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THE APPLICATION OF ISOTOPES IN FERTILIZER RESEARCH ON THE COCONUT PALM*

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SUMMARY

The majority of coconut soils in Ceylon are deficient in the major plant nutrients. Fertilizer application has resulted in an increase of coconut yields ranging from 30 to 200 per cent. The fact that fertilizer application leads to increased profits and reduced costs of production is well recognised. But there is little available information on the optimum methods, forms, time, and frequency of fertilizer application—information which would help to maximise the efficiency of fertilizer utilization.

The usual field experimental techniques adopted for the study of such problems depend on yield data. In the case of a perennial tree crop like the coconut palm such experiments necessarily involve long term periods (6-8 years at least) and large extents of land (25–30 acres). The application of isotopic methods to such studies offers a much quicker means of obtaining the required information. The extent of land required would also be considerably reduced.

In a study on fertilizer placement on coconut palms using radioactive phosphorus, we were confronted with the following problems which are likely to be common to similar studies on other tree crops:—

(i) Handling difficulties associated with the large quantities of radioactive material required—(5 millicuries of P^{32} had to be applied to each palm).

(ii) Determining the most suitable plant organ for assessing the uptake of P^{32} (there was variation in the distribution of P^{32} in nut water, leaves, and sap, and also variation according to stage of maturity).

(iii) Use of unskilled labour for sampling which had to be done by climbing the palm (e.g. the leaf at the same stage of maturity may not be always sampled).

(iv) Variation in rate of uptake by individual palms due to their heterogeneity.

(v) The need for using large quantities of plant material for analysis due to the small content of radioactivity ultimately found in the various plant organs.

(vi) The need to eliminate interference due to naturally occurring radioactivity (K^{40}), and also an unknown source of radioactivity, presumably due to fall out.

(vii) Possible effects of radiation damage in the use of large quantities of radioactive material.

(viii) Possibility of results being vitiated by isotopic exchange reactions in the soil where lands used for the experiments have already been treated with fertilizers.

The paper discusses these problems in relation to the experiments carried out.

The placement trials showed that contrary to traditional practice, and popular opinion, for maximum efficiency of utilization fertilizer should be applied round the palm in the entire area up to a distance of about 5½ feet from the bole.

INTRODUCTION

The coconut palm plays a major role in the domestic life and economy of the peoples in many of the developing countries in the tropics—particularly those in south and south-east Asia, the Malayan Archipelago, and the Pacific Territories. It probably yields more products useful to man than any other tree—practically every part of the tree being useful. Apart from being a source of food, drink and shelter, it also provides raw material for a number of important industries.

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The total world coconut acreage is estimated to be about 9 millions. The main coconut growing countries are the Philippines (2.5 million acres), India (1.6 million acres), Indonesia (1.5 million acres), Ceylon (1.1 million acres), Malaysia (0.6 million acres) and the British South Sea Islands (0.6 million acres). Coconuts are also grown in the West Indies, East and West Africa, and in Central and South America.

The coconut industry provides employment and is the main source of living for about one third of the populations of the Philippines, West Coast of India (Kerala State) and Ceylon. In Ceylon, Philippines and the South Sea Islands the coconut industry is also one of the main sources of foreign exchange earnings.

In contrast to the plantation crops such as tea, rubber and oil palm, coconut is mainly grown in small holdings. In the Philippines, about 80% of the coconut lands consists of small holdings with an average extent of about 5 acres. In India, most of the coconut lands are holdings below one acre. 70% of Ceylon's coconut acreage are small holdings below 20 acres. The nett income from an acre of coconut is considerably less than that obtained from tea, rubber, or oil palm. The necessity to enhance income and reduce costs of production by way of increased yields and efficient management practice is therefore particularly important to the coconut industry.

Although the coconut industry is so broad-based and intimately connected with the lives of the people in the coconut growing countries, inadequate attention has been paid to scientific research on the various problems confronting the industry. This is probably largely due to the fact that unlike the other major plantation products it is a poor man's crop.

2. FERTILIZER PROBLEMS

The soils in most coconut growing areas have been reported to be generally poor in the major plant nutrients. Field experiments in Ceylon, India, West Africa, Trinidad and the Pacific Territories have shown that significant increases in yields can be obtained through fertilizer application. In Ceylon, for instance, the application of NPK fertilizer mixtures has resulted in increases in coconut production ranging from 30 to 300 per cent. The fact that fertilizer usage leads to increased yields and reduced costs of production is well recognised. Today, about 30% of Ceylon's total coconut acreage of 1.1 millions receive inorganic fertilizers—the annual tonnage of fertilizer used on coconut lands amounting to 48,000 tons. But there has been little or no information on the optimum methods of fertilizer placement, and the most suitable form, time, and frequency of fertilizer application—information which would help to maximise the efficiency of fertilizer utilisation, and hence further increase profits and reduce costs of production.

Since coconuts are grown under a wide range of soil and climatic conditions, no unequivocal solution can be expected to any of these problems. It will probably vary with the different soil and climatic conditions.

The standard field experimental techniques adopted for studying such problems depend on yield data.

There is little difficulty in applying such methods to short term annual crops. Quick results can be obtained within a single season's cropping. But in the case of a perennial tree crop like the coconut palm, such experiments are laborious, time consuming, and expensive. Owing to the inevitable time-lag between yield responses and fertilizer application, and the possible interaction of climate—particularly rainfall—it takes at least 6 to 8 years before any conclusions can be drawn from a single field experiment. If the land selected for experimentation has been subject to manuring in the recent past, the time required may be even longer. In the case of a naturally rich soil, or one which has been heavily manured regularly, the treatment differences may not be reflected in the yield data even after 10 years of experimentation. Often, it is difficult to find suitable land which has also not been manured recently. A further problem is that owing to population heterogeneity in yield characteristics, large extents of land of at least 25-30 acres are required for a single statistically designed experiment. The application of isotopic methods to fertilizer research on coconut palms offers tremendous advantages over the standard field experimental techniques for obtaining quick and decisive results. The extent of land required would be comparatively small, and its past history would be of little or no consequence. If the isotopic method has proved to be a useful tool in fertilizer research on short term annual crops, it should prove to be of much greater value in research on perennial tree crops.

(a) Fertilizer Material

The usual sources of N, P, and K in coconut fertilizer mixtures are ammonium sulphate, saphos phosphate and muriate of potash respectively. The main factors taken into consideration in selecting the type of fertilizer to be used are cost/unit value, cost of transport and handling, storage quality, and ready availability in the market. Recently there has been considerable interest in the possible use of other sources of nitrogen (e.g. Urea, ammonium sulphate nitrate, nitrochalk) and phosphorus (e.g. superphosphate, magnesium ammonium phosphate). While investigations carried out by the Coconut Research Institute of Ceylon have positively shown that the expensive organic sources of N and P (fish meal, ground nut cake, sediment poonac, bone meal etc.) are in no way superior to the considerably cheaper inorganic sources—ammonium sulphate and saphos phosphate—there is little information on the relative merits of other sources of inorganic nitrogen and phosphorus.

Urea can be manufactured locally without importing any raw materials. It has also the advantage of being cheaper, and more concentrated source of nitrogen than ammonium sulphate. Would it be as efficient a source of nitrogen as ammonium sulphate? Again, would nitrates be more efficient than ammonium fertilizers on the highly acidic lateritic soils and the nearly sterile coarse littoral sandy soils which have poor capacity for nitrification? Under conditions of heavy rainfall, perhaps ammonium fertilizers are less liable to leaching than nitrates or urea. Would superphosphate be superior to saphos phosphate, particularly on the non-acidic non ferrugenous sandy soil types? Would nitrates and soluble phosphates be better utilised by coconut seedlings and young palms?

These are some of many problems on fertilizer material which can be elucidated very conveniently through the application of isotopic methods. A straight comparison can be made of the various nitrogeneous fertilizers by labelling the nitrogen with N^{15} and estimating the uptake of N^{15} by the palm through leaf analysis. Soluble phosphates can be similarly compared by labelling with P^{32}.

(b) Time of Fertilizer Application

Application of inorganic fertilizers must be done when the soil is wet. Most coconut planters prefer to apply their fertilizers after the heavy monsoon rains are over on the premise that then there would be less loss of fertilizer through leaching. While this may be correct on the sandy soil types, it need not necessarily hold for the heavier soil types capable of retaining soluble ammonium and potassium ions in the clay complex. In fact in areas where a short rainy period is followed by a long dry spell, it may be preferable to apply the fertilizers early in the rainy season so that the applied nutrients would be available to the palms for a longer period. The question whether fertilizer application early in the rainy season would result in more efficient fertilizer utilization depends not only on soil type, but also on the intensity and duration of the rains, and on the type of fertilizer material used.

These are problems which are of particular relevance to the soluble nitrogen and potassium fertilizers. They can be most conveniently solved through the application of istopic methods. Nitrogeneous fertilizers labelled with N^{15} can be used to study the proportion of fertilizer utilised by the palm and that lost from the soil by leaching. The use of radioactive rubidium would help to study the pattern of behaviour of potassic fertilizers.

(c) Frequency of Fertilizer Application

Until a few years ago, most coconut plantations in Ceylon followed the traditional practice of manuring once in two years. This was largely due to the fact that in the past cattle were the chief source of manure, and there were inadequate animals to manure the entire land in the same year. Today, with the increasing use of inorganic fertilizers, the general practice is to apply fertilizers annually. Although we have no experimental evidence to support either of these practices, on scientific grounds the latter should prove to be more efficient. In fact, in areas where two monsoon periods prevail, and particularly on sandy soils, we recommend that fertilizers should be applied at six monthly intervals for greater efficiency of utilisation. More frequent applications are now recommended for young palms.

The availability of soil nutrients to plants depends on the activity of the nutrient ions in the soil. Immediately after fertilizer application, this activity would be high. But it would gradually reduce with time due to leaching and soil fixation.

By reducing the time interval between successive fertilizer applications, it would be possible to maintain the activity of nutrient ions in the soil at higher level—particularly when soluble fertilizers such as ammonium sulphate and muriate of potash are used. More frequent manuring should therefore ensure greater efficiency of fertilizer utilization. But at what frequency would the economic benefits be highest, after allowing for costs of application which increases with increasing frequency of application? The answer to this question would again vary with the different soil and climatic conditions. Here too the application of isotopes would be the quicker way of solving the problems.

(d) Fertilizer Placement

Only a fraction of the fertilizers applied to soil is taken up by the crop—the rest being lost through the process of leaching, soil fixation, release to the atmosphere (in the case of nitrogen) or even physical wash off. Placement of fertilizers in close proximity to the zone of highest root activity would help to maximise fertilizer uptake by the plant. A knowledge of the distribution of active plant roots in the soil and the location of the region where the density of absorbing root surface is highest are therefore essential pre-requisites to the rational use of fertilizers.

In Ceylon, fertilizers have been applied to coconut palms in a 3 ft. wide circular, or semi-circular trench (6 inches deep) round the palm at a distance of 3 feet from the bole—a method based solely on traditional practice. Coghlan and Hinchley (1917) recommended that manures be placed in ploughed furrows between rows of palms on the basis that the roots of the coconut tree are more vigorous towards the extremities of their primaries. Sampson (1923) advocated the broadcast application of fertilizer in the whole area of the plantation on the premise that this practice promotes extensive development of feeding rootlets. In India, fertilizers are placed in circular basins of radius 4-6 ft. round the palm. This practice finds support in the observations of Menon and Pandalai (1958) who recorded that large numbers of rootlets which absorb plant food are concentrated round the bole up to a distance of about 5 to 6 feet. However, Salgado (1957) using the standard field experimental method based on yield data found no difference between the circular trench system and broadcast application of fertilizers. This experiment was carried out for 10 years. About 25 acres of coconut land were required for the experiment.

Since past work has not provided any conclusive information on the question of fertilizer placement we carried out some studies on the subject using radioactive phosphorus. The following placements were compared on bearing palms on sandy loam soils:—

(*a*) 3 ft. wide circular trench 3 ft. away from the base of the palm, (*b*) square or circle at centres between rows of palms and (*c*) basin extending to 5½ feet from the bole. Placement (*b*) was found to be 100% superior to either of the other two placements. Comparison of placements in full and half circles indicated the former to be about 40% more efficient. Each of these placement trials required only about ½ acre of land, and results were obtained within about 3 months.

In this work we were confronted with the following problems which are likely to be common to other similar studies on tree crops:—(i) handling difficulties associated with the field use of large quantities of radioactive material; (ii) determining the most suitable plant organ for assessing the uptake of radioactive material (there can be variation of radioactivity in different parts of the palm, and also variation according to stage of maturity); (iii) sampling of plant material which has to be done by unskilled labourers who have to climb the trees; (iv) variation of uptake of radioactive material by individual trees both due to soil as well as palm heterogeneity, (v) chemical analysis problems associated with the need to use large quantities of plant material (vi) the need to eliminate interference due to naturally occurring radioactivity, K^{40} and also an unknown source of radioactivity, presumably due to fall out; (vii) radiation damage (viii) isotopic exchange reactions in the soil.

I shall now discuss in some detail the general principles and experimental procedure adopted for the placement trials, giving special emphasis to the handling of the aforementioned problems.

1. General Principles

P^{32} was selected as the most suitable isotope to work with in this study. Apart from its convenient half life period of 14.3 days and the relatively mild health hazards in handling it, the high mobility of the phosphate ion in plants and its slow movement in soils are particularly advantages in root-zone studies.

Placement efficiency was assessed by measuring the radio activity taken up by palms when equal amounts of labelled phosphate solution were applied according to the different methods under comparison. The specific activity of the phosphate in comparable portions of plant tissue was used as the criterion for measuring the uptake of applied labelled phosphate. This minimises errors which can arise due to differences in the rates and capacities of nutrient uptake between individual palms which can occur if the comparisons are based solely on the total radioactive count in a particular portion of plant tissue.

2. Isotopic Exchange

Exchange reactions between the applied labelled phosphate and soil phosphates can invalidate absolute estimates of fertilizer absorption. However, isotopic exchange would not affect comparative estimates of fertilizer uptake by plants from different placements on the same soil provided that (i) the content of isotopically exchangeable phosphate in the soil is the same at the different points of placement, and (ii) the quantity of labelled phosphate is applied according to the different methods on equal surface areas of the soil. If condition (i) is not satisfied—as did happen in the case of a land on which previously localised fertilizer placement had been done—the uptake of labelled phosphate from locations where the content of exchangeable soil phosphate is higher can be under estimated due to isotopic dilution.

3. Handling Radioactive material

In these trials each coconut palm was treated with 10 litres phosphate solution containing 15.5 grms. P tagged with 5 millicuries P^{32}. It was necessary to apply a high dosage of radioactivity in order to ensure that there would be sufficient P^{32} absorbed by the palm for quantitative assay. For each experiment, about 100-150 millicuries P^{32} had to be handled and dispensed. This might normally be considered a hazardous operation in an ordinary chemical laboratory. Fortunately, the labelled phosphate was to be applied in solution, in 5 millicurie portions. The phial of 100-150 millicuries P^{32} was transferred directly to a thick walled glass round bottomed flask containing 2 litres phosphate solution. The water and the thick glass were instrumental in absorbing a fair portion of the radiation. Further protection from radiation was achieved by the use of a few lead accumulators between the operator and radioactive solution. Finally, the 5 millicurie portions were dispensed into winchester quart bottles containing about 12 litres phosphate solution. These proved to be ideal containers for transporting the labelled phosphate solutions to the field as they offered almost complete protection from radiation. The solutions were applied to the soil uniformily over the area concerned using polythene watering cans.

4. Radiation damage

When using radio isotopes in soil/plant relationships, due consideration must be given to the possible effects of radiation damage, particularly where large quantities of radioactive materials are used. In these studies, 5 millicuries P^{32} were distributed over an area of about 100 sq. feet of soil. It was found that within 7 days the radioactivity was distributed within the top 12 inches of soil. This amounts to only about 1 micro curie P^{32} per kilogram soil. It was assumed that this level of radioactivity under field conditions would not cause any significant radiation damage to the bearing coconut palms which were used in these experiments.

5. Choice of Plant Material for Analysis, and Sampling Problems

Preliminary studies showed that radioactive phosphorus is transported to the crown of an adult coconut palm within two hours of its application to the soil. Examination of the relative merits of toddy, nut water, spathe and leaf analysis as a means of studying the uptake of radioactive phosphorus showed that the moderately matured leaves are best suited for such work.

Within three days of the application round the palm of radioactive phosphate solution, there was sufficient radioactivity in the leaflets of an adult coconut palm for quantitative assay. The leaflets showed a higher quantity of radioactivity than the toddy, nut water or spathes.

Table 1 gives the distribution of radioactivity in leaflets of different fronds according to their position in the frond six weeks after the application of P^{32}. The fronds are numbered in increasing order of maturity, No. 1 being the first fully opened leaf. The youngest and most mature fronds have the lowest specific activities. In all fronds the leaflet in the upper sections of the fronds show a greater accumulation of radioactivity, while the distribution of P^{32} is seen to be most uniform between fronds 3 to 13.

The bunches of nuts showed the highest specific activity in the water of the least mature nuts. Analysis of spathes showed an accumulation of radioactivity in the male and female flowers at a level intermediate between that of the nut water and leaves.

In the sap collected by tapping unopened spathes (toddy), the radioactivity fluctuated according to time of tapping, and weather conditions.

The leaflets from either side of the middle portion of the 6th frond were selected as the most suitable plant material for this work.

For leaf sampling, we were entirely dependent on unskilled labourers. They climbed the tree, counted the fronds in increasing order of maturity, and cut down the 6th frond. After prior training on the ground, we found that these labourers did their job well. However, since it was observed that the radioactivity in moderately matured adjacent fronds was similar, the erroneous selection of fronds 5 or 7 instead of No. 6 for leaflet sampling would have been of little consequence.

6. Analytical Methods

On account of the low amount of radioactivity in the leaflets (even though the palms had been treated with high doses of P^{32}), it was necessary to use a large quantity of leaf material (about 20 grms.) for radioactive assay. The oven dry leaf samples (without midribs) were dry ashed and extracted with 1:1 HCL. P^{32} was measured by the liquid counting technique and total phosphate by the colorimetric vanado-molydate method.

The phosphate had to be precipitated as ammonium phospho molybdate and redissolved in ammonia before estimating the radioactivity due to P^{32} in order to eliminate interference caused by the presence of significant amounts of natural radioactivity in the coconut leaf samples, and also an unknown source of radioactivity which was detected in leaflets sampled since June 1962.

The natural radioactivity in leaflets was traced to K^{40}. It is presumed that the unknown source of radioactivity which showed a half life period of about 69 days, and which was observed only in leaflets sampled after June 1962, is due to radioactive fall out.

The P^{32} count in 8 grms. of oven dry leaflet samples from experimental palms ranged from 150 to 1500 counts/minute. Interference due to K^{40} and the unknown source was in the order of about 20 cts/mt and 60 cts/mt respectively. (See Table 2).

TABLE 1

Distribution of radioactive phosphorus in coconut leaflets and nut water sampled 6 weeks after soil application of labelled phosphate.

(Specific activities $\left(\frac{P^{32}}{P^{31}}\right)$ *in counts per minute/mg.* P_2O_5*) (%* P_2O_5 *on oven dry samples)*

(a) Leaflets

Frond No. (in increasing order of maturity)

Section	1		2		3		4	
	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$
Upper	0.35	19.8	0.31	69.8	0.36	94.9	0.32	91.4
Middle	0.35	12.6	0.26	44.6	0.34	74.4	0.32	73.4
Base	0.38	13.1	0.31	16.6	0.34	52.5	0.32	49.4

Section	6		9		13		Last	
	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$	$\%P_2O_5$	$\frac{P^{32}}{P^{31}}$
Upper	0.35	88.6	0.34	90.8	0.31	84.7	0.19	32.9
Middle	0.36	80.4	0.34	81.1	0.34	80.3	0.22	19.2
Base	0.37	64.5	0.39	67.5	0.36	61.2	0.21	12.6

(b) Nut Water

Bunch No. in decreasing order of Maturity	*No. of Nuts*	*Total volume of water ml.*	P_2O_5 *Conc. in mgm/litre*	*Specific activity*
3	8	1320	93.5	1.33
4	12	1840	135.0	4.49
5	8	2150	135.5	9.89
6	9	1600	131.5	6.65
7	9	2900	119.0	16.4
8	10	3680	125.0	11.0
9	14	5300	131.5	22.0
10	13	2920	122.5	22.2

TABLE 2

Blank radioactivity in coconut leaflets

(Sampled on 17.6.62 from 12 year old palms at Bandirippuwa Estate)

Counts per minute in 8 gms. oven dry samples

Palm No.	*Leaf No. 1 (1st fully opened)*		*Leaf No. 8*	
	Radioactivity due to potash (K^{40})	*Radioactivity from unknown source*	*Radioactivity due to potash* (K^{40})	*Unknown Activity*
102	22	21	16	60
106	20	11	18	60
113	23	3	20	46
201	24	16	20	40
218	20	11	16	40
220	19	9	15	29
279	19	5	14	56
289	20	15	18	43
295	22	19	14	58

7. Experimental Procedure

On account of the large quantity of P^{32} required, the experimental units were limited to single palms. Each placement was tested on individual palms replicated thrice, or five times. In order to minimise errors due to soil heterogeneity each replicate of the three different treatments were grouped together so as to form a block. To minimise errors due to palm heterogeneity, palms of similar bearing capacity and vegetative growth were selected for treatment comparisons within each block.

Each palm was treated with 10 litres solution of P containing 66 grms. dibasic ammonium phosphate labelled with 5 millicuries P^{32}. The solution was sprinkled uniformly in the entire area of placement. In the case of placement in the centres between rows of palms the full dosage of radioactive solution was applied to each of the four squares surrounding the experimental palm since the fertilizer applied to each square can be equally accessible to four palms.

Leaflets were sampled from each of the experimental palms at intervals of one week, one month and 3 three months after the application of labelled phosphate solution.

The results of one of the experiments on 50 year old palms is given in Table 3. The pattern of uptake was similar through-out the 3 months period. Similar results were obtained from another experiment carried out on young bearing palms (12 years).

Another experiment compared half circle and full circle application. The latter was found to be about 40% more efficient (Table 4).

These studies indicated that within a depth of about 2½ feet (this was the depth to which the labelled P had moved), the density of active roots is much higher in the area immediately surrounding the palms up to a distance of about 5½ ft. from the bole. For maximum efficiency of utilisation, fertilizers should be applied in the entire area up to 5½ feet from the bole.

TABLE 3

Experiment No. 2: Placement trial on adult palms at Marandawila Estate palms

Specific activities (counts per minute/mg.P) in 6th frond leaflets

	REPLICATE NOS																				
	1			2			3			4			5			*Mean*			*% Efficiency*		
Time after P^{32} application (weeks)	1	4	13	1	4	13	1	4	13	1	4	13	1	4	13	1	4	13	1	4	13
Method of Placement																					
A. Basin 5′ 8″ radius from bole outwards	20.5	156	415	5.20	34.8	127	15.8	111	376	16.3	84.9	198	6.01	60.1	173	12.7	89.4	258	100	100	100
B. Traditional circular trench 3′ wide 3′ away from bole	7.16	51.2	121	3.34	23.6	103	16.1	87.7	216	30.0	79.9	150	1.13	13.8	54.6	11.5	51.2	129	90	57	50
C. Centres of Squares	25.6	134	317	3.70	44.8	130	5.78	42.6	199	1.22	11.2	29.7	3.12	22.8	60.2	7.88	51.1	145	62	57	56

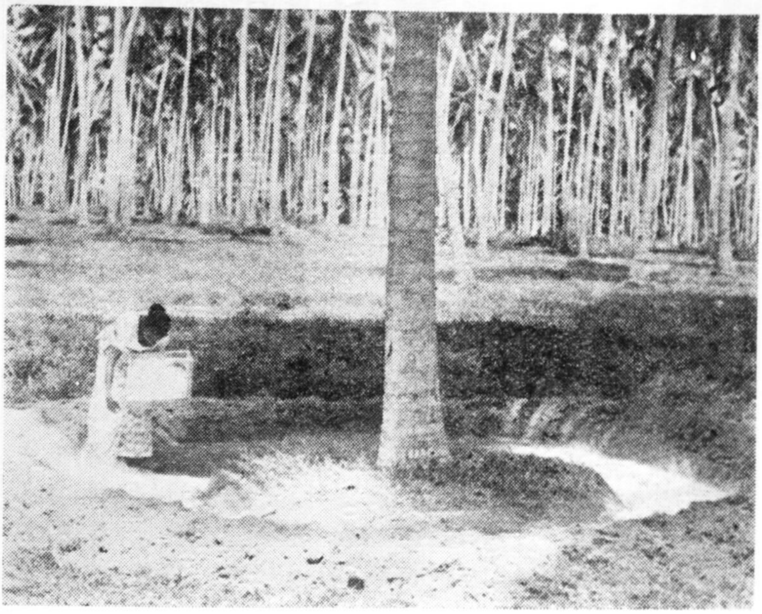
TABLE 4

Experiment No. 3: Comparison of Placement in full and half circles

Specific activities (counts/minute/mg. P) in 6th frond leaflets

	REPLICATE NOS.																				
	1			2			3			4			5			*Mean*			*% Efficiency*		
Time after P^{32} application (days)	10	39	70	10	39	70	10	39	70	10	39	70	10	39	70	10	39	70	10	39	70
Method of Placement																					
A. Full Circles	82.5	161	183	105.5	222	240	50.8	128	188	37.0	104	166	62.5	140	175	67.6	151	190	100	100	100
B. Half Circles	53.5	126	154	84.0	158	196	34.8	82	135	26.6	91.4	76	24.5	73.7	96	44.7	106	131	66	70	69

FERTILIZER PLACEMENT



Circular Trench Method

Surface Application