,366	00	..	..	..	..	..	..	..	..
50 Kg/Hectare.	33.94	6,788	00	422	00	103	00	103	00	319	00
100 Kg/Hectare.	35.05	7,010	00	644	00	206	00	206	00	438	00 *
105 Kg/Hectare.	35.11	7,022	00	656	00	216	30	216	30	439	70
III Potash											
100 Kg/Hectare.	32.64	6,528	00	..	..	70	00	..	..	..	..
150 Kg/Hectare.	33.72	6,744	00	216	00	105	00	35	00	181	00
200 Kg/Hectare.	34.46	6,892	00	364	00	140	00	70	00	294	00 *
240 Kg/Hectare.	34.91	6,982	00	454	00	168	00	98	00	356	00
IV Calcium											
0 Kg/Hectare.	31.43	6,286	00	..	..	..	..	..	..	..	..
600 Kg/Hectare.	34.32	6,864	00	578	00	120	00	120	00	458	00 *
900 Kg/Hectare.	34.96	6,992	00	706	00	180	00	180	00	526	00
1200 Kg/Hectare.	35.07	7,014	00	728	00	240	00	240	00	488	00

Cost of 1 Kg nitrogen = Rs.2.02
,, ,, phosphorus = Rs.2.06
,, ,, Potash = Rs.0.70
,, ,, Calcium = Rs.0.20

Price of 1 tonne of tapioca tubers = Rs. 200/-
* Economic dose of nutrients.

nitrogen and the highest level of potash (n_0 k_2).

Response curves and Economics of manuring: The yield dose relationships obtained as a result of the present investigation are presented in Fig. I A to D. Quadratic response curves were fitted to the data, for all the four plant nutrients and are given below:

Nitrogen:

$$y = 34.322 + 2.258 \left(\frac{N - 100}{50} \right) - 1.072 \left(\frac{N - 100}{50} \right)^2$$

Phosphorus:

$$y = 33.936 + 1.608 \left(\frac{P - 50}{50} \right) - 0.493 \left(\frac{P - 50}{50} \right)^2$$

Potash:

$$y = 33.722 + 0.914 \left(\frac{K - 150}{50} \right) - 0.171 \left(\frac{K - 150}{50} \right)^2$$

Calcium:

$$y = 34.322 + 1.815 \left(\frac{Ca - 600}{600} \right) - 1.072 \left(\frac{Ca - 600}{600} \right)^2$$

The average expected yields at different levels of nitrogen, phosphorus, potash and calcium were calculated and the economics of manuring is worked out and presented in Table XIV.

The optimum as well as economic doses of these nutrients for tapioca obtained as a result of the present investigation are given below:

Nutrients	Optimum dose (in Kg per hectare.)	Economic dose (in Kg per hectare.)
Nitrogen	152.65	132.70
Phosphorus	131.50	105.55
Potash	253.35	236.43
Calcium	1,108.20	898.04

It is evident from Table XIV, that among the nutrients tried, nitrogen has given the maximum profit, followed by calcium, phosphorus and potash.

DISCUSSION

DISCUSSION

The results on the effect of different levels of major plant nutrients in factorial combinations, on the growth, yield and quality of tapioca, variety " Malayan-4", under the soil and climatic conditions of Vellayani are discussed here under.

A. Growth:

1. Height of plants: Among the nutrients tried, potash alone has significantly contributed towards increasing the plant height in tapioca. Plants receiving the highest level of 200 Kg potash per hectare have recorded the maximum mean height of 323. 0 cm. However, the lower levels of potash failed to show any significant response for this factor (Table I & Fig. I.A.). Results of investigations carried out by Purewal and Dargon (1957), Ward (1959) and Dhesi et al. (1964), on different root crops are in conformity with this finding.

The combined effect of nitrogen and calcium, significantly depressed the height of plants, as compared to the application of nitrogen alone. The depression in height of plants, which received nitrogen in combination with calcium could be attributed to increased branching, which results in a general reduction of plant height (Table II).

The individual effects of nitrogen, phosphorus and calcium on the height of plants are not found significant.

ii. Branching in plants: Though it is seen from the analysis of variance (Appendix II) that none of the direct effects of nitrogen, phosphorus, potash, and calcium are significant, the mean values (Table II) show that the highest levels of phosphorus and calcium significantly increased branching, over their corresponding lower levels.

Graded doses of nitrogen showed a trend in increasing the mean percentage of plants branched in a graded manner, though the increase was not statistically significant, while in the case of potash the function was of a depressing nature.

The combined effect of nitrogen and calcium had a significant positive effect on the percentage of plants branched, thereby emphasising the role of calcium in nitrogen metabolism, and the needs of these two elements for the continued growth of apical meristems, as suggested by Meyer and Anderson (1956).

The positive influence of nitrogen and calcium in contributing to increased branching has resulted in a general reduction of plant height.

iii. Number of leaves: This factor has not been positively influenced by any of the treatments. However, in the case of nitrogen, as the levels are increased, an increasing trend is noticed in the total number of leaves produced per plant. A trend in reduction of the total number of leaves produced per plant was noted with the application of incremental doses of potash (Table III).

Similar observations were recorded earlier by investigators like Purewal and Dargon (1957), for nitrogen and phosphorus, and by Ho (1965) for potash, in the case of other tuber crops.

iv. Weight of vegetative parts: For the highest levels of nitrogen and potash significant increases were recorded for the factor under discussion (Table IV). The function of nitrogen in contributing to enhanced vegetative growth in plants is an established fact as reported by Russell (1948) Johnson and Ware (1948), Purewal and Dargon (1959), Buckman and Brady (1960) and Sommerfeldt and Knutson (1969) in other crop plants. This observation is also in agreement with the findings of Malavolta et al. (1955) in tapioca.

Likewise, the role of potash in controlling the over all metabolic activities of the plants is also an important function as reported by Russel (1948), Black (1957) and Jacob and Uexkull (1960)

A maximum mean weight of vegetative parts of 2.185 Kg per plant has been recorded in plots receiving 150 Kg of nitrogen per hectare. The corresponding value for the application of 200 Kg per hectare of potash stood at 2.166 Kg per plant.

Though the combined effect of nitrogen and potash has no significant effect, it is noted that among all the combinations of nutrients tried, application of 100 Kg of nitrogen and 200 Kg potash

FIGURE I. A.

Bar Diagram showing the mean height of plants, as influenced by the various levels of plant nutrients.

n_0	=	50 Kg N/Hectare.
n_1	=	100 Kg N/Hectare.
n_2	=	150 Kg N/Hectare.
p_0	=	0 Kg P_2O_5/Hectare.
p_1	=	50 Kg P_2O_5/Hectare.
p_2	=	100 Kg P_2O_5/Hectare.
k_0	=	100 Kg K_2O/Hectare.
k_1	=	150 Kg K_2O/Hectare.
k_2	=	200 Kg K_2O/Hectare.
Ca_0	=	0 Kg CaO/Hectare.
Ca_1	=	600 Kg CaO/Hectare.
Ca_2	=	1200 Kg CaO/Hectare.

FIGURE. I. B.

Bar Diagram showing the mean number of tubers per plant as influenced by the various levels of plant nutrients.

n_0	=	50 Kg N/Hectare.
n_1	=	100 Kg N/Hectare.
n_2	=	150 Kg N/Hectare.
p_0	=	0 Kg P_2O_5/Hectare.
p_1	=	50 Kg P_2O_5/Hectare.
p_2	=	100 Kg P_2O_5/Hectare.
k_0	=	100 Kg K_2O/Hectare.
k_1	=	150 Kg K_2O/Hectare.
k_2	=	200 Kg K_2O/Hectare.
Ca_0	=	0 Kg CaO/Hectare.
Ca_1	=	600 Kg CaO/Hectare.
Ca_2	=	1200 Kg CaO/Hectare.

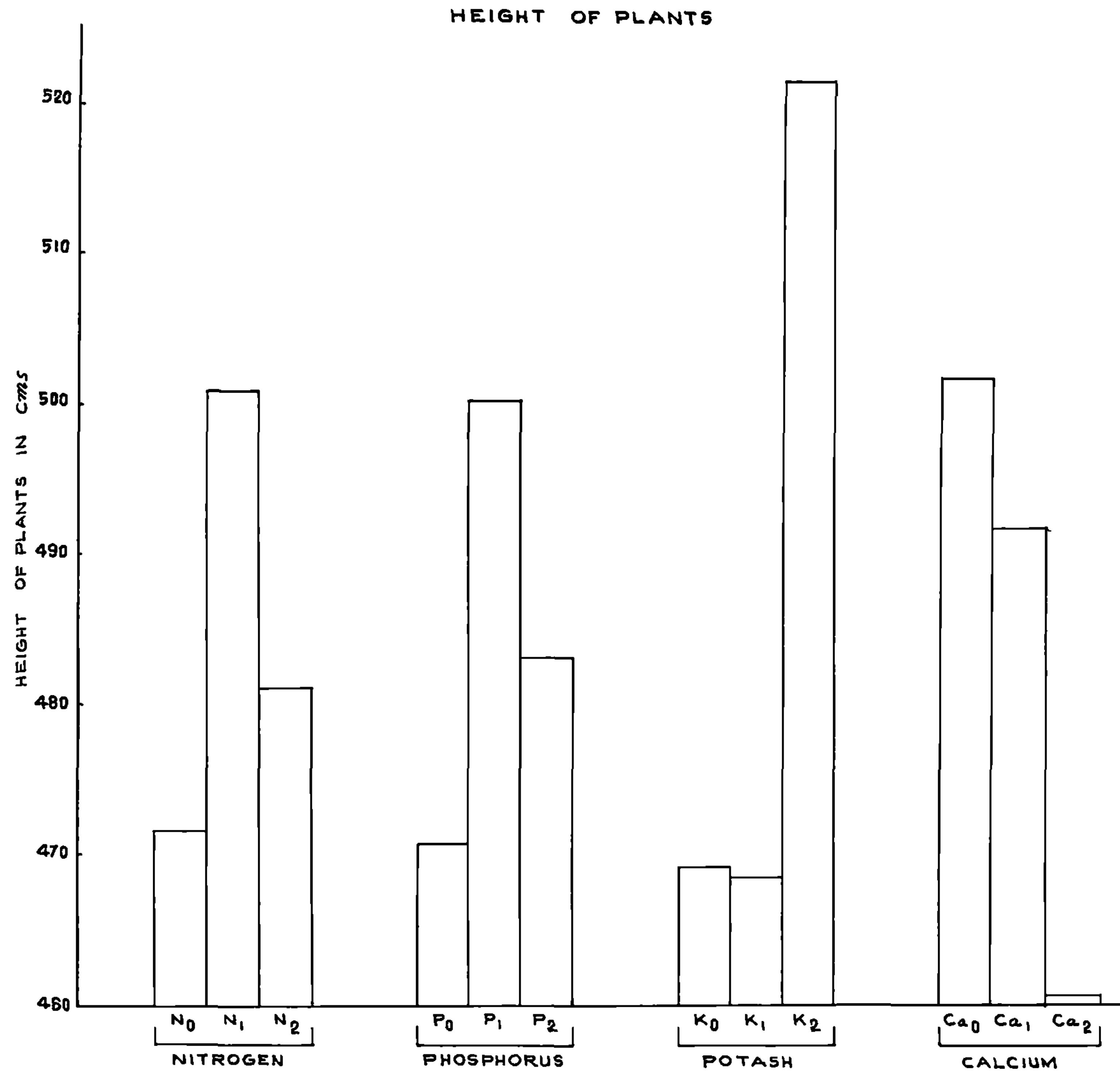

HEIGHT OF PLANTS
HEIGHT OF PLANTS IN cms
520
510
500
490
480
470
460
N0 N1 N2
NITROGEN
P0 P1 P2
PHOSPHORUS
K0 K1 K2
POTASH
Ca0 Ca1 Ca2
CALCIUM

FIG I A

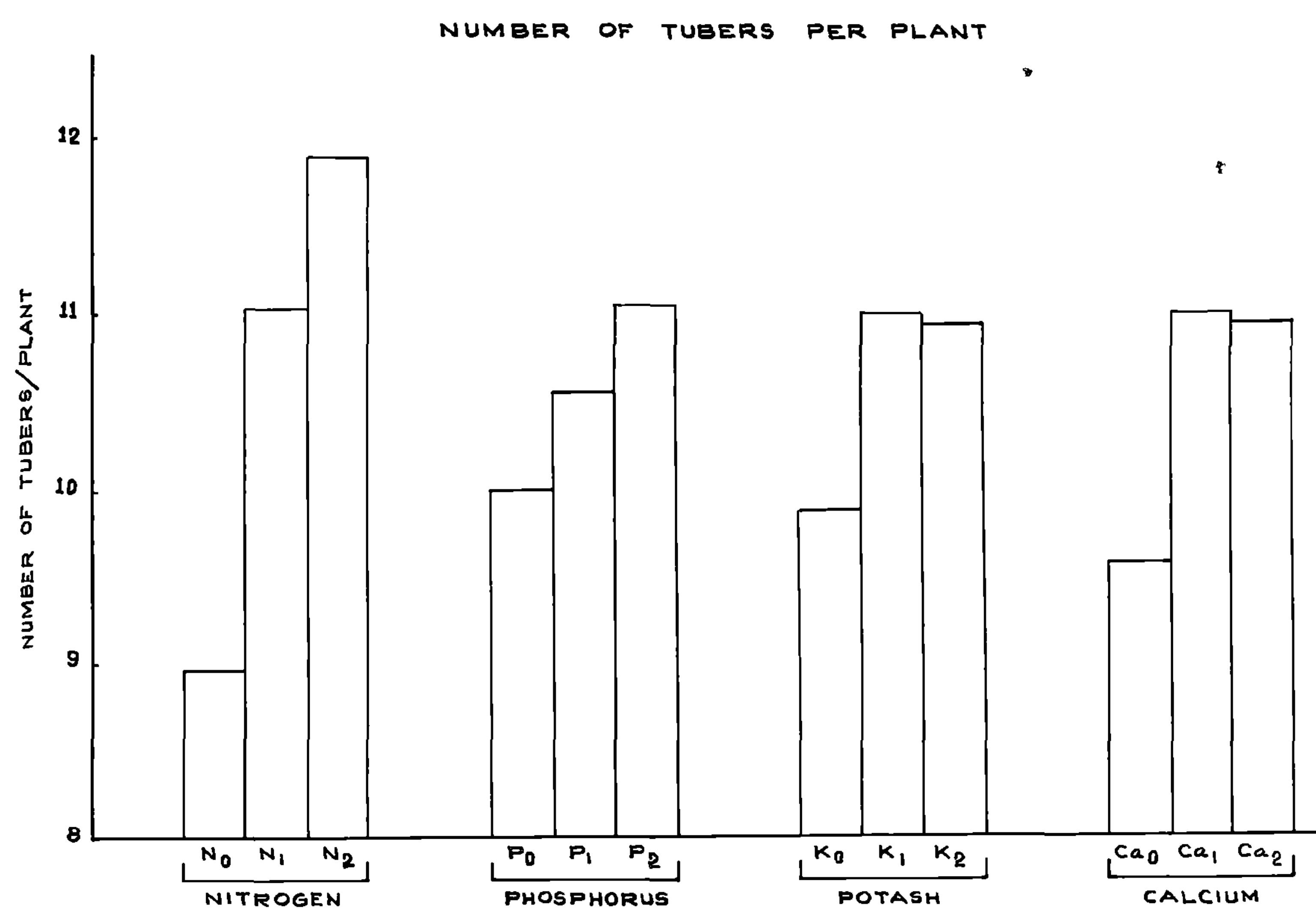

NUMBER OF TUBERS PER PLANT
NUMBER OF TUBERS/PLANT
12
11
10
9
8
N0 N1 N2
NITROGEN
P0 P1 P2
PHOSPHORUS
K0 K1 K2
POTASH
Ca0 Ca1 Ca2
CALCIUM

FIG I B

per hectare gave the highest mean weight of vegetative parts in tapioca (2.472 Kg per plant).

The above function appears to be in agreement with the findings of previous workers. Landrau and Samuels (1954) and Purewal and Dargen (1959) found no response to phosphorus application in increasing the weight of vines in sweet potato, which is in agreement with the present findings.

B. <u>Yield characteristics and final yield of tubers:</u> The final yield of tubers in tapioca is a function of a number of quantitative characters such as, number of tubers per plant, length and girth of tubers and the number of unproductive roots.

1. <u>Number of tubers:</u> It is evident from Table VI and Fig. I-B that nitrogen and calcium alone have significantly increased the number of tubers per plant. The difference between second and third levels is not statistically significant. Combined application of 150 Kg of nitrogen and 100 Kg phosphorus per hectare, has recorded the highest mean number of 12.75 tubers per plant.

Although the individual effect of phosphorus and potash are not found statistically significant, higher levels of phosphorus and potash also have significantly increased the number of tubers per plant.

The first objective in nitrogen fertilization of root crops, according to Black (1957) is to obtain rapid elaboration of leaves in

Meyer and Anderson (1956) have found that the role of phosphorus and nitrogen in plant metabolism is inter-related in a number of ways. Probably this might be the reason for getting the maximum mean number of tubers per plant from plots receiving 150 Kg of nitrogen and 100 Kg phosphorus per hectare.

ii. Number of unproductive roots: It is seen from Table VII that the different levels of mineral nutrients applied to tapioca in the present investigation, failed to manifest any significant difference in the mean number of unproductive roots per plant. However, incremental doses of nitrogen had a depressing effect on the mean number of unproductive roots, thereby increasing the number of tubers per plant. In this case also, application of 150 Kg of nitrogen and 100 Kg phosphorus per hectare recorded the minimum number of unproductive roots, among all other combinations tried, thereby emphasising the role of combined application of nitrogen and phosphorus for enhancing tuber formation in tapioca.

Malavolta et al. (1955) in their studies on the physiological basis for the nutrition of tapioca, also have reported similar results.

iii. Length of tubers: The mean length of tubers under the different treatments are not found to be significantly influenced by any of the nutrients applied singly or in combination, as evident from Table VIII. However, a slight increase in the mean length of tubers is noted with incremental doses of all the four nutrients.

the early part of the growth cycle. Without this the total capability of the plant for photosynthesis is diminished. Secondly, the growth of leaves must be checked by a decrease in nitrogen content at the proper time in order to give time for storage organs to develop properly.

Black (1957) has emphasised that phosphorus supply does have a special effect on the subterranean storage tissues of root crops. If a root crop is deficient in phosphorus supply, phosphorus fertilization usually increases the number and yield of tubers more than that of the above ground parts. A reasonable explanation for this behaviour seems to be that maximum leaf weight is attained at a later date by the phosphorus deficient plants than by the phosphorus fertilized plants, with the result that carbohydrate translocation to the storage tissues proceeds for a longer period of time in the phosphorus fertilized plants than in the phosphorus deficient plants.

The importance of potash in tuber formation of root crops has been proved beyond doubt by pioneer workers like Miller (1938) and Russell (1948).

The general effect of calcium in translocation of carbohydrates, formation of roots and development of tubers have been stressed by Miller (1938).

In sweet potato Rao and Rao (1954) have noticed the production of long and slender tubers with increasing doses of nitrogen. Dhesi (1964) has reported similar results in the case of carrots. Rao and Rao (1954), Gruner (1963) and Dhesi and Padda (1964) have also noticed the effects of nitrogen, phosphorus and potash application in the enlargement of tubers in sweet potato and potato respectively.

iv. Girth of tubers: Among the four different nutrients tried, nitrogen, potash and calcium have significantly increased the mean girth of tubers (Table IX). Application of 150 Kg of nitrogen and 200 Kg of potash per hectare has recorded the maximum mean girth of 23.11 cm, as compared to a mean girth of 18.33 cm recorded, when only 50 Kg of nitrogen and 100 Kg potash per hectare were applied.

Although the individual effect of phosphorus is not statistically significant, application of 50 Kg of phosphorus per hectare has resulted in a significant increase in mean girth of tubers, over the plants receiving no phosphorus.

The general effects of mineral nutrients on the mean girth of tubers in tapioca as observed under the present investigation is in overall agreement with the findings of Miller (1938) on turnips, Singh (1952) Gruner (1963) and Dhesi and Padda (1964) in potatoes, Rao and Rao (1954) in sweet potato and Dhesi (1964) in the case of carrots.

Yamato and Noda (1950) have studied the morphology of tuber formation in potato and found that tuberization takes place in four distinct stages, viz; elongation of stolon, tuber formation, tuber enlargementsand and tuber completion. Werner (1935) has found that in potatoes, whenever carbohydrates were manufactured in excess of the capacity of the plant to build new tissues, they accumulated in the tubers after a transitory period of storage in the leaves, stems and stolons. Higher doses of mineral nutrient supply might have naturally helped in the production of more carbohydrates in tapioca tubers and this in turn might have increased the mean girth of tubers under such treatments.

v. Yield of tubers: It is evident from the analysis of variance given in Appendix V and Table V that nitrogen, phosphorus, potash, calcium and the combined effect of nitrogen and potash have significantly increased the yield of tubers in tapioca.

The mean yield recorded as a result of application of 100 Kg and 150 Kg of nitrogen per hectare is found to be 34.32 and 35.50 tonnes per hectare respectively over an yield of 30.99 tonnes pér hectare recorded in plots receiving only 50 Kg of nitrogen per hectare. The difference in yield between the higher levels of nitrogen is not found to be significant.

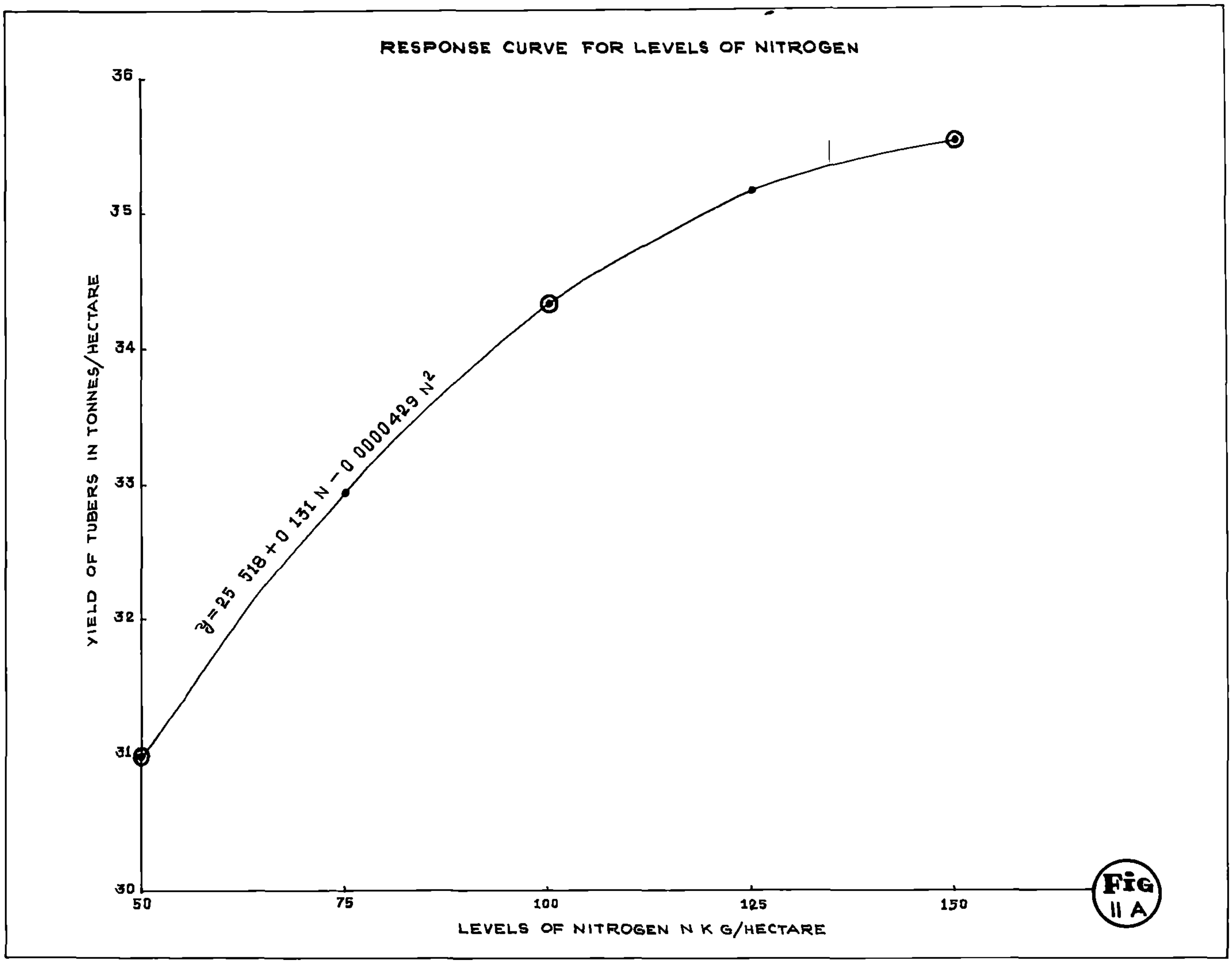
The influence of nitrogen in increasing the yield of tapioca has been proved conclusively on the basis of trials conducted at the

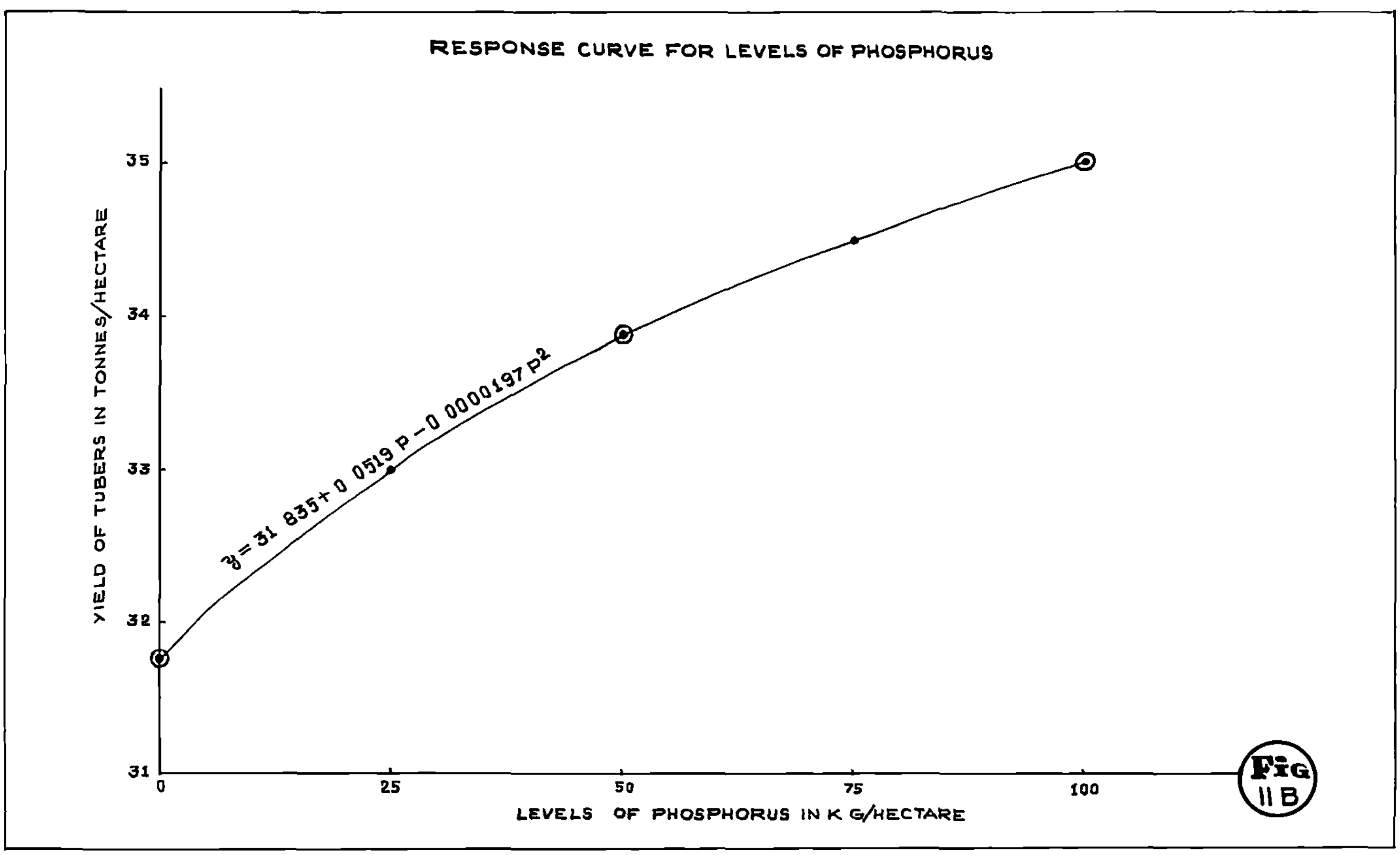
FIGURE II. A

Response curve of Nitrogen on the yield of tubers in tapioca.

FIGURE II.B.

Response curve of Phosphorus on the yield of tubers in tapioca.


RESPONSE CURVE FOR LEVELS OF NITROGEN
YIELD OF TUBERS IN TONNES/HECTARE
LEVELS OF NITROGEN N K G/HECTARE
y = 25 518 + 0 131 N − 0 0000429 N²
36
35
34
33
32
31
30
50
75
100
125
150
FIG II A


RESPONSE CURVE FOR LEVELS OF PHOSPHORUS
YIELD OF TUBERS IN TONNES/HECTARE
LEVELS OF PHOSPHORUS IN K G/HECTARE
y = 31 835 + 0 0519 P − 0 0000197 P²
35
34
33
32
31
0
25
50
75
100
FIG II B

Tapioca Research Stations in Kerala (Anonymous 1954, 1955, 1957 and 1963). Similar trends are also being noted in the manurial trials that are being conducted at the Central Tuber Crops Research Institute, at Sreekaryam in Kerala (Anonymous 1967). Results of manurial trials conducted by " Potaschem " in different parts of Kerala as reported by Chadha (1958) also have established the importance of nitrogen fertilization in stepping up the yield of tubers in tapioca. Malevolta et al.(1955) and Coure et al.(1961) also have observed similar trends and reported that highest yield of tubers in tapioca could be obtained by increasing the dose of nitrogen thereby enhacing shoot and root growth.

Higher doses of phosphatic fertilizers have also significantly increased the yield of tapioca tubers. Application of 50 Kg and 100 Kg of phosphorus per hectare has recorded an yield of 33.32 and 39.05 tonnes respectively per hectare as compared to 31.63 tonnes per hectare obtained from the control plots, receiving no phosphorus.

The above finding is in line with the results obtained by earlier workers like Doop and Don (1937), Malevolta et al.(1955) and Coure et al.(1961). The results of manurial trials conducted in the Tapioca Research Stations in Kerala over a number of years have shown that the response of tapioca to phosphatic fertilisation was erratic during many seasons. A fall in response was noticed beyond 90 lb of phosphorus per acre. However, a residual effect of phosphatic fertilizers has been noticed in all these trials (Anonymous, 1957, 1962). Manurial experiments conducted in cultivator's field by ' Potaschemo ' have also revealed the significant effect of phosphatic fertilisation during the second and third seasons, thereby showing a cumulative effect of its application (Anonymous, 1961). Recent experiments conducted at the Central Tuber Crops Research Institute at Sreekaryam in Kerala, also have revealed the significant effect of phosphorus application in increasing the yield of tapioca (Anonymous, 1967).

Work done on miscellaneous tuber crops by various workers has also proved the importance of phosphatic fertilization in stepping up the yield of tubers.

Gruner (1963), working on potatoes has opined that phosphates are not only an important constituent of numerous substances, but play an essential part in the process of transformation of substances and energy. High energy phosphates regulate the carbohydrate metabolism within the plant. Black (1957), has pointed out that phosphorus is also involved in the initial reactions of photosynthesis. Carbondioxide is thought to react with a 5-carbon sugar containing 2 phosphate groups with the formation of two molecules of a 3-carbon compound (Phospho-glyceric acid). The latter is upgraded by energy supplied by high energy phosphates.

In the present investigation higher doses of phosphorus application in conjunction with calcium might have naturally increased the availability of phosphorus to meet the requirements of plants for their metabolic activities, sybthesis and storage of carbohydrates, thereby giving a significant increase in the total yield. Similar trend of increased availability and uptake of phosphorus by potatoes has been observed by Mariakulandai (1955) as a result of liming, in Nilgiri soils.

Potash also has contributed significantly towards increasing the yield of tapioca. Application of 150 Kg and 200 Kg of potash per hectare has recorded an yield of 33.72 and 34.46 tonnes respectively of tubers per hectare, when compared to an yield of 32.63 tonnes obtained from plots receiving only 100 Kg of potash per hectare. It is evident that only the difference in response between the lowest and the higher levels, was significant. This may probably be due to the low status of available potash (0.00066%) in the soils of Vellayani, and the relatively higher potash requirements of tuber crops.

The general response of tapioca to potash fertilisation has been proved beyond doubt by earlier workers like White (1928), and by Grossman and de Assis (1951), Bolhuis (1954), and Cours et al.(1961). Experiments conducted at the Tapioca Research Stations, in Kerala and in cultivator's fields by the ' Potacchemo ' have also established this fact (Anonymous 1954, 1961, 1962 and 1963).

Result of recent experiments conducted at the Central Tuber Crops Research Institute, Sreekaryam in Kerala, also are in agreement with these findings.

Similar responses were also noted in the case of almost all other tuber crops by various workers in the field.

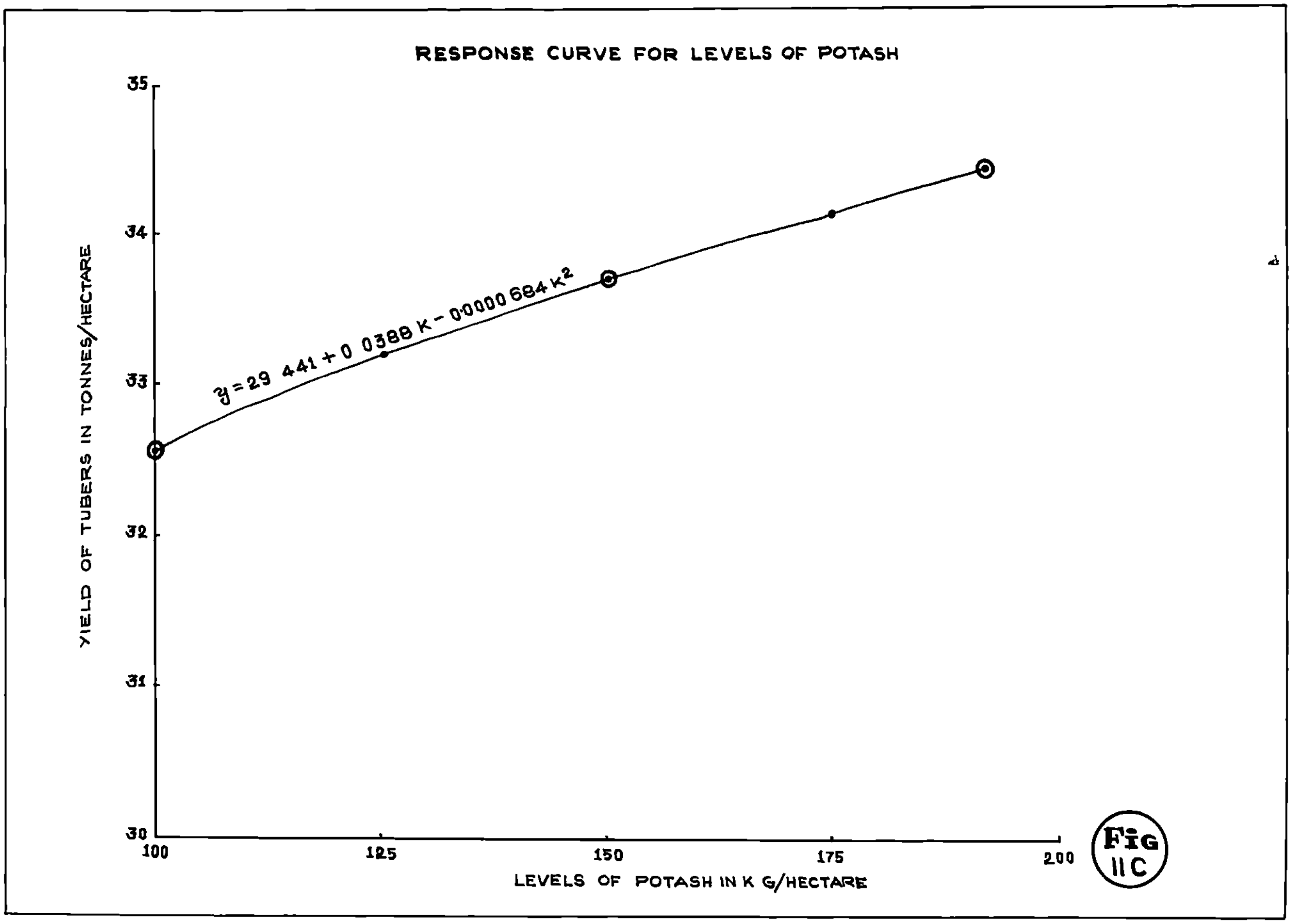
The importance of potash in carbohydrate metabolism is an accepted fact established by pioneer workers. Black (1957) has opined that the potash content of plants is positively correlated with the rate of metabolism. Potash is found to be essential in certain enzymatically catalysed transphosphorylation reactions involving the adenylic acid system. Far reaching consequences may be evisioned for the action of potash in transphosphorylation reactions. The adenylic acid system is the universal medium of energy exchange both in plants and in animals. In carbohydrates metabolism the reactions requring potash represent steps in the process by which energy is obtained from sugar for synthetic purposes. Total production of carbohydrates by potash deficient plants is limited in two ways. First, the rate of carbon dioxide assimilation per unit area of leaf surface is reduced probably as an indirect effect of other metabolic disturbances. Second effect is that of a premature dropping of leaves in such plants. A number of effect of potash deficiency on plant behaviour seem to stem from a deficiency of carbohydrates.

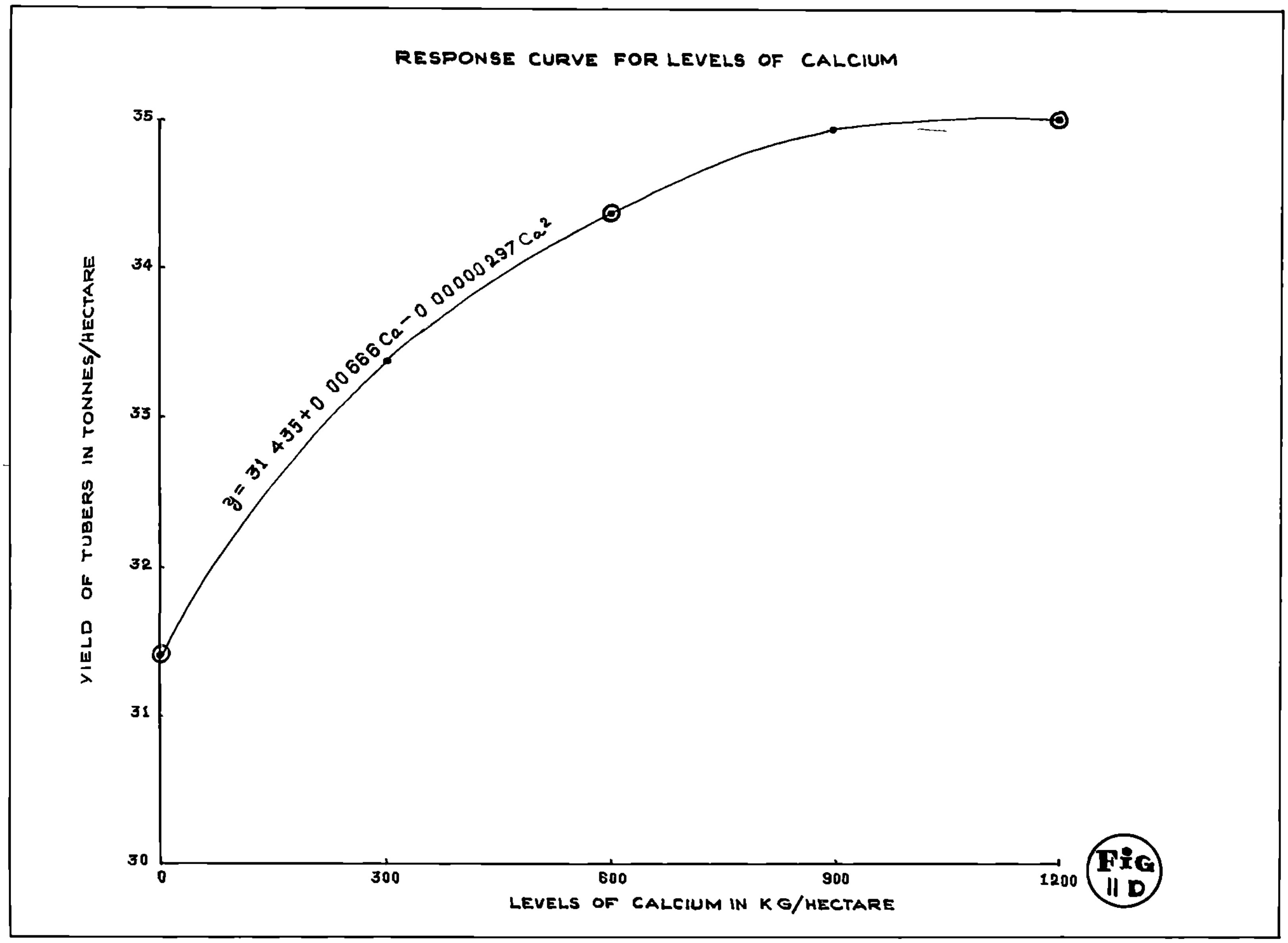
FIGURE II.C.

R esponse curve of potash on the yield of tubers in tapioca.

FIGURE II.D.

Response curve of calcium on the yield of tubers in tapioca.


RESPONSE CURVE FOR LEVELS OF POTASH
YIELD OF TUBERS IN TONNES/HECTARE
35
34
33
32
31
30
ŷ=29 441 + 0 0388 K - 0·0000684 K²
100
125
150
175
200
LEVELS OF POTASH IN K G/HECTARE
FIG 11 C


RESPONSE CURVE FOR LEVELS OF CALCIUM
YIELD OF TUBERS IN TONNES/HECTARE
35
34
33
32
31
30
ŷ= 31 435+0 00666 Ca - 0 00000297 Ca²
0
300
600
900
1200
LEVELS OF CALCIUM IN K G/HECTARE
FIG 11 D

It is evident from the above said functions ascribed to potash, that the higher doses of potash might naturally have contributed for increased yield of tubers in tapioca.

The inclusion of three levels of calcium in the present investigation in factorial combinations with different levels of major nutrients, has revealed a significant increase in the yield of tapioca, thereby emphasing the role of calcium in the nutrition of a root crop like tapioca, grown in the predominantly acidic soils of Kerala.

It is evident from Table V that application of calcium at the rate of 600 and 1200 Kg per hectare has resulted in an increased yield of 34.32 and 35.06 tonnes of tubers per hectare respectively, as compared to an yield of 31.43 tonnes only per hectare in plots receiving no calcium. The difference between these two levels however, was not found significant.

The increased yield obtained by the application of calcium for tapioca is in agreement with the findings of Stephens (1956) and Cours et al. (1961).

The beneficial effects of calcium as a plant nutrient as well as a corrective of soil acidity and its indirect role in the better utilization of nitrogen and phosphorus have been established by pioneer workers like Davis and Brewer (1940), Dunn (1947), Trough (1948), Heslep (1951), Mariakulandai (1955), Blue and Eno (1957) and Black (1957). Increased yield due to liming has also been reported in almost all other tuber crops like turnips, carrots, yams, sugarbeet, sweet potato and potatoes by various other workers.

Application of calcium might have enabled the better utilization of nitrogenous and phosphatic fertilizers as found by Mariakulandai (1955) in the case of potatoes. The general effects of calcium in the formation of roots and the translocation of carbohydrates have been reported by Miller (1938). Supply of adequate amounts of calcium might thus have resulted in an increased yield of tubers in tapioca.

Among the combined effects, the combined application of nitrogen and potash alone has significantly contributed towards increased yield of tubers. Application of 150 Kg of nitrogen and 200 Kg potash per hectare has recorded a mean yield of 37.67 tonnes of tubers per hectare as compared to a mean yield of 31.84 tonnes obtained from plots receiving only 50 Kg nitrogen and 100 Kg potash.

Similar results are reported by Acosta and Perez (1954) and Chadha (1958) in tapioca. Chadha (1958) found that maximum yields can be obtained from the use of nitrogen and potash in 1:1.75 ratio, which also is in agreement with the present findings.

The results obtained by Tsuno and Fugise (1965) in sweet potato and Imesi et al. (1964) in potatoes have also established the combined effect of nitrogen and potash in increasing the yield potential in tuber crops.

It can be concluded that the beneficial effects of these two elements were additive in nature in promoting the yield of tubers in tapioca, as well.

Among the other nutrient combinations, combined application of the highest doses of nitrogen (150 Kg) and phosphorus (100 Kg) resulted in the maximum mean yield of 38.02 tonnes per hectare, among all other combinations. In this connection, it must be remembered that the maximum mean number of tubers per plant and the minimum number of unproductive roots were recorded under this treatment. Acosta and Perez (1954) also have observed similar effects of interaction between nitrogen and phosphorus in increasing the yield of tapioca.

Application of 50 Kg of nitrogen alone with no phosphorus recorded minimum yield of 29.83 tonnes per hectare. The effect of N x P interaction, however, was not found statistically significant as is evident from Appendix V.

Correlation studies: Correlations worked out between the yield of tubers in tapioca and various other biometric and yield characters of plants have shown that yield is positively correlated with the number of tubers per plant, weight of vegerative parts and branching. There is no correlation between yield of tubers and height of plants, as well as between the total number of leaves produced.

Higher levels of nutrients especially nitrogen, phosphorus and calcium and the combined effect of calcium, have contributed towards increased branching in tapioca in the present investigation. Nitrogen and potash have significantly increased the weight of vegetative parts in tapioca. This might have helped in the synthesis of more of photosynthates, leading to the increased yield of tubers, along with an increase in the weight of vegetative parts and percentage of branching, thereby establishing a positive correlation.

Plant height was not found to be significantly increased by any of the nutrient elements except potash. So also, none of the individual nutrients or their combinations has contributed significantly towards the production of total number of leaves per plant, eventhough a slight increase in number of leaves is seen. This may probably explain the absence of any positive correlation between yield of tubers and number of leaves, and plant height.

C. Quality factors:

The relative proportion of rind and flesh, percentage of dry matter, starch content and crude protein content in tubers of

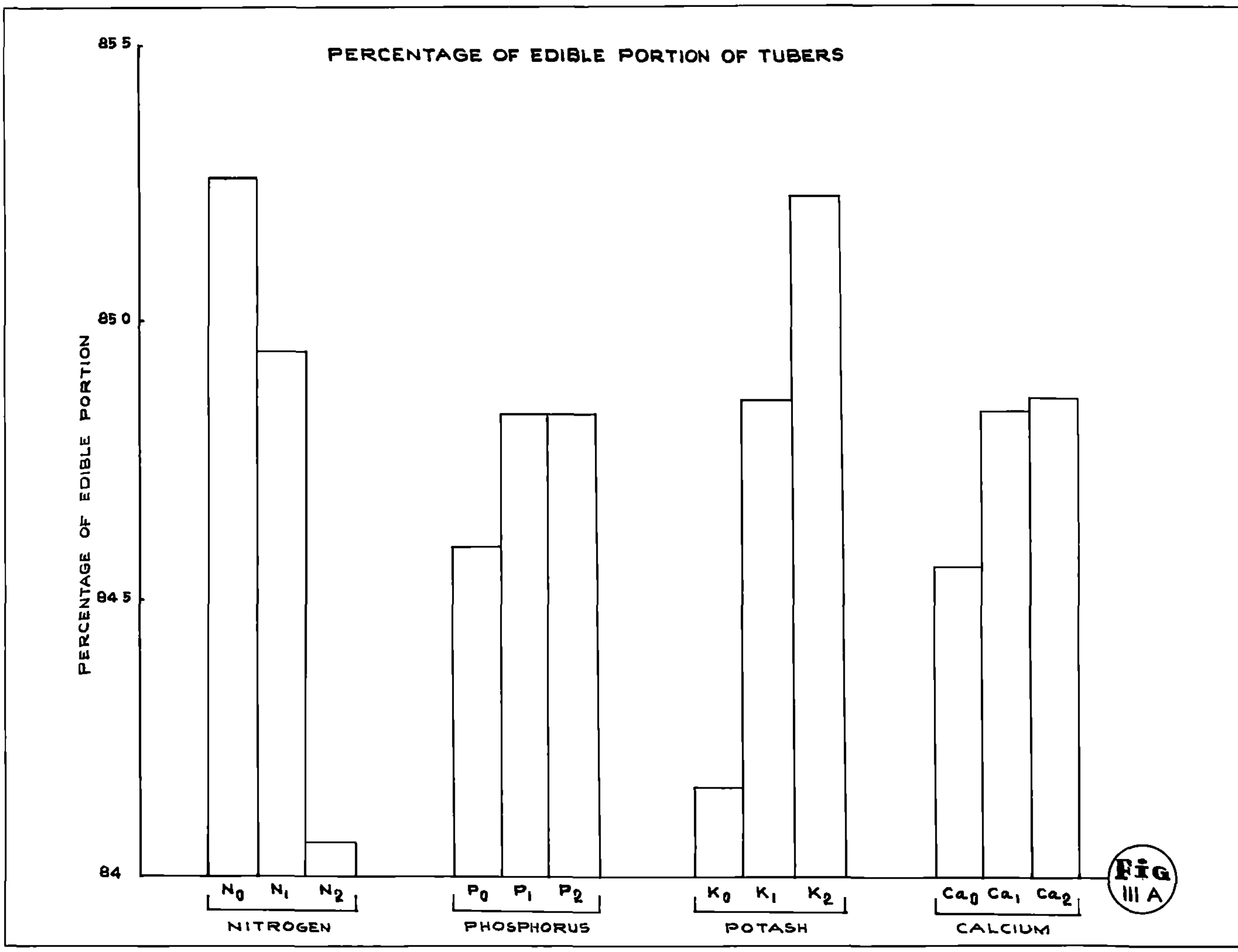
FIGURE III.A.

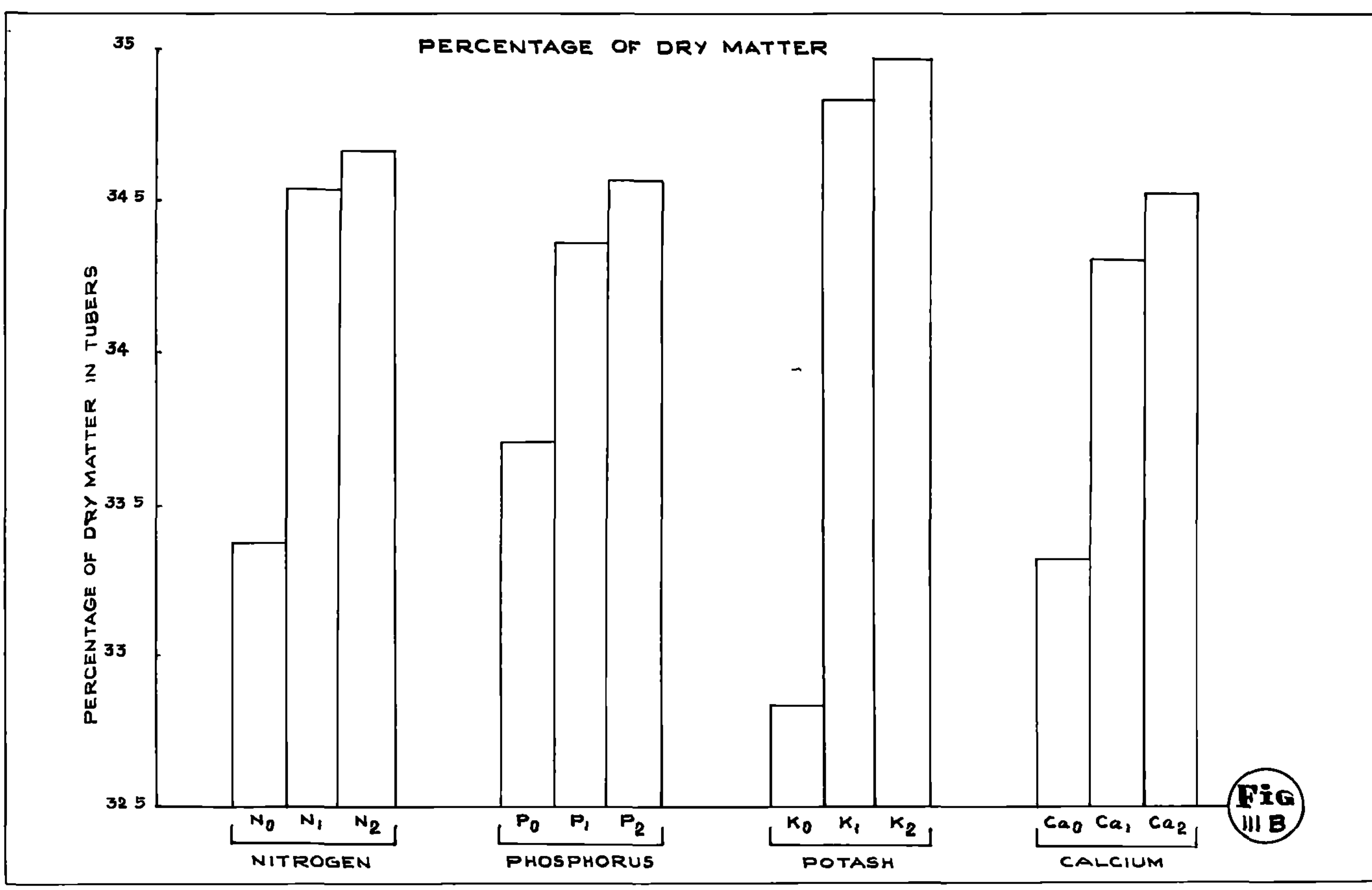
Bar Diagram showing the mean percentage of edible portion of tubers, as influenced by the various levels of plant nutrients.

FIGURE III.B.

Bar Diagram showing the mean percentage of dry matter content in tubers, as affected by the various levels of plant nutrients.

n_0	=	50 Kg N/Hectare.
n_1	=	100 Kg N/Hectare.
n_2	=	150 Kg N/Hectare.
P_0	=	0 Kg P_2O_5/Hectare.
P_1	=	50 Kg P_2O_5/Hectare.
P_2	=	100 Kg P_2O_5/Hectare.
k_0	=	100 Kg K_2O/Hectare.
k_1	=	150 Kg K_2O/Hectare.
k_2	=	200 Kg K_2O/Hectare.
Ca_0	=	0 Kg CaO/Hectare.
Ca_1	=	600 Kg CaO/Hectare.
Ca_2	=	1200 Kg CaO/Hectare.


PERCENTAGE OF EDIBLE PORTION OF TUBERS
PERCENTAGE OF EDIBLE PORTION
85 5
85 0
84 5
84
N_0 N_1 N_2
NITROGEN
P_0 P_1 P_2
PHOSPHORUS
K_0 K_1 K_2
POTASH
Ca_0 Ca_1 Ca_2
CALCIUM
Fig III A


PERCENTAGE OF DRY MATTER
PERCENTAGE OF DRY MATTER IN TUBERS
35
34 5
34
33 5
33
32 5
N_0 N_1 N_2
NITROGEN
P_0 P_1 P_2
PHOSPHORUS
K_0 K_1 K_2
POTASH
Ca_0 Ca_1 Ca_2
CALCIUM
Fig III B

tapioca as influenced by the factorial combinations of various levels of nutrient elements included in the present investigation are discussed hereunder.

1. Percentage of edible portion of tubers after removing the rind:

Table X and fig. III.A. show that there is a significant reduction in the percentage by weight of edible portion of tubers, with incremental doses of nitrogen application. Application of 100 Kg and 150 Kg of nitrogen per hectare has recorded a mean of 84.94 and 84.06% edible portion, as compared to 85.26% recorded in plots receiving only 50 Kg of nitrogen per hectare. The reduction in percentage of fleshy portion between the higher levels mentioned was not found significant.

Higher doses of potash application, however, had a significant effect on increasing the weight of edible portions of tubers and reducing the rind weight, the effect is just the reverse, as seen under nitrogen.

Even though the individual effect of phosphorus is not significant the trend is similar to that of potash. A maximum of 85.55% edible portion in tubers, is recorded as a result of combined application of 50 Kg of nitrogen and 150 Kg potash per hectare and minimum of 83.28% under the treatment receiving 150 Kg of nitrogen and 100 Kg potash per hectare. The above finding is in agreement with the results obtained in the Tapioca Research Station, Trivandrum (Anonymous 1955).

It is found that higher doses of nitrogen is increasing succulence in all plant parts and rind is no exception. Potash is having the reverse effect due to its role in synthesis and accumulation of more starchy foods in the fleshy portion of tubers as suggested by Miller (1938), Russell (1948), Meyer and Anderson (1956) and Black (1957).

ii . Dry matter content: The individual effects of all the four mineral nutrients and the combined effect of nitrogen and potash have significantly increased the percentage of drymatter in tubers of tapioca (Table XI and Fig. III B).

Among the combinations tried, a maximum of 35.55 per cent dry matter of tubers is obtained from treatments receiving 100 Kg of nitrogen and 200 Kg potash per hectare.

Results obtained by Malavolta et al.(1955) and Cours et al.(1961) support the present findings.

iii. Percentage of starch content:

Among the nutrient elements, nitrogen, phosphorus and potash have significantly contributed for an increase in the percentage of starch content in tapioca tubers. Highest level of calcium also had a significant effect. None of the interactions however, manifested

FIGURE III.C.

Bar Diagram showing the mean percentage of starch content in tubers, as influenced by the various levels of plant nutrients.

FIGURE III.D.

Bar Diagram showing the mean percentage of crude protein content of tubers, as influenced by the various levels of plant nutrients.

n_0	=	50 Kg N/Hectare.
n_1	=	100 Kg N/Hectare.
n_2	=	150 Kg N/Hectare.
p_0	=	0 Kg P_2O_5/Hectare.
p_1	=	50 Kg P_2O_5/Hectare.
p_2	=	100 Kg P_2O_5/Hectare.
k_0	=	100 Kg K_2O/Hectare.
k_1	=	150 Kg K_2O/Hectare.
k_2	=	200 Kg K_2O/Hectare.
Ca_0	=	0 Kg CaO/Hectare.
Ca_1	=	600 Kg CaO/Hectare.
Ca_2	=	1200 Kg CaO/Hectare.

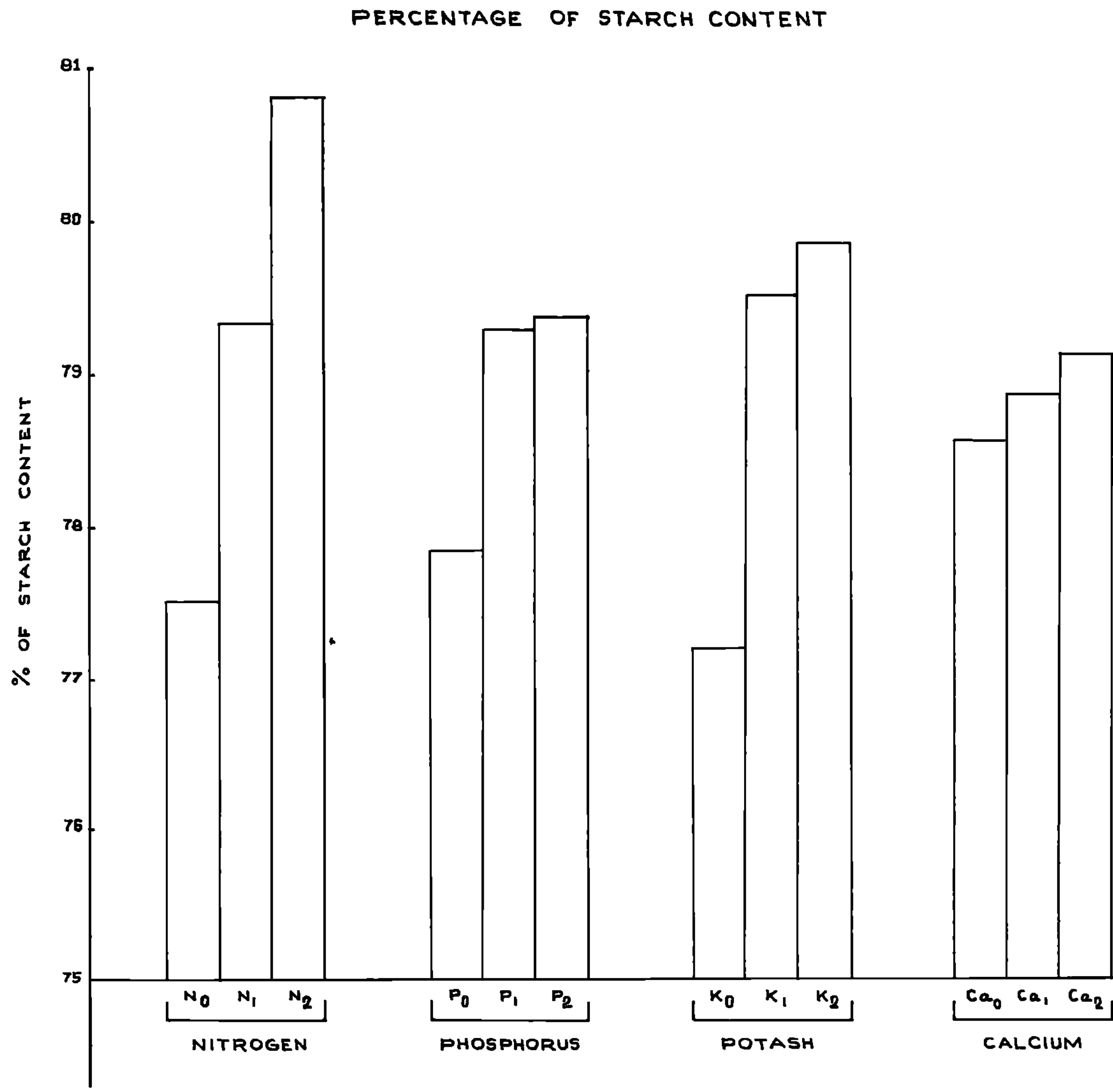


FIG III C

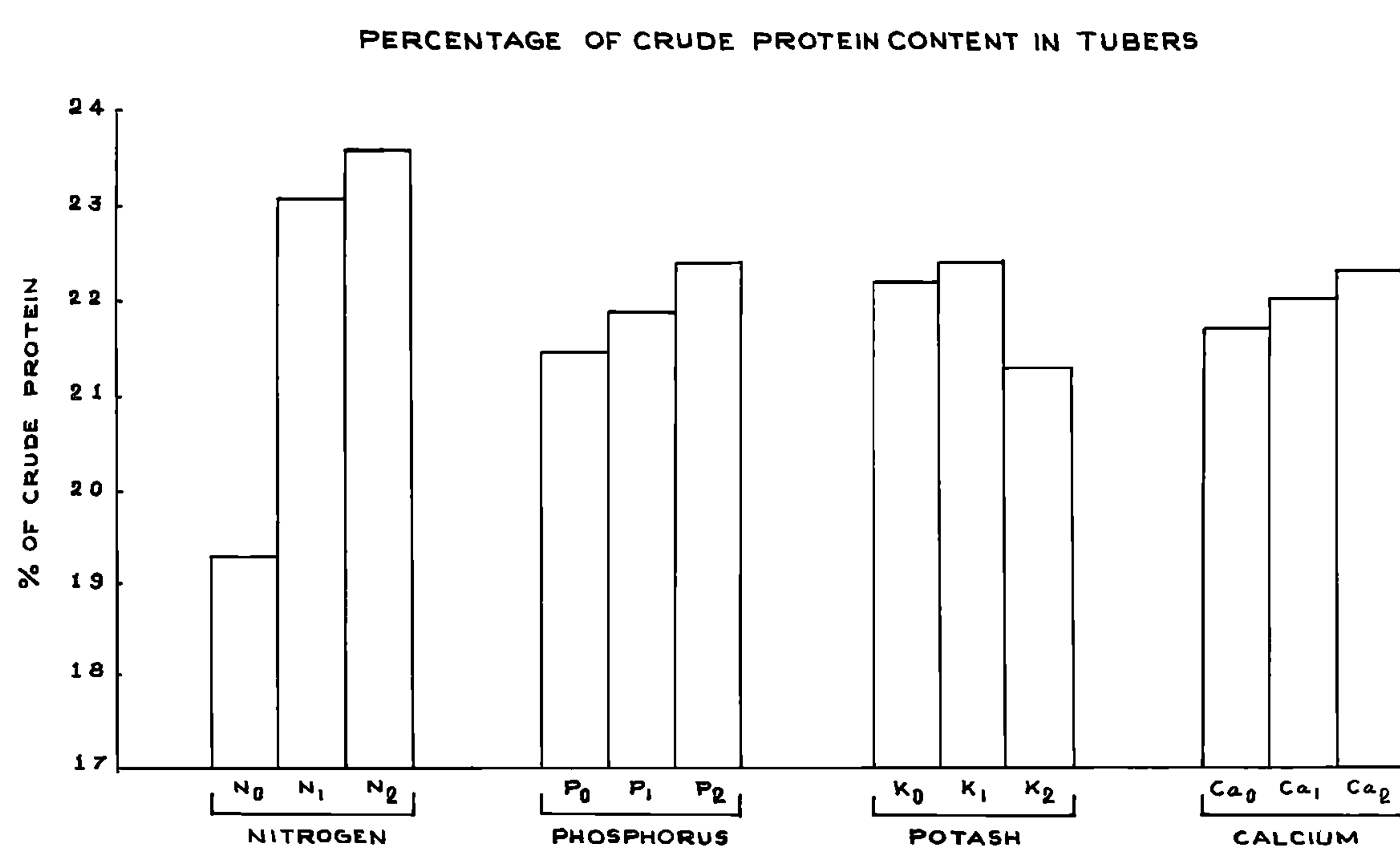


FIG III D

any significant influence on starch content of tubers (Table XII and Fig. III.C).

Among the combinations, application of 100 Kg of potash alone without any phosphorus recorded the minimum mean percentage of starch (76.16%); while a maximum of 80.68% of starch was recorded as a result of combined application of 150 Kg of nitrogen and 200 Kg of potash per hectare.

The above finding is in agreement with the results obtained at the Tapioca Research Station, Trivandrum, excepting for the effect found for nitrogen (Anon 1957). Rauter (1955), Malavolta et al.(1959) and Coure et al.(1961) also have reported similar results as observed in the present investigation.

The relative importance of these macrometabolic mineral elements on the production of more carbohydrates and synthesis of starch reserves in tubers needs no special emphasis, since it has been established by the early workers like Miller (1938), Russell (1948), and others on different root crops.

iv. Crude protein content: It is evident from Table XIII and Fig. III that incremental doses of nitrogen and phosphorus have significantly increased the percentage of crude protein content in tapioca tubers, the effect being highly pronounced in the case of nitrogen. On the contrary, application of the highest dose of 200 Kg of potash per hectare caused a significant reduction in protein content of tubers.

Results on similar lines were reported from the Tapioca Research Station, Trivandrum (Anonymous 1960), Mulder and Lakema (1956) and Furton (1957) have also observed similar results in potato.

Among the combinations, application of 150 Kg of nitrogen and 100 Kg phosphorus per hectare has recorded the maximum of 2.43 of crude protein in tubers.

Nitrogen in plants is mostly found in the form of proteins which serve as catalysts and directors of metabolism. Black (1957) has reported that with an abundant supply of nitrogen, the tendency is for carbohydrates to be used for the production of more of nitrogenous compounds. The functions of nitrogen and phosphorus in plant metabolism appears to be inter-related in many ways. Loyor and Anderson (1956) have opined that the synthesis of proteins apparently does not occur at usual rates in the phosphorus deficient plants, and this is often followed by an accumulation of sugars in the vegetative organs of such plants.

The highest dose of potash, viz. 200 Kg per hectare has caused a significant reduction in protein content, though the middle dose showed an increasing trend. This may probably be due to the synthesis of more starch in the edible portion of tubers (as evident from Table XI, XII and XIII) in treatments receiving the highest dose of potash. This might have caused a reduction in protein content under such treatments.

Response curves and economics of manuring: It is evident from Fig. II A to D and Table XIV, that " Malayan-4", the variety of tapioca chosen for the present investigation has responded to heavy doses of N, P, K and Ca fertilization. There is a steady increase in gross income as well as net profit with the application of increasing doses of all these nutrients. The results of the present investigation show that application of 130 Kg of nitrogen, 105 Kg. phosphorus and 235 Kg potash applied in conjunction with 900 Kg of calcium per hectare is an economic dose for tapioca under the agro-climatic conditions of Vellayani, for fetching the maximum profit.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSIONS

An experiment was conducted in the red loam soils of the central farm attached to the Agricultural College and Research Institute, Vellayani during the year 1966-1967, to study the response of graded doses of nitrogen (50, 100 and 150 Kg per hectare), phosphorus (0,50 and 100 Kg per hectare), Potash (100, 150 and 200 Kg per hectare) and calcium (0,600 and 1200 Kg per hectare) in factorial combinations, on the growth, yield and quality of a popular improved variety of tapioca, " Malayan-4". A 3^4 confounded factorial experiment was laid out, with 81 treatment combinations.

The data relating to the various biometric characters viz; height of plants, branching, number of leaves and weight of vegetative portions of the plants were studied. Yield components like number of tubers per plant, number of unproductive roots per plant, mean length and girth of tubers and the final yield of tubers, as influenced by the various treatment combinations were also studied. Quality factors like percentage by weight of rind and edible portion, dry matter content, starch content and crude protein content of tubers were also assessed. Quadratic response curves were fitted to the yield data, and the optimum as well as economic doses of individual nutrients were determined. Results of the investigations are summarised below:

(i) Plant height is significantly increased by the application of higher doses of potash. The combined application of 100 Kg nitrogen and 1200 Kg calcium, significantly depressed the plant height.

(ii) Branching is significantly increased by the combined effect of nitrogen and calcium.

(iii) Higher doses of nitrogen and potash alone significantly influenced the weight of vegetative parts.

(iv) Among the four plant nutrients nitrogen and calcium alone significantly increased the number of tubers per plant. Application of higher doses of phosphorus and potash also showed similar trends, though not significantly. The combined effect of application of 150 Kg of nitrogen and 100 Kg phosphorus per hectare has recorded the maximum mean number of tubers per plant.

(v) The mean length of tubers is not influenced by any of the treatment combinations.

(vi) Higher levels of nitrogen, potash and calcium increased the mean girth of tubers significantly.

(vii) There was significant response in yield due to the application of incremental doses of N, P, K and Ca. The combined effect of nitrogen and potash also had similar effect. Combined application of 150 Kg of nitrogen and 100 Kg phosphorus per hectare has given the maximum mean yield of 38.02 tonnes of tubers per hectare.

(viii) Correlation studies revealed that the yield is positively correlated with the number of tubers per plant, weight of vegetative parts and branching.

(ix) The percentage of edible portion of tubers is significantly increased by the application of graded doses of potash, while in the case of nitrogen a significant reduction in the percentage of edible portion resulted, with the application of higher doses.

(x) The dry matter content of tubers is significantly increased by the application of higher doses of nitrogen, phosphorus, potash and calcium. The combined application of nitrogen and potash also had a similar effect. Application of 100 Kg of nitrogen and 200 Kg of potash has recorded the maximum dry matter content of 35.55%.

(xi) Graded doses of nitrogen, phosphorus and potash progressively increased the starch content of tubers significantly. Maximum percentage of starch content (80.68) is recorded as a result of the combined application of 150 Kg of nitrogen and 200 Kg potash per hectare.

(xii) Crude protein content of tubers is significantly increased by the application of higher doses of nitrogen and phosphorus, while the application of the highest dose of 200 Kg potash per hectare resulted in a significant reduction in the crude protein content.

(xiii) Studies on the response curve of individual nutrients have shown that an optimum manurial dose for tapioca will be 150 Kg of nitrogen, 130 Kg phosphorus, 250 Kg potash and 1100 Kg of calcium per hectare, under the agroclimatic conditions of Vellayani.

(xiv) The economic dose of individual nutrients for tapioca, is found to be 130 Kg of nitrogen, 105 Kg phosphorus and 235 Kg potash applied in conjunction with 900 Kg of calcium per hectare.

The results of the present investigation when compared with the present fertilizer recommendation for tapioca followed in our state, emphasise the need for further investigations to determine the manurial requirements of popular high fertility strains of tapioca, grown under the different agroclimatic conditions of the state, to ensure maximum production and economic returns.

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* Originals not seen.

APPENDICES

Appendix I

Weight of plants at harvest

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	92,48,273.66	8	11,56,034.21	10.02**
N	1,76,753.06	2	88,376.53	1
P	1,77,497.55	2	88,748.78	1
NP	10,25,697.27	4	2,56,424.32	2.22
K	8,81,316.62	2	4,40,658.32	3.82*
NK	3,60,346.87	4	90,086.72	1
PK	10,81,714.09	4	2,70,428.52	2.34
NPK	7,68,073.94	6	1,28,012.32	1.11
Ca	4,42,709.05	2	2,21,354.52	1.92
NCa	20,58,108.88	4	5,14,527.22	4.46*
PCa	3,64,753.73	4	91,188.43	1
NPCa	21,92,272.54	6	3,65,378.76	3.16
KCa	5,09,143.66	4	1,27,285.91	1.10
NKCa	10,71,131.35	6	1,78,521.89	1.54
PKCa	11,82,785.52	6	1,97,130.92	1.70
NPKCa (Error)	18,44,562.76	16	1,15,285.17	
Total	2,33,85,140.17	80		

* Significant at 5 per cent level.

** Significant at 1 per cent level.

Appendix II

Percentage of plants branched

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	3,842.48	8	480.31	1.89
N	456.39	2	228.20	1
P	1,708.62	2	854.31	3.37
NP	371.69	4	92.92	1
K	672.70	2	336.35	1.33
NK	364.71	4	91.18	1
PK	887.58	4	221.89	1
NPK	683.43	6	113.90	1
Ca	1,604.62	2	802.31	3.16
N Ca	5,377.89	4	1,344.47	5.30*
P Ca	764.55	4	191.14	1
NP Ca	1,998.61	6	333.10	1.31
K Ca	1,152.48	4	288.12	1.14
NK Ca	1,036.77	6	172.79	1
PK Ca	1,866.71	6	311.12	1.23
NPK Ca (Error)	4,057.46	16	253.59	
Total	26,846.70	80		

* Significant at 5 per cent level.

Appendix III

Number of leaves per plant (Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	7,02,876.03	8	87,859.50	1.31
N	13,781.95	2	6,890.98	1
P	61,675.86	2	30,837.93	1
NP	2,10,027.10	4	52,506.78	1
K	45,126.98	2	22,564.49	1
NK	16,031.10	4	4,007.78	1
PK	2,87,064.96	4	71,766.24	1.07
NPK	1,59,962.05	6	26,660.34	1
Ca	37,355.86	2	18,677.93	1
N Ca	1,19,647.99	4	29,911.99	1
PCa	2,14,565.42	4	53,641.35	1
NPCa	3,57,775.89	6	59,629.31	1
KCa	1,46,865.19	4	36,716.29	1
NKCa	1,20,220.05	6	20,036.67	1
PKCa	1,13,476.18	6	18,913.03	1
NPKCa (Error)	10,70,466.75	16	66,904.17	
Total	36,76,923.36	80		

Appendix IV

Weight of vegetative parts

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	132.73	8	16.59	5.74**
N	55.24	2	27.62	9.55**
P	5.79	2	2.89	1.00
NP	21.86	4	5.46	1.88
K	24.06	2	12.03	4.16*
NK	16.86	4	4.21	1.45
PK	3.42	4	0.85	1
NPK	18.92	6	3.15	1.08
Ca	1.85	2	0.93	1
N Ca	27.07	4	6.77	2.34
P Ca	4.52	4	1.13	1
NP Ca	27.59	6	4.60	1.59
K Ca	8.31	4	2.08	1
NK Ca	10.34	6	1.72	1
PK Ca	21.93	6	3.65	1.26
NPK Ca (Error)	46.23	16	2.89	
Total	426.72	80		

* Significant at 5 per cent level.

** Significant at 1 per cent level.

Appendix V

Yield of tubers

(Analysis of variance)

Source	Sum of square	D.F.	Variance	F
Block	609.44	8	76.18	7.27**
N	497.02	2	248.51	23.73**
P	241.72	2	120.86	11.54**
NP	47.09	4	11.77	1.12
K	76.74	2	38.37	3.66*
NK	181.62	4	45.40	4.33*
PK	67.65	4	16.91	1.61
NPK	49.76	6	8.29	1
Ca	334.40	2	167.20	15.96**
NCa	75.02	4	18.75	1.79
PCa	32.09	4	8.02	1
NPCa	20.65	6	3.44	1
KCa	51.36	4	12.84	1.22
NKCa	65.16	6	10.86	1.03
PKCa	25.69	6	4.28	1
NPKCa (Error)	167.59	16	10.47	
Total	2543.00	80		

* Significant at 5 per cent level.

** Significant at 1 per cent level.

Appendix VI

Number of tubers per plant

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	667.51	8	83.44	1.37
N	2,024.92	2	1,012.46	16.61**
P	242.18	2	121.09	1.98
NP	258.86	4	64.71	1.06
K	411.88	2	205.94	3.38
NK	722.27	4	180.56	2.96
PK	72.34	4	18.08	1
NPK	284.37	6	47.39	1
Ca	448.18	2	224.09	3.68*
NCa	106.41	4	26.60	1
PCa	67.37	4	16.84	1
NPCa	158.52	6	26.42	1
KCa	12.34	4	3.08	1
NKCa	368.00	6	61.33	1.01
PKCa	453.64	6	75.60	1.24
NPKCa (Error)	975.39	16	60.96	
Total	7,274.18	80		

* Significant at 5 per cent level.

** Significant at 1 per cent level.

Appendix VII

Number of unproductive roots (Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	5,200.22	8	650.02	6.94**
N	58.96	2	29.48	1
P	211.27	2	105.64	1.13
NP	123.77	4	30.94	1
K	212.51	2	106.25	1.13
NK	240.08	4	60.02	1
PK	383.55	4	95.89	1.02
NPK	441.79	6	73.63	1
Ca	0.22	2	0.11	1
N Ca	315.48	4	78.87	1
P Ca	173.62	4	43.41	1
NPCa	139.94	6	23.33	1
K Ca	111.04	4	27.76	1
NKCa	581.04	6	96.84	1.03
PKCa	429.94	6	71.66	1
NPKCa (Error)	1,498.79	16	93.66	
Total	10,122.22	80		

** Significant at 1 per cent level.

Appendix VIII

Length of tubers

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	410.89	8	51.36	2.44
N	2.74	2	1.37	1
P	53.40	2	26.70	1.27
NP	51.86	4	12.97	1
K	25.40	2	12.70	1
NK	26.06	4	5.52	1
PK	23.00	4	5.75	1
NPK	68.65	6	11.44	1
Ca	7.90	2	3.95	1
N Ca	40.06	4	10.02	1
PCa	123.37	4	30.84	1.46
NPCa	108.15	6	18.02	1
KCa	21.59	4	5.39	1
NKCa	104.40	6	17.40	1
PKCa	185.32	6	30.89	1.46
NPKCa (Error)	337.21	16	21.08	
Total	1,590.00	60		

Appendix - IX

Girth of tubers

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	60.49	8	7.56	2.69 *
N	86.42	2	43.21	15.38 **
P	14.64	2	7.32	2.60
NP	19.87	4	4.97	1.77
K	37.08	2	18.54	6.60 **
NK	16.77	4	4.19	1.49
PK	16.33	4	4.08	1.45
NPK	23.58	6	3.93	1.40
Ca	59.16	2	25.58	9.10 **
NCa	24.25	4	6.06	2.16
PCa	9.58	4	2.39	1
NPCa	24.38	6	4.06	1.44
KCa	22.47	4	5.62	2.00
NKCa	24.00	6	4.00	1.42
PKCa	21.34	6	3.56	1.26
NPKCa (Error)	49.02	16	2.81	
Total	497.38	80		

* Significant at 5 per cent level

** Significant at 1 per cent level.

Appendix X

Percentage of edible portion of tubers after removing the rind

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	18.84	8	2.35	3.89**
N	21.04	2	10.52	17.41**
P	1.04	2	0.52	1
NP	5.15	4	1.29	2.21
K	15.59	2	7.80	12.91**
NK	2.54	4	0.64	1.06
PK	2.25	4	0.56	1
NPK	6.82	6	1.14	1.88
Ca	1.30	2	0.65	1.06
NCa	0.61	4	0.15	1
PCa	0.76	4	0.19	1
NPCa	3.45	6	0.57	1
KCa	0.84	4	0.21	1
NKCa	3.45	6	0.58	1
PKCa	2.71	6	0.45	1
NPKCa (Error)	9.67	16	0.604	
Total	96.06	80		

** Significant at 1 per cent level.

Appendix XI

Percentage of dry matter in tubers

(On ovendry basis)

(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	9.50	8	1.19	1.55
N	25.90	2	12.95	16.88 **
P	10.68	2	5.34	6.96 **
NP	4.08	4	1.02	1.32
K	76.35	2	38.17	49.76 **
NK	12.69	4	3.17	4.13*
PK	5.24	4	1.31	1.71
NPK	0.44	6	0.073	1
Ca	6.68	2	3.34	4.35*
NCa	2.36	4	0.59	1
PCa	1.36	4	0.34	1
NPCa	3.06	6	0.51	1
KCa	0.69	4	0.17	1
NKCa	1.15	6	0.19	1
PKCa	0.04	6	0.007	1
NPKCa	12.28	16	0.767	
Total	172.50	80		

* Significant at 5 per cent level.

** Significant at 1 per cent level.

Appendix XII

Percentage of starch content
(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	6.26	8	0.78	1.16
N	74.89	2	37.49	55.95**
P	40.30	2	20.15	30.07**
NP	3.75	4	0.94	1.40
K	111.40	2	55.70	83.13**
NK	6.50	4	1.63	2.43
PK	0.10	4	0.025	1
NPK	4.93	6	0.82	1.22
Ca	4.30	2	2.15	3.20
NCa	0.70	4	0.175	1
PCa	3.30	4	0.825	1.22
NPCa	2.64	6	0.44	1
KCa	2.40	4	0.60	1
NKCa	4.10	6	0.68	1.01
PKCa	4.64	6	0.77	1.14
NPKCa (Error)	10.76	16	0.67	
Total	280.99	80		

** Significant at 1 per cent level.

Appendix XIII

Percentage of crude protein content of tubers
(On oven dry basis)
(Analysis of variance)

Source	Sum of squares	D.F.	Variance	F
Block	0.32	8	0.040	3.33*
N	2.98	2	1.490	124.2**
P	0.11	2	0.055	4.58*
NP	0.06	4	0.015	1.25
K	0.17	2	0.085	7.08*
NK	0.04	4	0.010	1
PK	0.10	4	0.025	2.08
NPK	0.03	6	0.005	1
Ca	0.06	2	0.030	2.50
NCa	0.04	4	0.010	1
PCa	0.02	4	0.005	1
NPCa	0.04	6	0.007	1
KCa	0.09	4	0.022	1.83
NKCa	0.04	6	0.007	1
PKCa	0.10	6	0.017	1.41
NPKCa	0.19	16	0.017	
Total	4.39	80		

* Significant at 5 per cent level

** Significant at 1 per cent level.

Appendix XIV

Meterological data recorded at the Agricultural College farm, Vellayani during the period of crop growth

Month	Mean Temperature in °F		Relative humidity	Total rainfall (in mm)
	Maximum	Minimum		
July 1966	86	74	89.6	585
August 1966	86	76	87.6	341
September 1966	86	74	86.7	768
October 1966	88	74	88.5	862
November 1966	86	74	89.2	295
December 1966	86	74	89.0	120
January 1967	88	76	86.0	74
February 1967	88	74	83.0	Nil
March 1967	90	76	84.5	Nil
April 1967	90	78	87.0	64

PLATE I. A general view of the experimental plots, 45 days after planting.

PLATE II. Tuber development in a plant, from the N_{100} P_{100} K_{200} Ca_{1200} plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

PLATE I

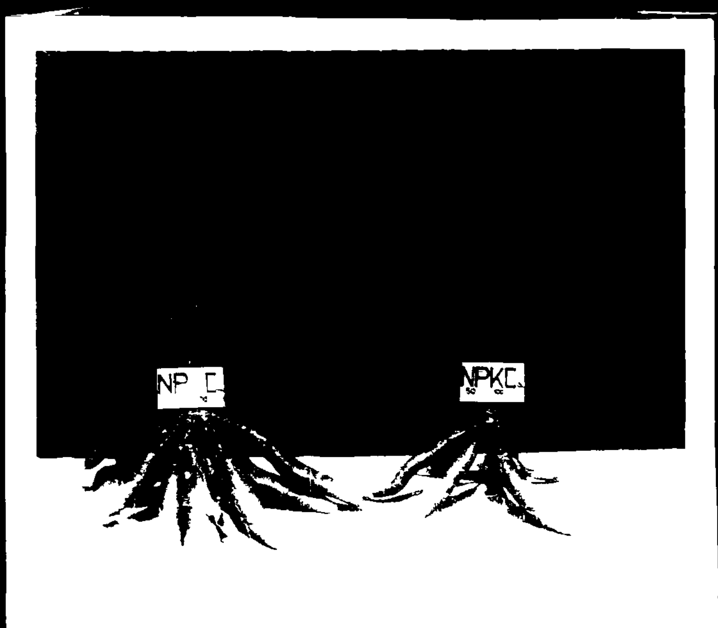

PLATE II

PLATE III. Tuber development in a plant from the N_{150} P_{100} K_{200} Ca_{600} plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

PLATE IV. Tuber development in a plant from the N_{50} P_0 K_{150} Ca_0 plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

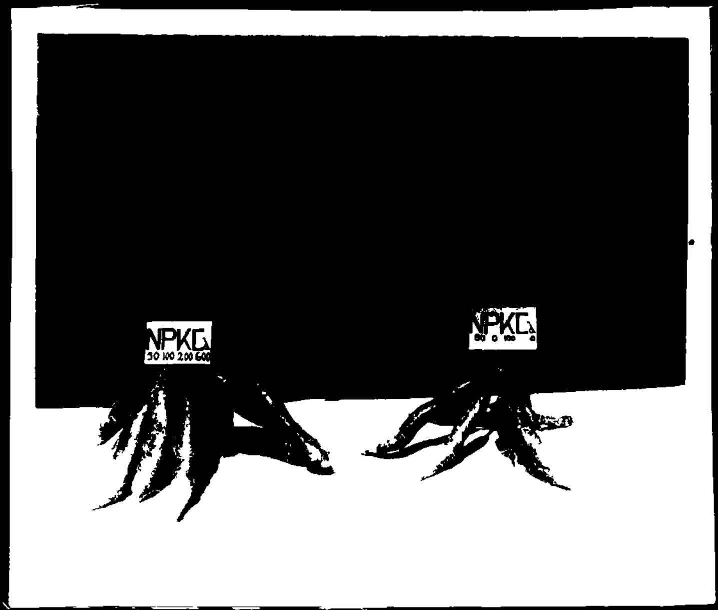

PLATE III

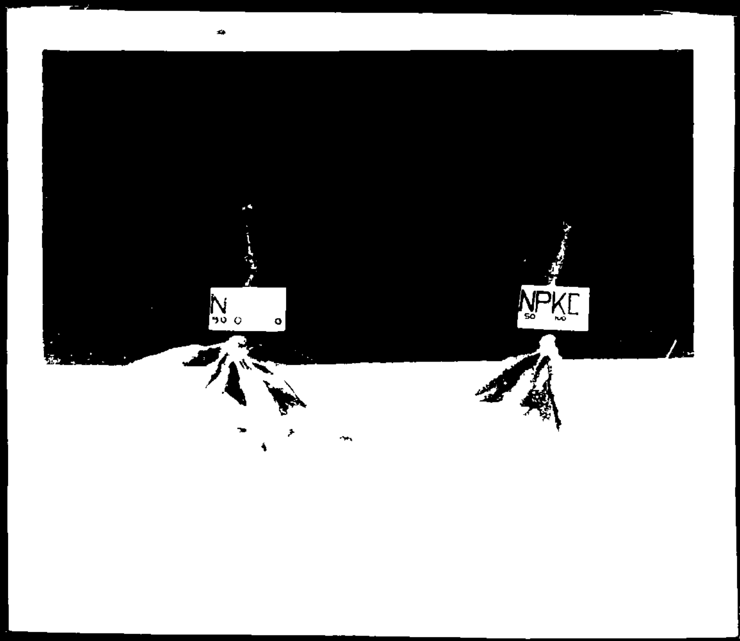

PLATE IV

PLATE V. Tuber development in a plant from the N_{50} P_{100} K_{150} Ca_{1200} plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

PLATE VI. Tuber development in a plant from the N_{150} P_{50} K_{200} Ca_{600} plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

PLATE V

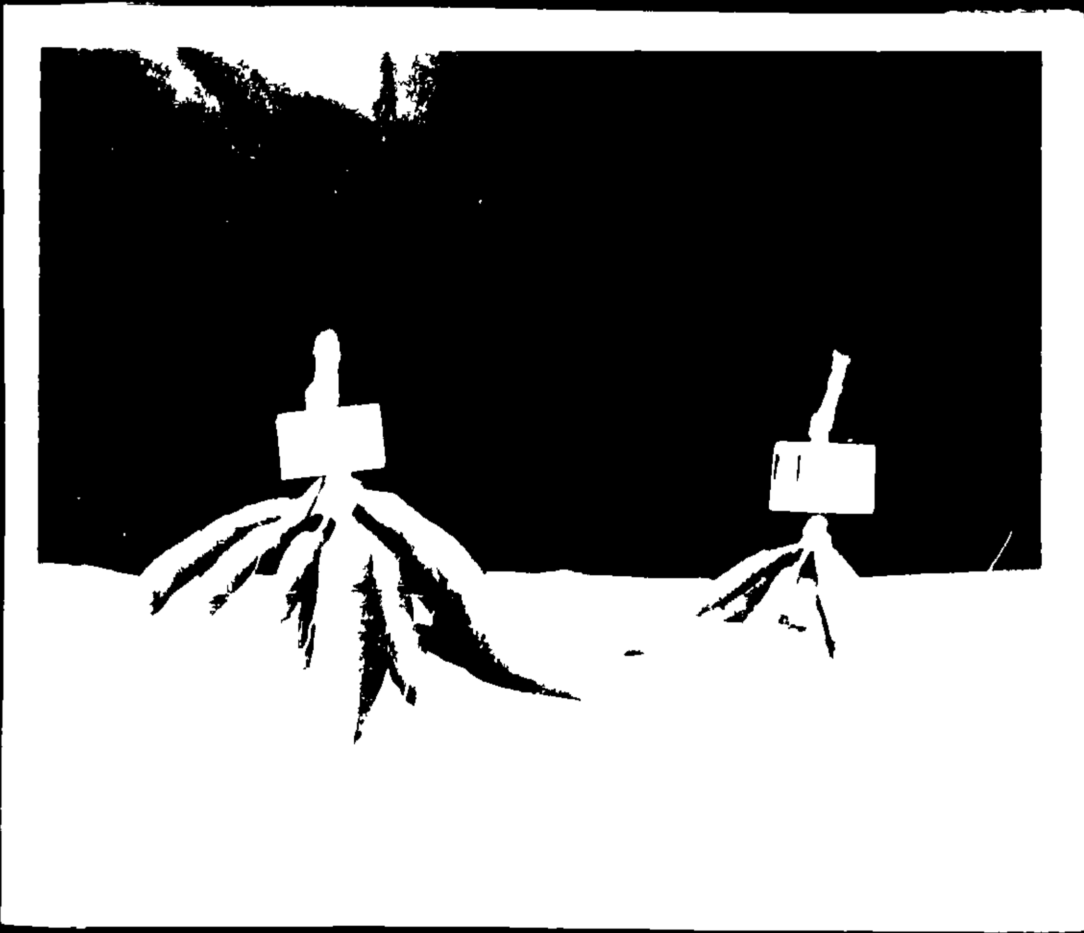

PLATE VI

PLATE VII. Tuber development in a plant from the N_{150} P_{100} K_{200} Ca_{1200} plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

PLATE VIII. Tuber development in a plant from the N_{100} P_{50} K_{150} Ca_{600} plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

PLATE VII

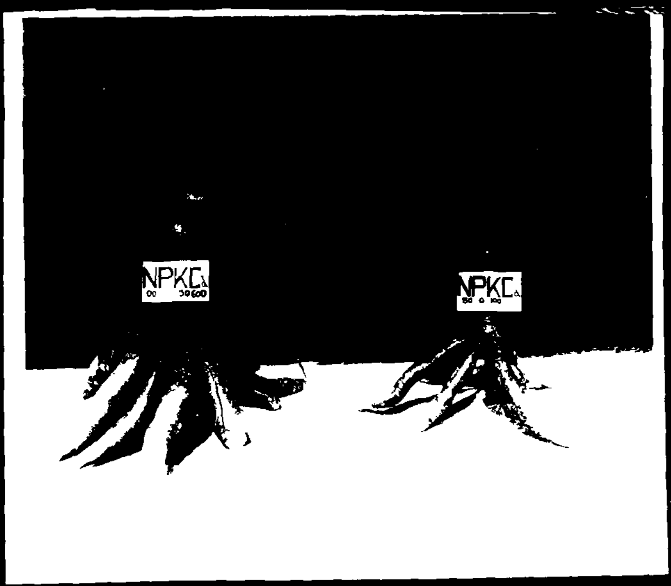

PLATE VIII

PLATE IX. Tuber development in a plant from the N_{100} P_{50} K_{150} Ca_{600} plot, as compared to that of a plant from the N_{50} $P_0 K_{100}$ Ca_0 plot (Control).

PLATE X. Tuber development in a plant from the N_{150} P_{100} K_{200} Ca_{600} plot, as compared to that of a plant from the N_{50} P_0 K_{100} Ca_0 plot (Control).

PLATE IX

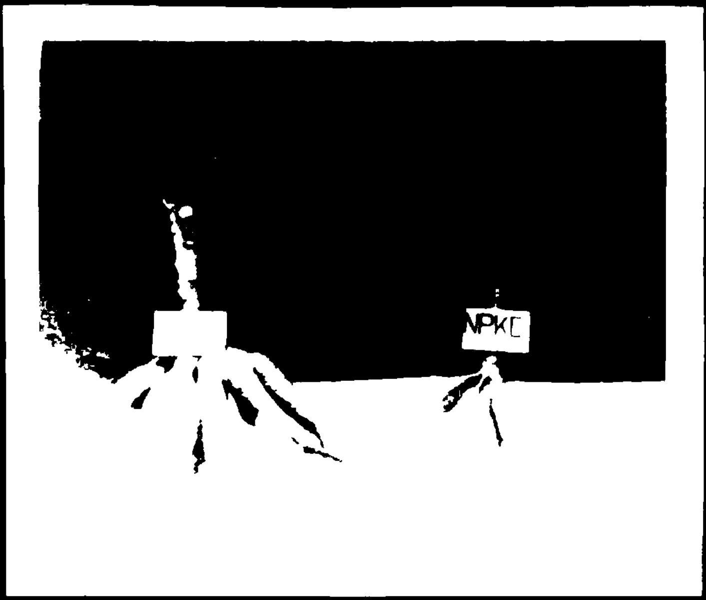

PLATE X