

Cropping and Soil Fertility Studies at Keravat, New Britain. 1954-1962.

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ABSTRACT.

At the Lowlands Agricultural Experiment Station, Keravat, on the Island of New Britain, two long term farming systems trials have been in progress since 1954. The trial sites are 4 degrees south of the equator, near sea level, and the climate is wet tropical. The trials are sited on deep pumice derived alluvial soils which, in the virgin state, supported rain forest.

Soil Exhaustion Trial.

The rate at which sweet potato yields declined with constant cropping was studied. The soil was considered exhausted after a five-year period during which ten crops of sweet potato had been grown. A fertilizer trial was then superimposed on the trial plots. The only significant result was a negative response to nitrogen in the form of urea. This result may have been associated with omission of potassium and magnesium from the fertilizer trial treatments. Levels of total potassium in the soil are high. Work is continuing on the project.

Three-Course Rotation Trial.

This trial compares seven different rotations, four of which are wide and three are narrow. Each rotation cycle lasts three years; the narrow rotations consist of almost continuous foodcropping, while the wide rotations consist of one and a half years' foodcropping alternated with one and a half years' covercropping. After two rotation cycles it is evident that even in the wide rotations, foodcrop production cannot be maintained at original levels. It is apparent also that under such conditions of cropping, insect, disease and weed problems can be quite serious. Work on the trial is continuing.

INTRODUCTION.

In the Territory of Papua and New Guinea, subsistence foodcrops are traditionally produced by a method of farming which is generally referred to as 'shifting cultivation' or the 'bush fallow system'.

This system is dependent on the development of a natural bush fallow at the completion of the cropping period, after which land is cleared again and the cropping and fallow cycle repeated. In Papua and New Guinea, land is usually cleared and burned by men of the village. Large unburned logs and stumps often remain on the garden plot. Planting is mostly undertaken by the women of a village and many crop species are frequently planted together in the one plot, each species being harvested as it matures. Certain species such as cassava and bananas may be left to compete with the natural regrowth once

the plot has been abandoned. Maintenance of gardens is normally quite good in the early stages of the cropping period but deteriorates in time. After the completion of cropping, the garden is allowed to revert through the various stages of the sere, toward the climax vegetation for the environment. Depending on the pressure of the population on the land, the sere may be interrupted at any stage, and the land replanted as a garden. This often results in conversion of bushland to grassland.

Although individual gardens are rather small, ranging up to the order of five or six acres, it is usual for a clan to maintain several gardens at the one time, each separated by a considerable distance of bushland. A village community garden is often planted as well, and is divided up into very small individually owned plots. This village garden is usually much bigger than the individual clan gardens. Once the gardens in a particular area have been harvested, land is usually opened up in another area, isolated from the first, and the process is repeated.

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Owing to the ruggedness of much of the Territory, flat land is scarce in many regions, and gardens are generally sited on steep hillsides.

Bush fallow rotations have been evolved by countless generations as a result of their efforts to develop a system of farming which was in harmony with their environment. The system serves to maintain crop yields at a satisfactory level by preventing the soil from becoming exhausted, and by avoiding a build-up of insect pests, disease organisms and weeds. Successive crops are planted in soil of reasonable to good fertility. Isolation between concurrently planted gardens and successive gardens helps to prevent the spread of pests and diseases.

However, it has been estimated that 14 million square miles of the tropics are farmed by shifting cultivation and that this area of land supports some 200 million inhabitants—an average of only 14 people per square mile. With the present growth in world population, this spectacular land wastage must be overcome, for with improved medical and social facilities and the expansion of commercial cropping, population pressures on land are increasing and will continue to increase. The bush fallow period is becoming shorter, land is being over-cropped, levels of fertility are falling and soil erosion increasing. Isolation between gardens and successive crops is being reduced, resulting in an increase in pest, disease and weed infestations.

In a few areas of the Territory of Papua and New Guinea, this stage is fast being reached. A more intensified system of farming is therefore required which is consistent with satisfactory yield and reasonable production costs. This would allow a more rational system of land utilization and land settlement and the development of unit farms and would therefore assist in the stabilization of agriculture. Long term land improvements would be possible while more land would be available for commercial development. In particular, a more intensive system of foodcrop farming would be of considerable value for the increasing number of settlers who are participating in land settlement schemes.

For these reasons, two trials were started at the lowlands Agricultural Experiment Station, Keravat, with the aim of studying soil fertility problems associated with intensified farming in the tropics. One was a *Three Course Rotation Trial*, aimed at studying the effects of rotational

cropping both on crop yields and soil fertility, and also on the occurrence and control of pests, diseases and weeds. The other trial was a *Soil Exhaustion Trial*, in which the behaviour of the crop yields and soil fertility were studied under a system of continuous exploitative cultivation.

Location.

Keravat, where the two trials were carried out, lies 100 feet above sea level, near the north-eastern tip of the Island of New Britain, at longitude 152 degrees east and latitude 4 degrees 20 minutes south. Since 1950, rainfall has averaged 110 in. per annum, with a period of lower rainfall between June and August. However, rainfall is very variable both in annual total and distribution and has ranged from 85 to 132 in. per annum. Temperature is fairly constant, averaging about 80 degrees F. with a normal diurnal range of 70 degrees F. to 90 degrees F. Relative humidity is high.

Site.

The area used for the Trials had been under secondary regrowth for eight to nine years. Prior to that it had been used by the Japanese army for foodcropping during their wartime occupation. The land is flat, and of fairly uniform soil type. The soil is well over 20 ft. deep, and is derived from volcanic pumice and ash. It was probably deposited as a river flat during snap floods, which occur at times of volcanic eruption. The soil is a loamy sand, containing small amounts of clay and 70 to 80 per cent. coarse sand. It is dark brown in colour, and was originally high in organic matter. Organic matter decreases rapidly down the profile to 14 in. then increases slightly to 27 in., decreasing to nil at 33 in., indicating the presence of a buried profile. Most of the exchange capacity of the soil lies with the organic matter.

PART 1.—THE SOIL EXHAUSTION TRIAL.

Exhaustion of the Soil.

The Trial was designed to investigate the effect of continuous cropping with sweet potato on the level of soil fertility as measured by sweet potato yields, with the ultimate object of cropping the soil to exhaustion. It was planned to then investigate the fertilizer requirements for restoration of fertility and sweet potato yields to the original levels.

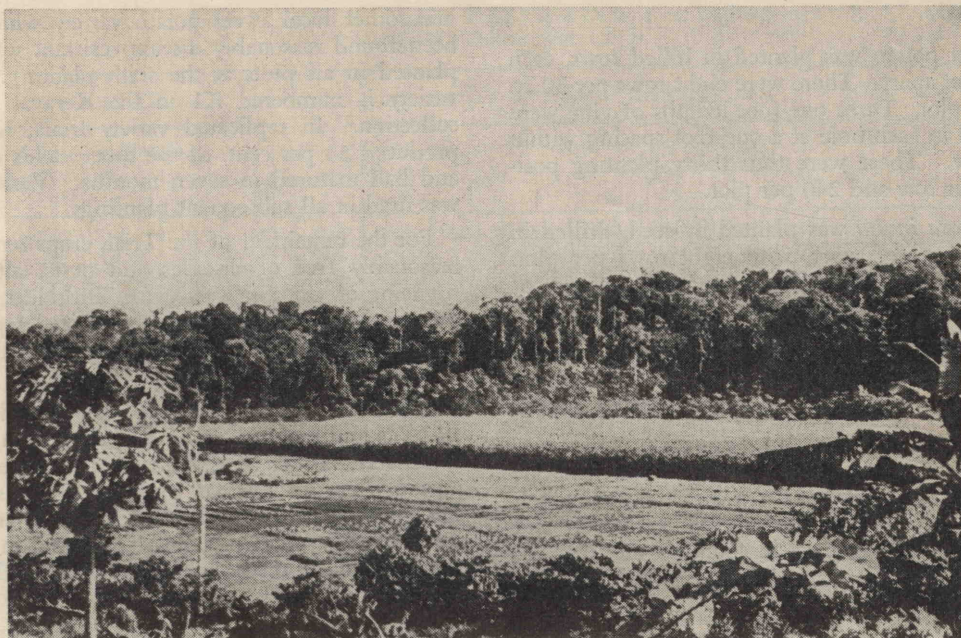


Plate I.—General view of the cropping and soil fertility trial plots in the programme.

Layout and Design.

Measurement of declining soil fertility through yields of successive crops is complicated by fluctuations in yield caused by seasonal conditions. The Trial was therefore designed so that declining fertility would be measured by study of crop behaviour on plots on which cropping had commenced at different times. The four treatments comprised four dates of planting to the first crop of sweet potato, treatment 2 being planted at the date of the second planting of treatment 1, treatment 3 at the date of the third planting of treatment 1 and treatment 4 at the date of the fourth planting of treatment 1 (*Table 1*). Each treatment was thus a replicate in time.

As it was impractical to retain the original secondary bush cover on later planted plots, all were cleared simultaneously. The short term leguminous cover crop *Phaseolus calcaratus* was sown on the plots of treatment 2 and the long term leguminous cover crop *Mimosa invisa* was sown on the plots of treatments 3 and 4. These cover crops were turned in before planting the first crops of sweet potato.

Details of the planting programme are shown in *Table 1*. The plots were set out in the form of a 4×4 latin square as shown in *Figure 1*.

Table 1.—Soil Exhaustion Trial—Keravat.
Experimental Design.

Planting.	Treatment 1.	Treatment 2.	Treatment 3.	Treatment 4.
1	SP	P.c	M	M
2	SP	SP	M	M
3	SP	SP	SP	M
4	SP	SP	SP	SP
Thereafter	SP	SP	SP	SP

Treatments replicated four times in space.

SP = Sweet potato "*Ipomoea batatas*".

P.c = "*Phaseolus calcaratus*".

M = "*Mimosa invisa*".

Figure 1.—Soil Exhaustion Trial—Keravat.
Layout of Treatments.

2	3	4	1
4	1	2	3
3	4	1	2
1	2	3	4

Plot Size—30 ft. square.

Plots separated by 4 ft. paths.

Procedure.

Sweet potato was planted in hilled rows, each four feet apart. There were eight rows per 30 ft. square plot. Three one-foot lengths of vine were planted in each hole at a one-foot spacing within the row. There were thus thirty planting positions per row and 240 per plot.

Mimosa invisa was planted by seed, drilled in rows four feet apart, with eight rows per plot. For ease of handling, the thornless strain of *Mimosa invisa* was used.

Phaseolus calcaratus was planted by seed in drills fifteen inches apart, the plants being subsequently thinned to a six-inch spacing within each row.

The first planting of the Trial was in May, 1954, with a local variety of sweet potato which is numbered K3 in the Keravat collection and which normally matures in about six months.

Maturity was judged to have been reached when the sap exudate from a cut tuber formed beads at the point of exudation, rather than spreading freely over the cut surface. When the crop matured, plots were harvested, and the total tuber yields of each plot were recorded. Sweet potato top growth was cut and carried away from the plots.

After each harvest an average of four weeks was required to prepare the plots for the following planting. For each consecutive planting, the direction of the hills was changed 90 degrees so that a fairly thorough mixing of the top 12 in. of soil in the plots was achieved as the Trial proceeded.

Sweet potato variety K3 was used in the first five plantings of the trial. However, in the third planting severe disease and insect damage practically destroyed the crop and symptoms of 'little leaf virus' were noted. Fresh vines from an outside source were introduced for the fourth planting, and the crop was sprayed regularly with B.H.C. miscible oil and white oil.

Severe damage to the crop by insects and disease occurred again during the fifth planting and all plots were planted to *Sorghum vulgare* for a period of six months in an attempt to clear the Trial site of diseases and to combat suspected infestations of soil nematodes and the crown rot fungus *Sclerotium rolfsii*.

Another local sweet potato variety which had been found reasonably disease resistant was then planted in all plots at the sixth planting. This variety is numbered K1 in the Keravat variety collection. In replicated variety trials, K1 had produced 53 per cent. of the tuber yields of K3, and had matured in seven months. Variety K1 was used in all subsequent plantings.

For the remainder of the Trial, crops remained reasonably free of diseases and pests, although roguing of vines infected with 'little leaf virus' was necessary. The crops were dusted regularly with a mixture of B.H.C. and copper oxychloride.

By the tenth planting yields had fallen drastically with extremely poor vine growth evident on all plots and leaf size and internode length greatly reduced, although small isolated patches supported vigorous normal growth. It was considered that the soil had been exhausted and the study of exhaustion rate was terminated in order that a study of methods of rejuvenating the exhausted soil could be undertaken.

During the first ten plantings six series of soil samples were collected for chemical analysis at the intervals indicated below :—

- 1st sampling—prior to the first planting.
- 2nd sampling—After the first harvest.
- 3rd sampling—After the second harvest.
- 4th sampling—After the third harvest.
- 5th sampling—After the fourth harvest.
- 6th sampling—After the sixth harvest.

Ten soil samples were taken from each 30 ft. square plot at both the 0 to 6 in. and 6 to 12 in. levels.

In collecting these samples a two inch diameter pipe was hammered into the soil to a depth of six inches, withdrawn, and the 0 to 6 in. core removed. A similar pipe was inserted into the same hole, and hammered in another six inches, withdrawn and the 6 to 12 in. core removed. The ten samples from each plot at each depth were bulked, dried and one pound subsamples bagged and labelled for subsequent analysis.

Results.

A summary of yields from the first ten plantings of the Soil Exhaustion Trial is shown in Tables 2A and 2B.

Aphids caused distortion of leaves in most plantings and damage to the tubers by the weevil *Cyrtolabus formicarius* and two species of hawkmoth,

Table 2A.—Soil Exhaustion Trial Yield Data, First 10 Plantings.
Mean Wt. Tubers/Plot (lb.).

VARIETY K3.						VARIETY K1.									
Treatment.	Planting.					Planting. Adjusted Yields *									
	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10
1	502	402	215	307	Nil	266	213	114	163	—	335	181	208	134	56
2	P.c.	480	221	329	Nil	P.c.	254	117	175	—	355	193	232	132	71
3	M	M	205	366	Nil	M	M	109	194	—	379	207	228	158	67
4	M	M	M	449	Nil	M	M	M	238	—	416	212	226	124	76

Sorghum grown on plots for six months between 5th and 6th plantings.

* In a variety trial K1 yielded 53 per cent. of K3 yield.

M=Mimosa invisa.

P.c.=Phaseolus calcaratus.

Table 2B.—Soil Exhaustion Trial Yield Data, First 10 Plantings.
Mean Wt. Tubers/Plot (lb.).

No. of Successive Crops (Variety K1).											
Treatment.	1	2	3	4	5	6	7	8	9	10	
1	266†	213†	114†	163†	Nil	335	181	208	134	56	
2	254†	117†	175†	Nil	355	193	232	132	71	....	
3	109†	194†	Nil	379	207	228	158	67	....	....	
4	238†	Nil	416	212	226	124	76	....	....	....	
Mean	217†	175†	235*	251*	263	220	162	136	103	56	

* Means derived from addition of K1 and adjusted K3 yields.

† Means adjusted from K3 yields.

No. of Successive Crops (Variety K3).					
Treatment.	1	2	3	4	5
1	502	402	215	307	Nil
2	480	221	329	Nil	355†
3	205	366	Nil	379†	207†
4	449	Nil	416†	212†	226†
Mean	409	330	320*	299*	263†

* Means derived from addition of K1 and K3 yields.

† K1 yields.

Protoparce convolvulae and *Hippotion celerio*, occurred in varying degrees during the trial. A leaf scab similar to that caused by the fungus *Elsinoe batatas* was observed but was not positively identified. Giant African snails (*Achatina fulica*) caused minor damage to vines in the second planting, but were generally controlled with metaldehyde baits.

The variety K1 was able to resist the effects of 'little leaf virus' quite well, particularly if infected plants were rogued out. Varieties K1 and

K3 were both subject to a certain degree to damage from the other pests and diseases noted.

The effect of length of cropping period on sweet potato yields was established by analysis of the yield data for each treatment at a particular harvest (Table 2A). This analysis showed that the general downward trend in yields was due to increased periods of cropping in each treatment. Statistical significance for this effect was attained in only the fourth and sixth harvests, but the trend was positive to the eighth harvest. It became negative in the ninth harvest and positive again in the tenth.

A further analysis was carried out, to investigate the relationship between seasonal factors, soil fertility levels and yields. To facilitate the analysis, all K3 yields were converted to the equivalent yield of K1, using data obtained from field variety trials carried out on land adjoining the Soil Exhaustion Trial. This analysis was based on the assumption that the soil fertility would decline asymptotically to some low level



Plate II.—Unthrifty sweet potato crop in the Soil Exhaustion Trial, 10th planting.

at which yields would remain constant, a typical experience with exhaustion trials. The model fitted was :—

$$Y = S [1 - a (1 - e^{-kt})]$$

where

Y = yield

S = seasonal factors including pests and diseases

t = the number of the crop in the series

a and k are constants determined by the trend between the crops in the same year, but for the different durations for which the plots had been under sweet potato.

Omitting the yields from the third planting, where severe insect and disease infestation caused a distortion of the relative yields, the values of a and k were calculated :—

$$a = 0.472 \pm 0.059$$

$$k = 0.365 \pm 0.100$$

The indication is that if the seasonal effects remain constant, the relative yield would be $1 - a (1 - e^{-kt})$ in succeeding crops. The decrease in relative yield is shown in the graph in Figure 2A.

FIGURE 2A
SOIL EXHAUSTION TRIAL

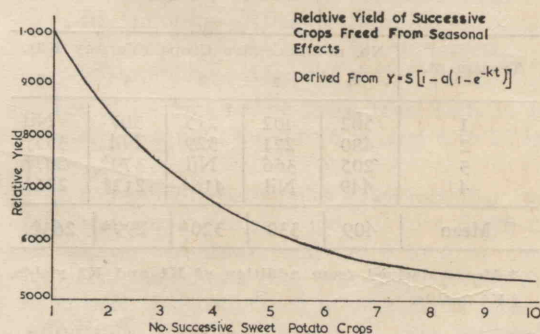
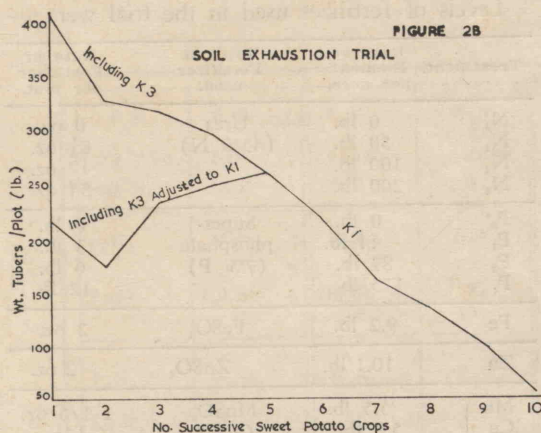


Figure 2B shows the actual yield curve recorded in the first ten plantings of the trial, and is derived from plot yields recorded after cumulative periods of successive sweet potato crops as set out in Table 2B.

Results of the analysis of soil samples collected at the first and fourth samplings are shown in Table 3. Unfortunately no other samples were analysed. Of more importance, no soil samples were collected after the 10th planting of the trial, when the soil was considered exhausted.



FERTILIZER STUDIES ON THE EXHAUSTED SOIL.

Having achieved exhaustion of the soil by continuous cropping with sweet potato, studies were undertaken to determine the fertilizer applications required to restore the soil to its original productive capacity.

Pot test.

As a preliminary study, a pot test was carried out in the laboratory with a composite sample of soil taken from all plots during the 10th planting of the Soil Exhaustion Trial. Sweet potato was the test plant and treatments were as follows:—

1. Control.
2. N.
3. NP.
4. NPK.
5. NPK + trace elements.
6. NPK + trace elements — Fe.
7. NPK + trace elements — Zn.

Trace elements were Fe, Mn, Zn, Cu, B, Mo, Co.

There were three replications of each treatment.

The only significant response of certainty was to the addition of P. It is possible that the absence of an N effect was due to mineralization of organic matter when the soil was disturbed during collection and potting.

Layout and Design of Field Trial.

After completion of the pot test and following the harvest of tubers from the tenth planting, a fertilizer trial was superimposed on the Soil Exhaustion Trial Plots. In this trial, fertilizers were applied to the eleventh and twelfth plantings of sweet potato.

To permit adequate replication of each of the fertilizer combinations tested, each of the sixteen plots of the Soil Exhaustion Trial was quartered as shown in Figure 3. Subdivision was thus into 64 plots, each 15 ft. by 14 ft. with an area of 1/207 acre.

The trial compared four levels of nitrogen and phosphorus in all combinations. Zinc and iron were also applied, singly, in combination and as nil treatments. An application of other minor elements, referred to as the Shotgun (Sh) mixture, was confounded with the blocks.

The sixteen combinations of nitrogen and phosphorus used in the trial resulted in application of these elements in the following ratios:—

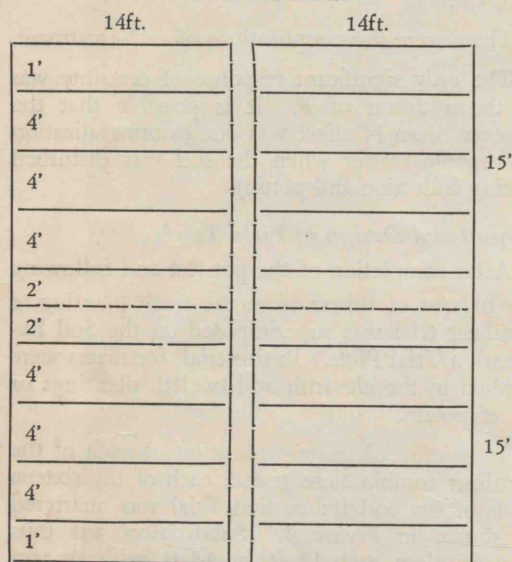
N_4P_1	1 level at 4 : 1.
N_4P_2 N_2P_1	2 levels at 2 : 1.
N_1P_1 N_2P_2 N_4P_4	3 levels at 1 : 1.
N_1P_2 N_2P_4	2 levels at 1 : 2.
N_1P_4	1 level at 1 : 4.

Table 3.—Soil Analysis.

Soil Analyses of first and fourth samplings—Means of four Plots.

	pH.	Specific Conductivity (Mhos ^{cm}).	Available P (Olsen) p.p.m.	C% Walkley Black).	N%	C/N.	Exchangeable Cations (m.e. %).			K/N.	Exchange Capacity (m.e. %).
							Ca.	Mg.	K.		
Sampling 1	6.8	83	8	2.6	0.465	10.6	17.5	1.8	1.15	2.5	19.9
Sampling 4	6.4	85	12	4.9	0.301	8.5	17.4	2.1	1.03	3.7	
	***	***	***	***	***	***				**	
Difference	0.433	—2.9	—4.0	2.34	0.164	2.12	0.17	—0.46	0.12	—1.19	

Figure 3.—Subdivision of 30 ft. x 30 ft. Plot into Four Sub-Plots.



A 1 : 2 ratio of nitrogen and phosphorus is commonly quoted for sweet potato cultivation in various parts of the world.

Other combinations of nitrogen and phosphorus which were applied in addition to the N_0P_1 , N_0P_2 , N_0P_4 , and P_0N_1 , above were N_0P_0 , P_0N_2 , and P_0N_4 .

The layout of the plots and the treatment combinations used are shown in Figure 4.

Procedure.

As before, sweet potato runners were cut into one-foot lengths, three of which were planted in each hole. Each hole was at one foot spacing in the row and there were four hilled rows per plot, each fourteen feet long, and each supporting fourteen sweet potato plants.

Sweet potato variety K1, as used in the last five plantings of the exhaustion phase of the Soil Exhaustion Trial, was planted.

The fertilizers used in the minor element mixture were ground and mixed with approximately one pound of river sand before being added to the rest of the fertilizer to be applied to each plot. Where the total fertilizers to be added to a plot were too small for even distribution, sawdust was used as a spreader.

Levels of fertilizer used in the trial were :—

Treatment.	Rate of Element per acre.	Type of Fertilizer used.	Rate of Fertilizer per plot.
N_0	0 lb.	Urea	0 oz.
N_1	50 lb.	(45% N)	8½ oz.
N_2	100 lb.		17 oz.
N_4	200 lb.		34 oz.
P_0	0 lb.	Super-phosphate	0 lb.
P_1	44 lb.	(7% P)	3 lb.
P_2	87 lb.		6 lb.
P_4	175 lb.		12 lb.
Fe	9.2 lb.	$FeSO_4$	2 oz.
Zn	10.1 lb.	$ZnSO_4$	2 oz.
Mn	5.5 lb.	$MnSO_4$	1 1/5 oz.
Cu	5.0 lb.	$CuSO_4$	1 oz.
B	2.2 lb.	H_3BO_3	1 oz.
Co	4.8 lb.	$CoSO_4$	1 oz.
Mo	0.54 lb.	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	2 gm.

Sh = Mixture of Minor Elements.

In the eleventh planting, full fertilizer treatments were applied to each plot prior to planting. For application, sweet potato hills were first built up to a height of approximately four inches, the fertilizer mixture was spread along the tops of the partially completed hills and hilling was then completed.

In the twelfth planting, sweet potato was planted one month before any fertilizer application was made and fertilizer was applied in three equal split applications, which together were equivalent to the full fertilizer dressing of the eleventh planting. Applications were made when the crop was one month, three months and five-and-a-half months old, the crop being harvested when seven months old.

Leaf samples were collected from all plots periodically during both plantings. During the eleventh planting, four samplings were made for studies of leaf sampling techniques for sweet potato. During the twelfth planting, six leaf samplings were made, the first being twelve weeks after planting and the remainder at monthly intervals until the crop was harvested. The first, second and third mature leaves were collected from eight randomly selected vines per plot and all leaves from the four replicates of each N : P treatment were bulked.

Soil samples were collected at the completion of the twelfth harvest, the sampling procedure used being the same as that described earlier. The 0 to 6 in. and 6 to 12 in. samples were

FIGURE 4

P ₀ N ₁ FeZnSh Plot No.1	P ₄ N ₁ Nil 2	P ₁ N ₂ FeZnSh 3	P ₂ N ₀ ZnSh 4	P ₁ N ₄ FeZnSh 5	P ₄ N ₁ FeZn 6	P ₄ N ₂ Nil Sh 7	P ₄ N ₄ Fe 8
P ₄ N ₂ FeSh 16	P ₁ N ₄ Nil Sh 15	P ₀ N ₀ × Nil Sh 14	P ₀ N ₄ Fe 13	P ₄ N ₀ ZnSh 12	P ₀ N ₂ Fe 11	P ₁ N ₂ Zn 10	P ₁ N ₁ FeSh 9
P ₄ N ₄ ZnSh 17	P ₂ N ₂ Nil 18	P ₁ N ₁ Zn 19	P ₁ N ₀ Fe 20	P ₂ N ₀ FeSh 21	P ₀ N ₁ ZnSh 22	P ₂ N ₂ FeZnSh 23	P ₂ N ₄ Zn 24
P ₄ N ₀ FeZn 32	P ₀ N ₂ Zn 31	P ₂ N ₁ FeSh 30	P ₂ N ₄ FeZn 29	P ₂ N ₁ Nil 28	P ₁ N ₀ Nil 27	P ₀ N ₄ Nil Sh 26	P ₀ N ₀ × FeZn 25
P ₁ N ₀ FeZnSh 33	P ₄ N ₄ Nil 34	P ₂ N ₄ FeSh 35	P ₂ N ₀ Nil 36	P ₄ N ₁ FeSh 37	P ₁ N ₂ Nil Sh 38	P ₁ N ₄ Fe 39	P ₂ N ₁ ZnSh 40
P ₄ N ₁ ZnSh 48	P ₁ N ₂ Fe 47	P ₂ N ₁ FeZn 46	P ₀ N ₂ Nil Sh 45	P ₂ N ₀ FeZn 44	P ₀ N ₀ FeSh 43	P ₁ N ₀ ZnSh 42	P ₀ N ₄ Zn 41
P ₄ N ₂ FeZn 49	P ₁ N ₄ Zn 50	P ₀ N ₄ FeZnSh 51	P ₀ N ₀ × Zn 52	P ₄ N ₂ Zn 53	P ₂ N ₄ NilSh 54	P ₀ N ₂ FeZnSh 55	P ₀ N ₁ Nil 56
P ₁ N ₁ Nil Sh 64	P ₂ N ₂ ZnSh 63	P ₀ N ₁ Fe 62	P ₄ N ₀ FeSh 61	P ₂ N ₂ Fe 60	P ₄ N ₀ Nil 59	P ₄ N ₄ FeZnSh 58	P ₁ N ₁ FeZn 57

Figure 4.—Trial on Rejuvenation of Exhausted Soil Superimposed on the Soil Exhaustion Trial.

bulked for each of the sixty-four plots, thoroughly mixed, and a one quarter subsample prepared for analysis. This was labelled the 13th soil sampling.

Results.

11th Planting.

A summary of sweet potato tuber yields from all plots in the 11th planting is shown in Table

4. These figures do not indicate any significant response to the elements applied other than a negative response to nitrogen. It was thought that the lack of positive response may have been caused by leaching. The trial was therefore repeated using three equal split applications of fertilizer, each one equivalent to a third of the original application.

Table 4.—Mean Treatment Yields—11th Planting (lb./Plot).

—	Po.	P1.	P2.	P4.	Mean.
N ₀	23	22	23	24	23
N ₁	18	18	25	25	22
N ₂	21	21	17	20	20
N ₄	13	16	16	12	14
Mean	19	19	20	20	20

No responses from Fe, Zn or Sh treatments.

N₁+N₂ 39 39 42 45
Results of analyses carried out on the first four lots of leaf samples collected are not considered because of variations in sampling technique.

12th Planting.

A summary of yields from the 12th planting is shown in Table 5. Table 6 shows the variation in levels of leaf nitrogen, phosphorus, potassium and calcium as the crop aged.

Table 5.—Mean Treatment Yields—12th Planting (lb./Plot).

—	Po.	P1.	P2.	P4.	Mean.
N ₀	39	34	34	39	37
N ₁	33	24	35	30	31
N ₂	30	28	27	28	28
N ₄	24	26	25	18	23
Mean	32	28	30	29	30

No responses from Fe, Zn or Sh treatments.

A summary of soil analyses for the 13th sampling is shown in Table 7.

During the 12th planting, visual appraisals were made on the vigour of sweet potato on all plots, when the crop was 10 weeks and 28 weeks old. Points were allotted to each plot according to the following scale:—

Good 2 points;
Fair 1 point; and
Poor 0 point.

Plot means of these points according to nitrogen and phosphorus treatments were as follows:—

Crop 10 weeks				Crop 28 weeks.			
N ₀	0.1	P ₀	1.1	N ₀	0.1	P ₀	1.1
N ₁	0.9	P ₁	1.1	N ₁	0.9	P ₁	1.1
N ₂	1.3	P ₂	1.1	N ₂	1.4	P ₂	1.0
N ₄	2.0	P ₄	1.0	N ₄	1.9	P ₄	1.2

Insect and disease attack during the 11th and 12th plantings was minor, and similar to that on sweet potato variety K1 during the 6th to 10th plantings of the trial.

Table 6.—Leaf Analyses from 12th Planting. Percentage Oven Dry Basis.

Weeks After Planting.		N.	P.	K.	Ca.
4	1/3 Fertilizer Application				
7	P ₀	4.86	0.51	2.78	0.42
	P ₁	5.07	0.56	2.80	0.42
	P ₂	4.96	0.55	2.90	0.45
	P ₄	4.79	0.62	3.14	0.57
	N ₀	4.06	0.54	3.11	0.47
	N ₁	4.87	0.54	2.85	0.47
	N ₂	5.28	0.57	2.90	0.44
	N ₄	5.47	0.58	2.76	0.50
12	P ₀	3.99	0.52	2.84	0.54
	P ₁	4.04	0.55	2.55	0.56
	P ₂	3.91	0.59	2.09	0.57
	P ₄	3.92	0.62	2.82	0.57
	N ₀	4.20	0.61	2.98	0.55
	N ₁	3.94	0.57	2.69	0.58
	N ₂	3.79	0.54	2.59	0.58
	N ₄	3.92	0.55	2.54	0.53
14	1/3 Fertilizer Application				
16	P ₀	4.53	0.48	2.56	0.54
	P ₁	4.65	0.56	2.72	0.58
	P ₂	4.66	0.56	2.54	0.62
	P ₄	4.77	0.59	2.66	0.59
	N ₀	4.06	0.55	2.64	0.47
	N ₁	4.59	0.55	2.57	0.58
	N ₂	4.82	0.54	2.63	0.63
	N ₄	5.13	0.55	2.64	0.65
21	P ₀	3.94	0.53	2.48	0.72
	P ₁	3.87	0.54	2.40	0.91
	P ₂	3.81	0.61	2.45	0.74
	P ₄	3.80	0.61	2.55	0.63
	N ₀	3.86	0.58	2.53	0.75
	N ₁	3.59	0.58	2.42	0.80
	N ₂	3.82	0.55	2.55	0.73
	N ₄	4.15	0.56	2.38	0.71
23	1/3 Fertilizer Application				
25	P ₀	4.46	0.56	3.01	0.82
	P ₁	4.48	0.55	2.72	0.66
	P ₂	4.51	0.56	2.55	0.50
	P ₄	4.68	0.60	2.67	0.48
	N ₀	4.01	0.57	2.76	0.61
	N ₁	4.48	0.59	2.75	0.65
	N ₂	4.70	0.55	2.69	0.60
	N ₄	4.95	0.56	2.74	0.61
30	P ₀	3.82	0.43	1.87	0.45
	P ₁	3.68	0.45	2.02	0.45
	P ₂	3.41	0.45	2.03	0.46
	P ₄	3.64	0.50	2.02	0.46
	N ₀	3.40	0.50	2.12	0.48
	N ₁	3.54	0.46	2.08	0.43
	N ₂	3.40	0.46	1.93	0.45
	N ₄	3.96	0.42	1.82	0.46

Compared to table in Cihes + Samuels (1957), N is higher, P is right, K is right (v. variable for Cihes + Sam.).

Table 7.—Means of Soil Analyses of 13th Sampling according to N and P Treatments.

Treatment.	pH	Specific Conductivity (mhos x 10 ⁶)	Available P Olsen (p.p.m.)	C % Walkley Black	N %	C/N	Exchangeable Ca m.e. %	Exchangeable Mg m.e. %	Exchangeable K m.e. %	K/N	Exchange Capacity m.e. %
P ₀	6.4	116	4	4.6	.474	9.6	16.1	2.4	0.63	1.4	19.7
P ₁	6.4	148	8	4.7	.481	9.7	17.3	2.4	0.62	1.3	20.9
P ₂	6.3	173	10	4.4	.463	9.4	16.8	2.5	0.62	1.4	20.4
P ₄	6.2	242	21	4.1	.440	9.4	17.2	1.8	0.62	1.5	19.9
N ₀	6.4	160	11	4.3	.422	10.3	17.1	2.8	0.65	1.6	20.6
N ₁	6.4	157	10	4.5	.472	9.4	17.6	2.7	0.63	1.4	21.2
N ₂	6.2	178	11	4.4	.483	9.1	15.9	1.8	0.62	1.3	19.1
N ₄	6.2	185	12	4.5	.482	9.4	16.7	1.9	0.59	1.2	20.0

Average A statistical analysis of the yields of the 11th and 12th plantings showed that the only significant response to the fertilizer treatments applied was a negative yield response to nitrogen.

DISCUSSION.

Plantings 1 to 10.

There was a trend for yield to decline rapidly as cropping with sweet potato continued (Figure 2B). The effects of adjusting K3 yields to 'equivalent' K1 yields have distorted the curve, so that it seems probable that the conversion factor of 53 per cent. is incorrect. Even if the factor were correct under the conditions of the variety trial, it apparently did not hold under the range of conditions experienced during the first five plantings of the Soil Exhaustion Trial.

The significant yield declines recorded between treatments at the fourth and sixth trial harvests indicate that at least part of the decline was attributable to length of cropping with sweet potato. The indication is also that the leguminous cover crops used during the first three plantings of the Trial had the effect of maintaining soil fertility better than did sweet potato cropping.

Factors which may have been responsible for the rapid decline in yields of all treatments are:—

1. *Change in climate.*—Apart from normal weather variations there was no evidence of consistent change for worse in climate at the site over the period of the trial.
2. *Weed Infestation.*—The trial plots were hand weeded constantly throughout the trial period. As sweet potato vigour declined,

the effort required to keep weeds in control increased. In general the plots were kept weed-free fairly successfully. It may be that in spite of the rigorous control programme, weed infestation contributed to sweet potato yield decline.

3. *Disease.*—Sweet potato 'little leaf virus' infected many plants and for this reason a change in sweet potato variety was necessary after the fifth harvest. The disease problem was quite serious throughout the trial despite control measures and it is probable that sweet potato yield decline resulted at least in part from disease infestations.
4. *Insect Damage.*—Insect attacks in general were a great problem throughout the trial. Continuous cropping with sweet potato, as well as constant proximity of sweet potato in other trials would have provided infection reservoirs. It is possible that insect attacks were a predominant cause of sweet potato yield decline in the trial.
5. *Soil Deterioration.*—Table 3 shows that between the 1st and 4th soil samplings (taken at 1st planting and 3rd harvest respectively) there were significant declines in pH, per cent. C, per cent. N and C/N ratio, while there were rises in available P and K/N ratio. These data would suggest that soil fertility may have declined during the first three plantings of the trial. The apparent rise in available phosphorus may have resulted from the phosphorus fixation in the soil of the first sampling between its collection in 1956 and analysis in 1962.

Spence & Ahmad. all leucis are high.



Plate III.—Sweet potato 'little leaf virus' and aphid leaf cure.

Statistical analysis of the soil chemical data indicated no difference between treatments, even though Treatment 4 had not yet been cropped with sweet potato. This would suggest that the leguminous cover crops used at the beginning of the trial had no chemical effect on the soil more beneficial than did sweet potato.

Removal of topgrowth after each crop of sweet potato would have added considerably to the nutrient drain on the soil. It would also have adversely affected the soil organic matter level. It has been shown that the soil at the trial site has a clay fraction of only about three per cent. It follows that the exchange capacity of the soil would be very dependent on its humus content. Thus removal of sweet potato topgrowth could have had a large effect on soil fertility.

It would be expected that leaching would account for heavy nutrient removal from such a light soil under the high rainfall conditions (110 in./annum).

Evidence of topsoil movement is dealt with under the discussion of Plantings 11 and 12.

Plantings 11 and 12.

Fertilizer trials were superimposed on the 11th and 12th plantings of the soil exhaustion trial to assess the hypothesis that sweet potato yield decline observed in the first ten plantings was due to nutrient stress.

The fertilizer trials failed to support the hypothesis in that the only significant treatment response was a depression in yield as nitrogen application increased. However, the results of the trials did not disprove the hypothesis, since potassium and magnesium treatments were not included. Potassium was omitted because of the high levels of total potassium previously recorded in the pumiceous soils at the site, and because of the lack of a potassium response in the pot trial. After the lack of response in the 11th Planting, it was thought that differential leaching may have affected the balance of nutrients applied. However, in spite of careful placement of split dressings in the 12th Planting, results were again similar to those of the 11th Planting.

Therefore no conclusions regarding the causes of sweet potato yield decline in the first ten plantings of the trial can be drawn as a result of the two fertilizer trials.

Results of chemical analyses of the soil sampled after the 12th Harvest (*Table 7*) show a marked increase in available P corresponding to phosphorus treatments. A similar trend occurred in specific conductivity. Soil exchangeable potassium levels are of the order of 0.6 m.e. per cent. It is considered that a level of available potassium of 0.4 m.e. per cent. is critical for sweet potato, with levels up to 0.8 m.e. per cent. being marginal. Thus it is uncertain from chemical analysis whether sweet potato would respond to potassium in this soil. It is possible that the negative yield response to nitrogen application was progressively enhanced by imbalance between available nitrogen and available potassium in the soil.

Statistical analysis of soil chemical data in *Table 7* showed highly significant differences between results recorded from each of the four block quarters of the trial (*Table 8*).

The strongest trend is from quarter 1 to quarter 4, with quarters 2 and 3 generally taking intermediate values. The strong trend in carbon towards quarter 4 would reflect accumulation of organic matter by surface wash. The low magnesium and potassium values for this quarter could be a result of heavy leaching at the area of organic accumulation. This pattern of chemical behaviour in the soil may be a result of surface levelling.

Leaf chemical analysis data (*Table 6*) show increased nitrogen uptake corresponding to urea application, while leaf phosphorus levels have not been greatly affected by superphosphate application.

The low leaf levels of N, P and K recorded in the 10th sampling are normal for maturing plants.

Leaf potassium levels are generally low, and appear to have been affected adversely by urea application. Since the only sweet potato yield response in the trial was a negative response to urea application, and since leaf potassium uptake

appears to have been depressed by the same fertilizer treatment, it could be postulated that the soil potassium status was sub-optimal and that it became critically limiting as the soil nitrogen status was raised.

Although these fertilizer trials failed to show the yield increase to be expected if nutrient stress were the cause of the yield decline observed over the first ten plantings, evidence of both soil and leaf chemical analysis left potassium as a suspected deficiency, particularly in relation to increased soil nitrogen levels. Factors other than nutritional deficiencies or imbalance, as listed in the discussion of the first ten plantings, may well have affected the sweet potato yield decline.

FURTHER INVESTIGATIONS.

The failure of fertilizers to restore yields of sweet potato in the 11th and 12th Plantings of the trial precluded the formulation of any conclusions concerning the cause of the yield decline. Despite this, a deterioration in soil fertility is the most likely factor responsible and future efforts will be directed at pot test studies of the soil as a forerunner to further fertilizer tests on the plots. The planning and design of these fertilizer tests will be guided by the indications from the pot tests and further soil analyses.

During the period in which pot tests will be carried out, the plots will be cropped continuously with sweet potato in an attempt to remove to the greatest degree possible the effects of previous fertilizer applications.

Should the next fertilizer trial fail to show any positive yield response to fertilizer applications, it should then be clear that some other factor has been responsible for the fall in yields, and a new approach to the problem may be necessary.

To provide a reserve of 'exhausted' soil for future studies a square 1.6 acre block has been planted to continuous sweet potato.

Table 8.—Means of Soil Analysis of 13th Sampling according to Trial Blocks.

Quarter.	pH	Spec. Cond.	Avail. P. (Olsen)	C _{org} (W.B.)	N%	C/N	Ca	Mg	K	K/N	Exch. Cap.
1	6.37	137	11.06	3.68	.427	8.59	16.31	3.18	0.68	1.62	20.40
2	6.28	172	9.88	4.31	.469	9.29	15.53	2.63	0.65	1.41	19.58
3	6.29	187	10.63	4.13	.446	9.34	15.76	1.44	0.58	1.32	17.98
4	6.37	184	11.69	5.61	.516	10.89	19.68	1.90	0.58	1.16	22.94
Difference		**		***	***	***	***	**	***	***	***

Average 6.33 170 10.82 4.43 .464 9.53 16.82 2.29 .62 1.38 20.22

PART II. THE THREE-COURSE ROTATION TRIAL.

DESIGN.

The trial was designed to compare seven different rotations, each with three replications in space. The basic block unit or 'series' therefore consisted of twenty-one plots and there were three of these series in the trial. Each series was a replication in time, so that seasonal effects on the results could be allowed for. The whole trial therefore comprised 7 rotations by 3 replications by 3 series = 63 plots.

A planting plan of the trial and the seven rotations tested are shown in Table 1.

From this it can be seen that Series A is two plantings (or phases) ahead of Series C in the rotation cycle, while Series C is two plantings ahead of Series B.

One cycle of the rotations takes approximately three years to complete.

For half of this three-year period, Rotations 1 and 2 have a cover-crop of *Mimosa invisa*, while Rotations 6 and 7 have a cover-crop of *Pueraria phaseoloides*. These four rotations are referred to as 'wide rotations'.

Rotation 3 has two separate three-month periods under *Phaseolus calcaratus*, while Rotations 4 and 5 have corresponding periods under peanuts, with either trash removed or trash returned respectively. For the remainder of the three-year cycle, plots in these rotations are under sweet potato and taro. These three rotations are referred to as narrow rotations.

Once in every three-year cycle all plots of a series have a sweet potato crop concurrently. Because of this and because the rotations in each series are at different stages (two crops apart), one of the series has sweet potato on all plots at every second planting of the whole trial. This allows comparisons between rotations at frequent intervals.

To summarize: within each series the seven rotations are replicated three times in a balanced incomplete block design. The three series were laid down contiguously in the field (Table 2).

LAYOUT AND PROCEDURE.

General.

After clearing, the site was ploughed twice with a sundercut plough and all debris removed.

Each plot was thirty ft. square and strips five ft. wide were left between plots.

SWEET POTATO (*Ipomoea batatas*) was planted on ridges spaced four feet apart and there were eight ridges or rows per plot. The planting material consisted of runners cut into lengths of approximately eighteen inches.

Three cuttings each were planted in holes one foot apart within rows. The sweet potato variety used, numbered K 1 in the Keravat collection, matures in about seven months. When plots were harvested, weights of tuber yield per plot were recorded and tubers and vine growth were removed from the plots.

TARO (*Colocasia antiquorum*) was planted at a three feet square spacing which gave one hundred positions per plot. As is customary in the planting of taro, offshoots of parent plants were used. The variety numbered K 12 in the Keravat collection was planted. At harvest, the number of plants and the weight of tubers per plot were recorded. Following harvest, tubers and top growth were removed from the plots. K 12 matures in approximately eight months.

PEANUTS (*Arachis hypogaea*) were planted in rows two ft. apart, with a nine-inch spacing within the rows. This gave 600 positions per plot. The variety Red Spanish was used for the first cycle of the trial, but was replaced by Schwarz 21 in the second cycle, because of susceptibility of Red Spanish to the fungus *Sclerotium rolfsii*. Also, in the second cycle, the practice of returning peanut crop trash to the plots in Rotations 1, 2, 5, 6, and 7 was discontinued in an effort to reduce the build-up of this crown rot fungus. Thus, all P+ treatments in the first cycle became P— treatments in the second cycle. At each peanut harvest, the number of plants per plot, and the yield per plot of peanuts in the shell were recorded. For both varieties, maturity was reached in about three months.

SORGHUM (*Sorghum vulgare*) was planted in drills eighteen inches apart. When the crop reached about six in. in height, plants were thinned to a six-in. spacing within the row. The variety known locally as Red Sorghum was used throughout the trial. During the first cycle when sorghum was grown, one crop only was planted, and the trash was left to lie on the plots until the corresponding taro crop in the same planting had been harvested. In the second cycle sorghum plots were retained under crop

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Table 1.—Three-Course Rotation Trial Planting Plan—Keravat.

	Series A.						
Rotation No.	1	2	3	4	5	6	7
Planting No. 1	SP	SP	SP	SP	SP	SP	SP
Planting No. 2	To	So	To	To	To	To	So
Planting No. 3	P+	P+	Ph	P—	P+	P+	P+
Planting No. 4	M	M	SP	SP	SP	Pu	Pu
Planting No. 5	M	M	To	To	To	Pu	Pu
Planting No. 6	M	M	Ph	P—	P+	Pu	Pu

	Series B.						
Rotation No.	1	2	3	4	5	6	7
Planting No. 1	M	M	To	To	To	Pu	Pu
Planting No. 2	M	M	Ph	P—	P+	Pu	Pu
Planting No. 3	SP	SP	SP	SP	SP	SP	SP
Planting No. 4	To	So	To	To	To	To	So
Planting No. 5	P+	P+	Ph	P—	P+	P+	P+
Planting No. 6	M	M	SP	SP	SP	Pu	Pu

	Series C.						
Rotation No.	1	2	3	4	5	6	7
Planting No. 1	P+	P+	Ph	P—	P+	P+	P+
Planting No. 2	M	M	SP	SP	SP	Pu	Pu
Planting No. 3	M	M	To	To	To	Pu	Pu
Planting No. 4	M	M	Ph	P—	P+	Pu	Pu
Planting No. 5	SP	SP	SP	SP	SP	SP	SP
Planting No. 6	To	So	To	To	To	To	So

M = *Mimosa invisa* SP = Sweet potato (*Ipomoea batatas*) P+ = Peanuts (*Arachis hypogaea*)—trash returned
 Ph = *Phaseolus calcaratus* To = Taro (*Colocasia esculenta*)
 Pu = *Pueraria phaseoloides* So = Sorghum (*Sorghum vulgare*) P— = Peanuts—trash removed.

Table 2.—Layout Three-Course Rotation Trial.

Rotation.	Rotation.	Rotation.	Rotation.	Rotation.	Rotation.	Rotation.	
7	5	6	3	6	4	2	S e r i e s B
1	7	1	7	4	3	1	
3	6	2	5	4	2	5	
6	1	2	3	1	5	6	S e r i e s A
2	3	4	3	7	4	1	
7	5	2	6	4	5	7	
1	7	1	6	4	2	5	S e r i e s C
3	3	6	5	3	1	7	
4	6	2	7	5	2	4	

for the full period of the corresponding taro crop. Yields of all crops were recorded, and in the second cycle, crop residues were removed from the plots. Crops matured in about ten weeks.

MIMOSA INVISA AND *PUERARIA PHASEOLOIDES* seed were drilled in rows four feet apart and, as with the sweet potato, there were eight rows per plot. Both cover crops were continued over the three plantings indicated in Table 1 and were thus retained on the plots for about eighteen months. At the end of this period, when crops in the other rotations had been harvested, *Mimosa* and *Pueraria* were slashed, allowed to dry on the plots, and then turned under.

PHASEOLUS CALCARATUS was planted by seed in drills fifteen inches apart, and the plants were later thinned to a six-in. spacing. At the conclusion of the corresponding peanut crop, *P. calcaratus* was slashed, allowed to dry on the plots, and then turned under.

Soil Samples.

Soil samples were collected at various stages through the trial for chemical analysis. In all, eight samplings were made as follows:—

1st Sampling. Prior to the first planting, first cycle.

2nd Sampling. After the first harvest, first cycle.

3rd Sampling. After the second harvest, first cycle.

4th Sampling. After the third harvest, first cycle.

5th Sampling. After the fourth harvest, first cycle.

6th Sampling. After the fifth harvest, first cycle.

7th Sampling. After the sixth harvest, first cycle.

8th Sampling. After the first harvest, third cycle.

Unfortunately, no sampling was made at the end of the second cycle, but the eighth sampling, made after the first planting, third cycle, was quite useful for comparative purposes.

In the first seven samplings, soil samples were taken from depths of 0 in.-6 in. and 6 in.-12 in., ten samples at each depth being taken from each plot. A two-inch diameter pipe was hammered into the soil to a depth of six inches, withdrawn, and the 0 in.-6 in. core removed. A similar pipe was inserted into the same hole, hammered in another six inches, withdrawn and the 6 in.-12 in. core removed. The ten samples from

each depth from each plot were bulked, dried, and one pound subsamples prepared. These were bagged and labelled for subsequent analysis. In the 8th sampling, ten one-inch auger samples were collected 0 in.-12 in. from each plot. These samples were then bulked for each rotation within a series, and the composites used for chemical analysis.

RESULTS.

Summaries of the yields of the various crops are shown in *Tables 3 to 6*, while yield trends are shown graphically in *Figures 1 to 4*.

Table 7 shows the summary of results of chemical analyses of the 1st and 8th soil samplings. In the 1st soil sampling, samples were collected separately from each plot from depths of 0 in.-6 in. and 6 in.-12 in., and bagged separately. However, because of the mixing of the surface 12 in. of soil by cultivation during the seven year period over which the first two cycles extended, it was decided by the time the 8th sampling was taken that a 0 in.-12 in. sample would give more accurate results. It was necessary therefore to mix equal volumes of the 0 in.-6 in. and 6 in.-12 in. plot samples of the first sampling to form composite plot samples for analysis and direct comparison with results from the 8th sampling. One other difference between comparative sets of figures in *Table 7* should also be noted. Results for a particular rotation at the first sampling have been derived by calculating the arithmetic mean of results from the individual plots of that rotation, whereas results for the 8th sampling are from samples bulked from all crops in a rotation.

Assays could not be performed on the first sampling of Rotations 6 and 7 of Series B. These samples were inadvertently lost.

DISCUSSION.

Yield Trends.

An examination of the yield responses of the different crops to the various rotations suggests that yield trends over a period of time are different between crops. Possible causes for these differences are :—

1. Differences between species in reaction to nutrient stress ;
2. Differences between species in reaction to diseases, insect pests or weather ; and
3. Different soil conditions at different phases of the rotations.

It was considered unprofitable at this relatively early stage of the trial, to analyse yield trends statistically. However, the graphs of yields versus planting number (*Figures 1, 2, 3 and 4*) show that the general trend for sweet potato and taro yields is definitely downwards, while peanut and sorghum yields appear to be holding.

For the present, however, the main effects to be considered are the reactions of individual crops to the different rotations in which they are grown.

For convenience in *Tables 3 to 6*, crops are distinguished by number according to their sequence of planting as in Series A, viz. :—

First Crop	.....	.....	sweet potato.
Second Crop	.....	.....	taro or sorghum.
Third Crop	.....	.....	peanuts.
Fourth Crop	.....	.....	sweet potato.
Fifth Crop	.....	.....	taro.
Sixth Crop	.....	.....	peanuts.

Sweet Potato.

From *Table 1* it can be seen that all rotations of a series come into a crop of sweet potato at the same time and these simultaneous sweet potato plantings therefore serve as the main basis for comparison of rotation effects. From *Figure 1* it can be seen that there was very little difference between the yields of sweet potato in the various rotations until the third and fifth plantings of the second cycle when the superiority of the wide rotations became apparent. At this stage the mean yield for all four wide rotations was superior to the mean yield for the three narrow rotations. Further, within the wide rotations, the mean of rotations 6 and 7 (*Pueraria*) was superior to the mean of Rotations 1 and 2 (*Mimosa*). This result may be due to the fact that *Mimosa* is a coarser plant than *Pueraria*, taking longer to rot and release its nutrients. It also appears to have much less leaf litter than *Pueraria*. Rotting *Mimosa* may even lock up nitrogen from the soil more than the rotting *Pueraria*.

The superiority of the wide rotations was not so marked at the beginning of the third cycle and if mean yields for the wide and narrow rotations continue to approach each other it would suggest that other effects, e.g. soil nutrient deficiencies, are negating any advantageous effects of the legume cover.

Table 3.—Sweet Potato Yields (lb. per acre).

	Planting	First Cycle.						Second Cycle.						Third Cycle.
		1	2	3	4	5	6	1	2	3	4	5	6	1
Rotation	First Crop :													
	Series :	A		B		C		A		B		C		A
	Fourth Crop :													
	Series :		C		A		B		C		A		B	
1		17956		24926		17969		12745		16569		11293		8244
2		19408		24119		16424		13520		15101		14423		7139
Mean		18682		24523		16897		13133		15835		12858		7692
6		18360		27104		14810		15617		20034		17440		6042
7		18650		31202		14746		15085		20054		17295		6703
Mean		18505		29153		14778		15351		20054		17367		6373
3		18490	5308	25764	3275	15795	11003	14520	12552	13568	5001	14585	6760	4550
4		23022	6469	24861	3759	13713	15601	15278	13665	9712	7260	7567	6276	5066
5		19731	7631	21570	2952	16537	14068	14213	14617	9906	6502	10995	4533	6816
Mean		20414	6469	24065	3329	15348	13557	14670	13611	11062	6254	11049	5856	5477
Variance Ratios	Grouped Rotations	1.16		3.65		0.32	***	6.17*		16.85**		17.81***		2.24
	Ungrouped Rotations	1.21	0.53	1.87	0.25	0.21	16.16	2.47	0.82	6.21**	2.31	9.31***	1.95	1.21
L.S.D. Between Rotations	{ 5%						2013			5211		3708		
	{ 1%						3310			7222		5139		
L.S.D. Between 1, 2, & 6, 7	{ 5%							1400		3685		2622		
	{ 1%							1941		5107		3634		
L.S.D. Between 1, 2 or 6, 7 & 3, 4, 5	{ 5%							1278		3364		2394		
	{ 1%							1771		4662		3317		

Table 4.—Taro Yields (lb. per acre).

	First Cycle.						Second Cyc.e.						Third Cycle.	
	Planting	1	2	3	4	5	6	1	2	3	4	5	6	1
Rotations	Second Crop :													
	Series :	A		B		C		A		B		C		
	Fifth Crop :													
	Series :	B		C		A		B		C		A		B
1			5017		6211				4130		5227		1823	
6			4227		7099				3227		4130		1468	
3		3372	4082		5953	5517		3275	2049	2581	3516	2097	1323	1791
4		4178	3888		6550	6018		4001	2726	3646	2694	2759	1613	1033
5		4130	4517		5227	5227		4356	2839	3533	2274	3275	1823	984
Mean		3893	4162		5910	5587		3877	2538	3253	2828	2710	1586	1269
Variance Ratios	Grouped Rotations		1.05		1.96				11.78**		7.06*		0.44	
	Ungrouped Rotations	2.82	0.72		1.79	1.77		1.25	6.98**	10.45*	4.13*	3.76	0.64	17.61*
L.S.D. Between Rotations	5%								911	626	1821			373
	1%								1295	949	2588			565
L.S.D. Between 1 or 6 & 3, 4, 5	5%								744		1487			
	1%								1057		2113			

Table 5.—Sorghum Yields (lb. per acre).

	First Cycle.				Second Cycle.		
	Planting	2	4	6	2	4	6
Rotation	Second Crop : Series :	A	B	C	A	B	C
2		1468	2323	1000	1234	1129	2081
7		1613	2823	1186	984	1226	1758
Variance Ration		0.37	1.82	0.98	1.61	0.36	2.37

Table 6.—Peanut Yields (lb. per acre).

	First Cycle.						Second Cycle.						Third Cycle.	
	Planting	1	2*	3*	4	5	6	1	2	3	4	5	6	1
Rotation	Third Crop : Series :	C		A		B		C		A		B		C
	Sixth Crop : Series :		B		C		A		B		C		A	
1		2517				1678		2823		2678		2404		1710
2		2743				1888		2888		3620		2210		1800
Mean		2630				1783		2855		3154		2307		1605
6		2952				1581		2791		2839		2710		1533
7		2662				1662		2501		2727		3211		1517
Mean		2807				1621		2646		2783		2960		1525
4		2952			1129	1726	855	2517	2469	2678	1823	2388	2113	1517
5		2807			1033	1549	823	2549	2404	2888	1855	2517	1839	1517
Mean		2880			1081	1637	839	2533	2436	2783	1839	2452	1976	1517
Variance	Grouped Rotations Ungrouped Rotations	1.05				1.53		6.28*		0.83		3.16		0.79
Ratios		0.94			0.91	1.41	0.25	3.56	0.43	1.21	0.03	1.68	2.17	0.68
L.S.D. Between	Grouped Ro- tations	5%						202						
		1%						282						

* Crop destroyed by "Sclerotium rolfsii"

Table 7.—Summary of Chemical Analyses of Soils.

	pH	EC mhos x 10 ⁶	Olsen P ppm	C % (Walkley Black)	N %	Exchangeable Cations (m.e. %)			Exch. Cap. (m.e. %)	K/N	C/N
						Ca	Mg	K			
Rotations 1 and 2											
1st Sampling Means	6.6	122	4	6.0	0.635	18.3	2.4	1.24	24.8	2.2	10.6
8th Sampling Means	6.2	135	8	6.0	0.551	16.1	1.9	0.75	23.4	1.5	11.2
Rotations 6 and 7											
1st Sampling Means	6.6	128	5	5.9	0.591	21.3	2.8	1.41	27.0	2.4	9.9
8th Sampling Means	6.2	133	7	5.6	0.519	15.4	2.0	0.75	24.3	1.5	10.9
Rotations 3, 4 and 5											
1st Sampling Means	6.3	109	3	6.2	0.579	15.4	2.5	1.19	24.3	2.0	10.6
8th Sampling Means	6.2	123	7	5.3	0.486	15.3	1.9	0.61	21.5	1.3	11.1

SWEET POTATO

FIGURE 1

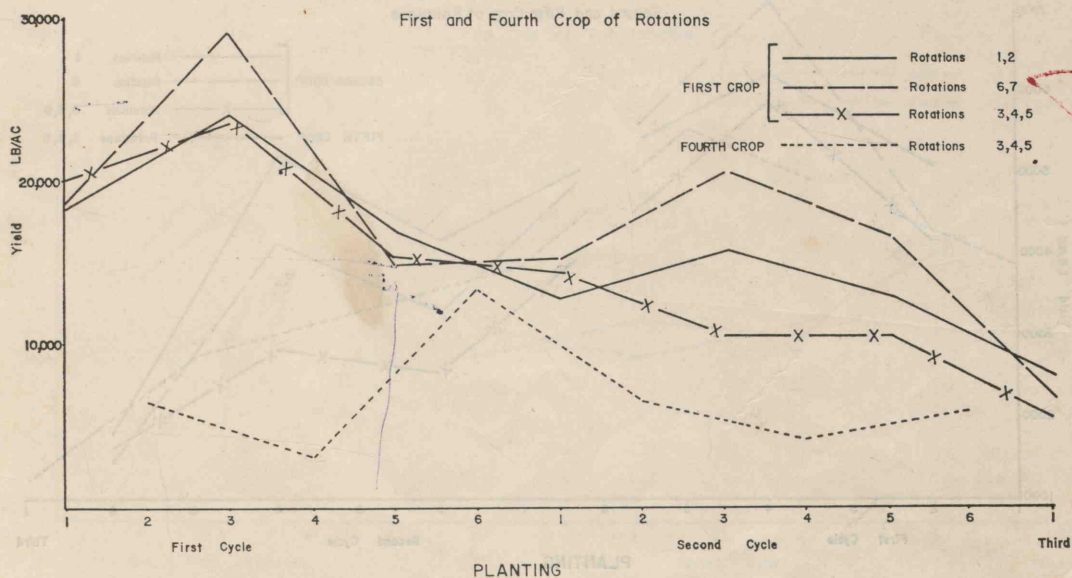
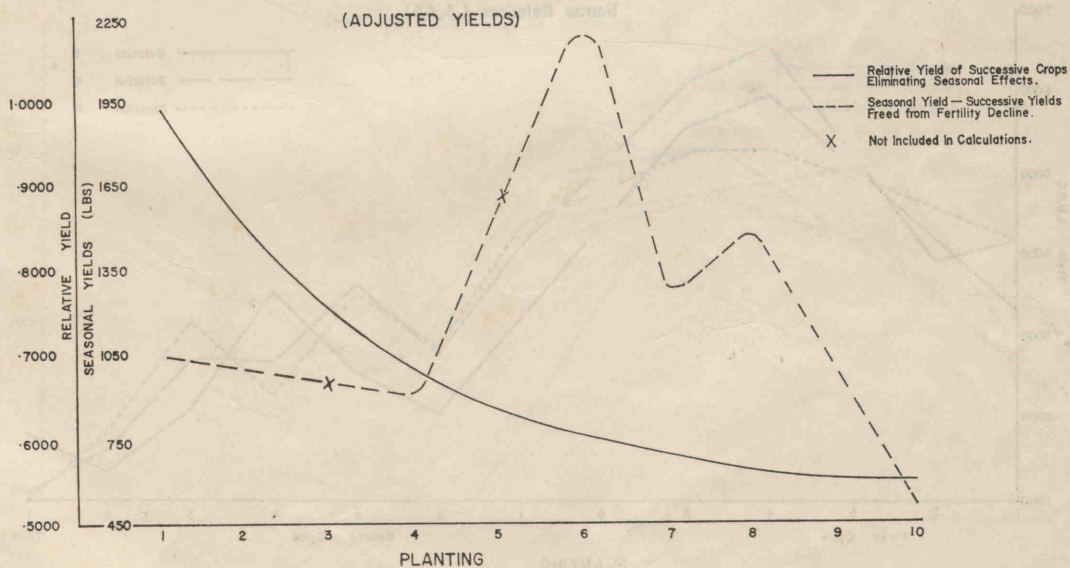
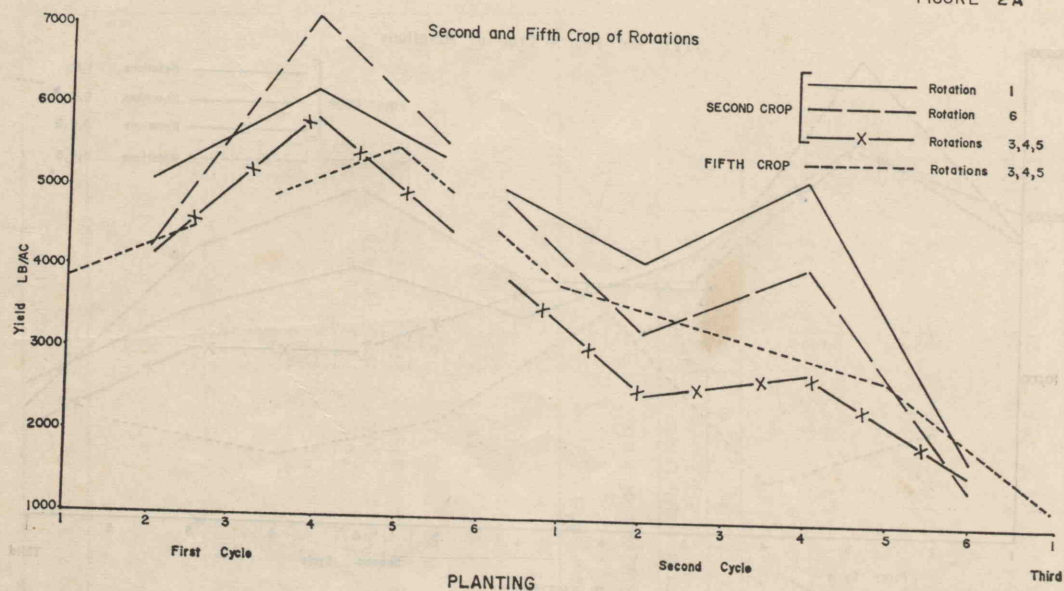


Figure 2



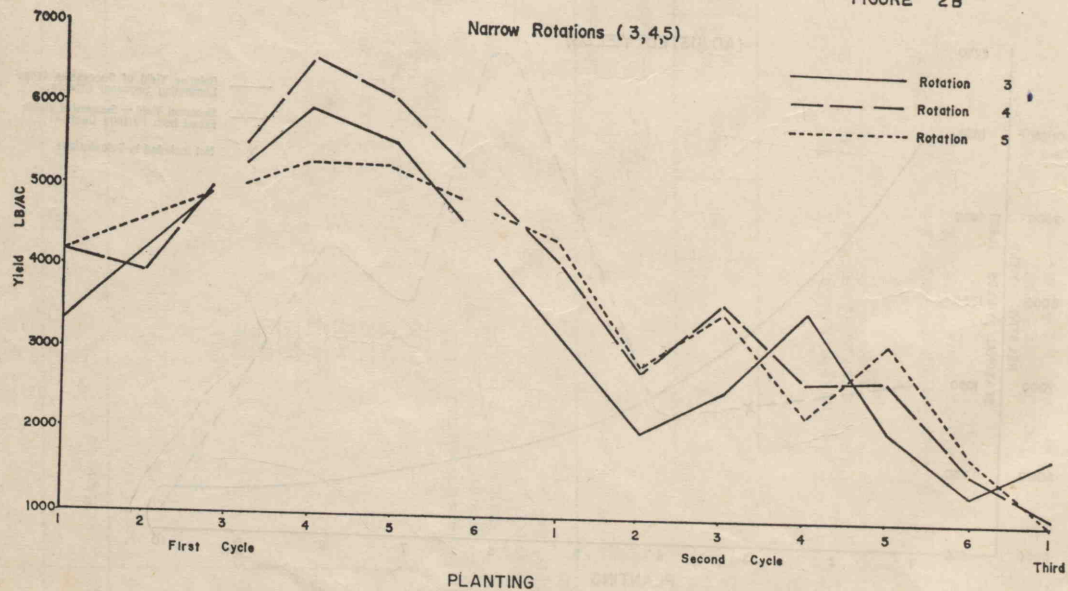
TARO

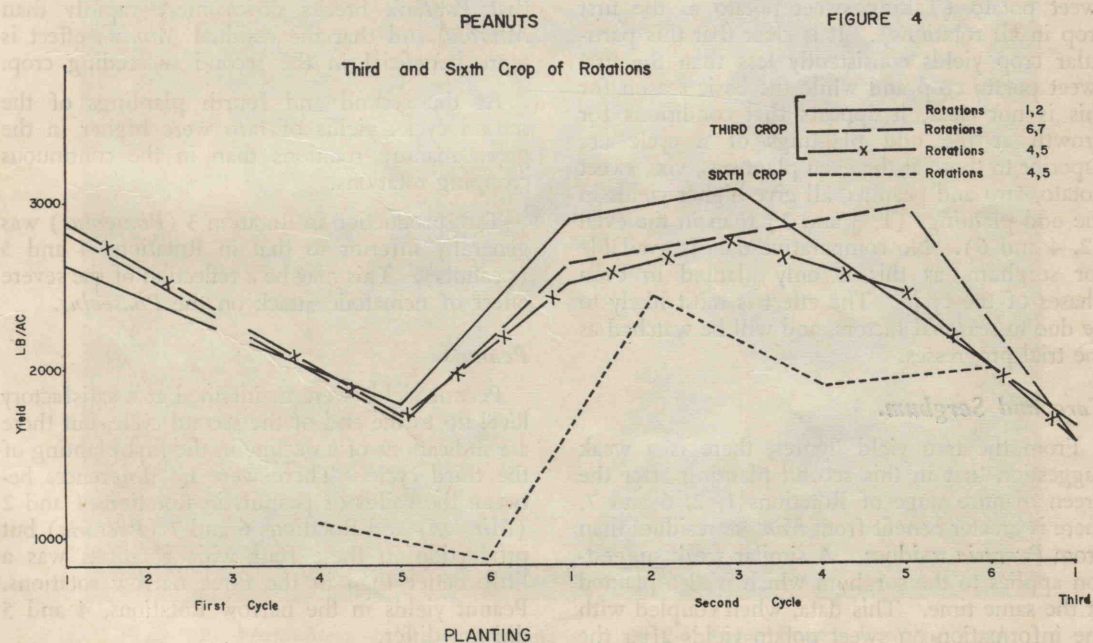
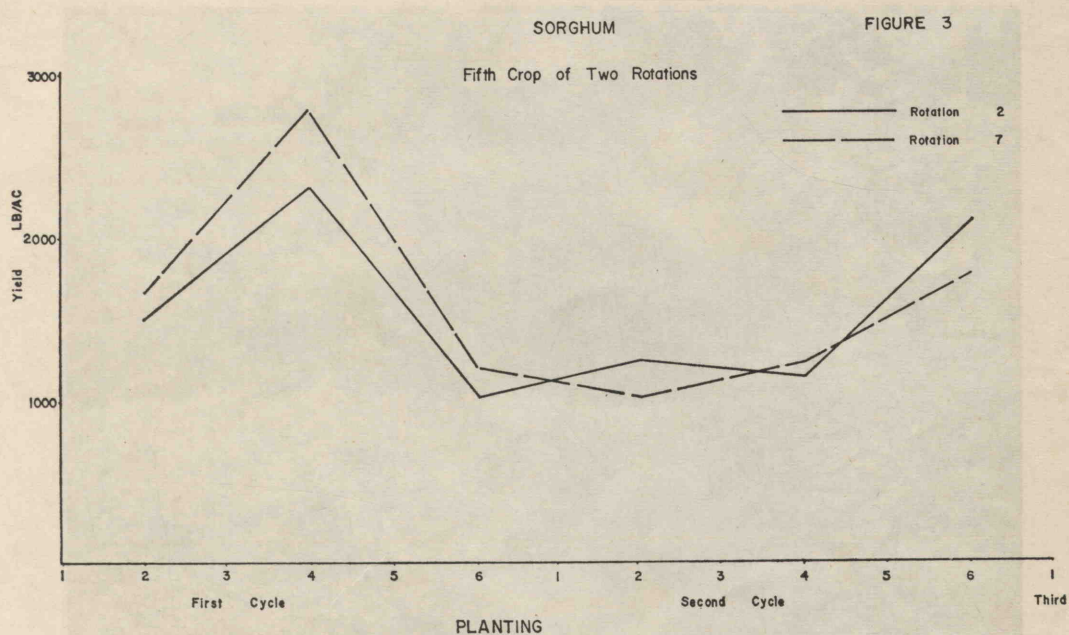
FIGURE 2A



TARO

FIGURE 2B





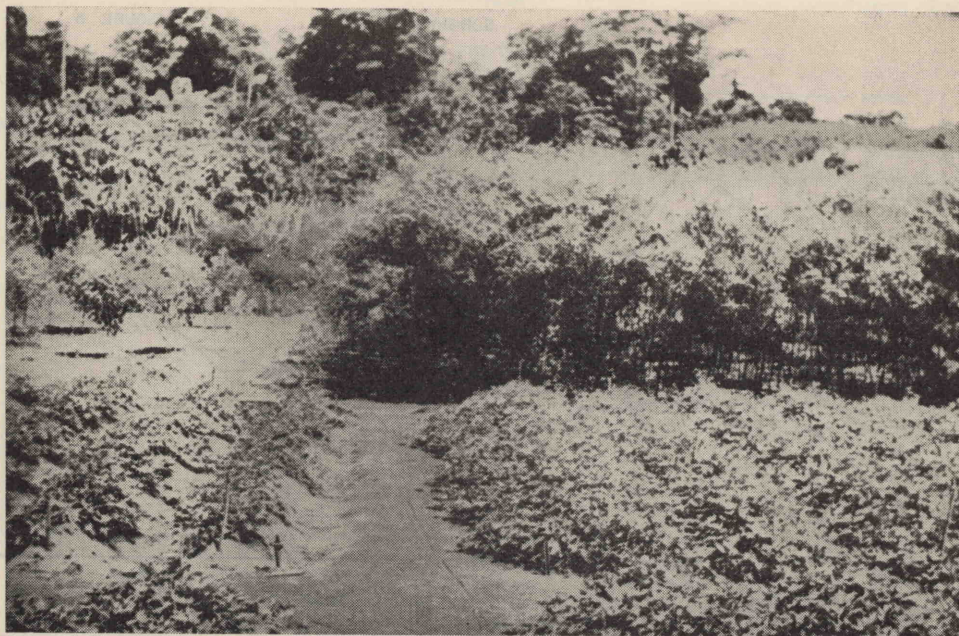


Plate IV.—Comparative vigour of sweet potato vine in some rotation : Rotations 5 7
2 1.

In rotations 3, 4 and 5, the fourth crop is sweet potato (Taking sweet potato as the first crop in all rotations). It is clear that this particular crop yields consistently less than the first sweet potato crop and while the basic reason for this is not clear, it appears that conditions for growth at the odd plantings of a cycle are superior to those at the even plantings, viz., sweet potato, taro and peanuts, all give higher yields in the odd plantings (1, 3 and 5) than in the even (2, 4 and 6). No comparative data is available for sorghum, as this is only planted in even phases of the cycle. The effect is most likely to be due to seasonal factors, and will be watched as the trial progresses.

Taro and Sorghum.

From the taro yield figures, there is a weak suggestion that in this second planting after the green manure stage of Rotations 1, 2, 6 and 7, there is greater benefit from *Mimosa* residues than from *Pueraria* residues. A similar weak suggestion applies to the sorghum which is also planted at the same time. This data, when coupled with the information on sweet potato yields after the

two cover-crops have been turned in, suggests that *Pueraria* breaks down more rapidly than *Mimosa*, and that the residual *Mimosa* effect is more beneficial in the second succeeding crop.

At the second and fourth plantings of the second cycle, yields of taro were higher in the green manure rotations than in the continuous cropping rotations.

Taro production in Rotation 3 (*Phaseolus*) was generally inferior to that in Rotations 4 and 5 (peanuts). This may be a reflection of the severe effect of nematode attack on the *Phaseolus*.

Peanuts.

Peanut yields were maintained at a satisfactory level up to the end of the second cycle, but there are indications of a decline in the first planting of the third cycle. There were no differences between the yields of peanuts in Rotations 1 and 2 (*Mimosa*) and Rotations 6 and 7 (*Pueraria*) but production in these four wide rotations was a little better than in the three narrow rotations. Peanut yields in the narrow Rotations, 4 and 5 did not differ.



Plate V.—Sweet potato 'little leaf virus' in the Three Course Rotation Trial.



Plate VI.—*Phytophthora colocasia* infecting taro in the Three Course Rotation Trial.

Diseases and Pests.

Plant diseases affected crop yields, particularly in the first cycle when effective control measures had not been developed.

Sweet potato suffered periodic infection with 'little leaf' virus which causes a reduction in tuber size on diseased plants, but attacks were not widespread enough to have a serious influence on crop production. The disease was kept in check by roguing out infected vines.

Taro leaves were attacked throughout the first two cycles of the trial by the fungus, *Phytophthora colocasiae*. The intensity of attack varied, and on occasions reduced effective leaf area to below 50 per cent. All taro crops were damaged to some degree. Partial control of the diseases was obtained by spraying with copper oxychloride or Bordeaux mixture. Investigation of a suspected virus disease of taro showed that the symptoms of leaf crinkling were due to physiological causes.

In the first cycle of the trial, peanuts were severely attacked by the crown rot fungus, *Sclerotium rolfsii*, two crops of Red Spanish being completely destroyed. Changes in cultural prac-

tice (hilling was discontinued) and in variety (to Schwarz 21) were therefore instituted in an effort to reduce losses.

Sclerotium rolfsii is a facultative saprophyte and the return of infected crop residues to the plots after harvest facilitated the carry-over of the disease from one crop to the next. The five treatments in the trial in which peanut trash was returned to the plots were therefore amended after the completion of the first cycle, and all peanut crop residues were removed from the plots. In the second cycle the fungus ceased to be a problem, although occasional infected plants were found.

Minor infections of Schwarz 21 peanuts with Marginal Chlorosis virus were reported.

The legumes, *Mimosa invisa* and *Phaseolus calcaratus*, were attacked by root knot nematodes, *Meloidogyne* spp. *M. invisa* was able to withstand the attacks sufficiently to maintain a cover on the plots for the eighteen months required. However, *Phaseolus calcaratus* was sometimes killed by nematodes well before maturity. Nematode infestation appeared to increase as the Trial proceeded. Commencing late in the first cycle of the trial, attempts were made to control nema-



Plate VIII.—*Phaseolus calcaratus* showing effects of nematode damage.

todes by injection of ethylene dibromide into the soil, prior to planting susceptible species. E.D.B. was injected at six inches depth, at the rate of 3 to 5 cc. per injection, on a 12 to 18-in. grid. This provided a measure of control sufficient to allow crop survival, but failed to eliminate the nematode population.

Insect damage to crops was noted throughout the trial. Aphid attacks on sweet potato leaves led to distortion of the leaves. Control by a mixture of benzene hexachloride miscible oil and white oil proved effective. Two species of Hawk-moth, *Protoparce convolvulae* and *Hippotion celerio* and the weevil, *Cyrtolabus formicarius*, were also responsible for damage to the crops.

Taro tubers were attacked by two species of scarab beetle of the genus *Papuana*. Leaves were attacked by the cutworm *Prodenia litura*.

Throughout the Trial special effort was required to control insect and disease infestations. Cultural and chemical means were necessary, as well as a change of variety in the case of peanuts. In the second cycle, as a result of precautions taken, insect and disease damage were only moderate.

Soil Chemical Analysis.

Results were not analysed statistically. It is evident that potassium levels dropped markedly from a satisfactory level at the 1st sampling to a marginal level at the 8th sampling. However this is not reflected in the differences in crop behaviour between the grouped rotations.

Phosphorus levels rose between the 1st and the 8th samplings. Both sets of samples were analysed in 1963, and the apparent rise may be due to fixation of phosphorus during storage of the samples taken at the first sampling.

Generally, other nutrient levels fell in all rotations but there appears to be little difference between levels for the wide and narrow rotations. Thus, the analyses have not reflected the agronomic differences between rotations shown in the trial.

CONTINUATION OF THE TRIAL.

The trial is at an interesting stage of development, with sweet potato and taro yields tending to decline, while peanut and sorghum yields were being maintained. It will be continued for the purpose of determining how these relative yield differentials will respond in time and at what stage the decline in yields will level off. It is clear that none of the rotations has maintained the productive capacity of the soil at a satisfactory level, but at this stage there is no direct evidence, other than the marked decline in potassium levels, to indicate whether the drop in yields is in fact due to soil deterioration.

NOTE ON ANALYSIS.

In the statistical analysis of the trial, evidence on block effects was sought from the analysis of the first phase sweet potato yields, in the three series, over the two cycles. For no series at any harvest was the block effect, freed from effects of the rotations, significant. Taken over the three series and two cycles, the average value of the mean squares for blocks and the residual variation within blocks were 4,538 and 3,959. A locality effect would be expected and evidence was not to the contrary, but the effects were so small that virtually nothing was lost in precision by ignoring it. Consequently all phases of the rotations at each planting were analysed as if the plots were completely randomized.

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