THE APPLICATION OF RADIO-ISOTOPIC TECHNIQUES TO FERTILISER PLACEMENT STUDIES IN OILPALM CULTIVATION [1])

H. BROESHART

Laboratory of Soils and Fertilizers, Agricultural University, Wageningen, The Netherlands [2])

SUMMARY AND CONCLUSIONS

1. In nurseries and plantations, fertilizers should always be applied on the surface. There is not any advantage in howing in of the fertilizer. Placement at a depth varying between 5–15 cm compared very unfavourably with placement on the surface.

2. The optimal distance of fertilizer placement for one year old palms is close to the stem, inside crown diameter. For two year old palms the uptake from fertilizer placed close to the stem and at crown diameter is approximately equal. The optimal distance for 3 and 4 year old palms is at crown diameter. In adult plantations, where the crowns are overlapping, no optimal distance of placement was found, although placement close to the stem, inside the clean weeded ring would seem less favourable.

3. Spraying results in a very rapid uptake of phosphate. The total quantity which can be sprayed per palm is very limited however and the period of uptake reduced by the leaching effect of rainfall. The proportion of P, taken up in respect of the quantity of P supplied is very much higher for spraying than for application to the soil. Spraying may well be an economic procedure in nurseries, particularly in combination with fungicide sprays.

4. The effect of rainfall on phosphate uptake is important in nurseries and 1–2 year old plantations. Dry periods reduce the amount of P taken up considerably in these cases. In 3–4 year old plantations the effect of dry periods on P uptake is much smaller and in the case of adult palms no effect could be observed. Therefore fertilizer applications to young palms should preferably be made in the rainy seasons.

PART I PRELIMINARY INVESTIGATIONS

A INTRODUCTION

During recent years, the general level of productivity in oilpalm cultivation, has been greatly increased, due to regular fertilizer, applications. The quantities of fertilizer, applied to plantations, may be considerable, as has been shown by FERWERDA (1). Up to the present, very little attention has been paid to the method of application of fertilizers with regard to oilpalm. Taking into consideration the enormous quantities of fertilizers required to increase or maintain the production level of a plantation, the question may be raised whether placement of fertilizers at a certain distance from the palm or at a certain depth, would not ensure the maximum possible effect of fertilization, which is particularly of importance in the case of phosphate fixing soils. If such a problem is investigated by means of ordinary methods, i.e. long term fertilizer placement experiments combined with soil- and leaf analyses, considerable time will be involved. The experiments would necesarily involve many replications and would have to be repeated for several years, in order to establish significant treatment effects, because the variation in production level and the chemical composition of leaves due to various methods of placement, may be relatively small.

1) Received for publication April 24, 1959.

2) Formerly Research Department Huilever S.A. Belgian Congo.

The use of radio-isotopes opens wide perspectives with regard to fertilizer placement studies. As opposed to the classical approach, the time required for placement trials employing radio-active fertilizer is very small, usually a matter of a few weeks only. Moreover, the sensitivity of the method is such that quantities, chemically not detectable, may be determined by means of Geiger-counter equipment.

The principle of experiments, employing fertilizers tagged with a radio-isotope, consists of the determination of the radio-activity in the palms, shortly (1–6 weeks) after the applications have been made.

If the same quantity of fertilizers of a particular specific activity has been supplied according to various placement methods, the best method will correspond to the highest radio-activity in the palm.

There are, however, several complications which may invalidate the conclusions to be drawn from experiments of the above mentioned type. These difficulties may arise from phenomena such as: *A*, irregular distribution of elements in the palm; *B*, radiation damage; *C*, isotopic dilution of the applied element in the soil.

Preliminary investigations into the nature of these factors are therefore essential, to interprete the results of actual placement experiments in the field, correctly.

B The uptake and translocation of elements in oilpalms

1 *Description of the experiment*

The distribution of elements in the oilpalm was investigated for Calcium and Phosphorus. 160 g Mono-calcium-phosphate, tagged either with 380 μC P^{32} or 380 μC P^{32} + 300 μC Ca^{45} was supplied to 20 months old palms, growing in 500 liter drums in sandculture from which phosphate was absent. [3])

The influence of method of placement on the uptake of P^{32} and Ca^{45} in the palms was determined by comparing the following treatment combinations:

a placement of the fertilizer at one point and in a ring around the palm;

b placement of the fertilizer on the surface and at a depth of 20 cm.

One leaflet, from the central part of all the leaves, with the exception of the oldest dessiccated leaves, was sampled resp. 5, 12, 19, 26 and 33 days after the fertilizer application had been made, for the determination of the activities of P^{32} and Ca^{45}. The samples were dried at 90° C and ashed at 500° C. The ash content as a % of dry matter was determined and 30 mg of ash suspended on a counting tray, in a few drops of water containing some teepol. After drying the suspension under an infrared lamp, the ash became finely dispersed and stuck firmly to the counting tray. For the simultaneous determination of Ca^{45} and P^{32} activity, the sample was counted twice, but the second time an aluminium filter of 70 mg/cm^2 was placed between sampling tray and counterwindow. The filter transmitted 64% of the β particles emitted by P^{32} but absorbed the low energy β radiation from Ca^{45} completely. From each pair of count rates, the activity from P^{32} and Ca^{45} could than be calculated.

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[3]) The fertilizer phosphate was prepared by precipitation from mono-sodium-phosphate and calciumchloride.

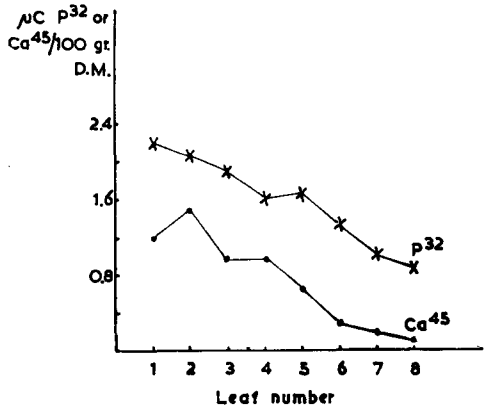

FIG. 1 THE UPTAKE OF P^{32} AND Ca^{45} AS A FUNCTION OF LEAF AGE (LEAF 1 — YOUNGEST FULLY DEVELOPED LEAF).

2 *Results*

Figure 1 shows the distribution of P^{32} and Ca^{45} as a function of leaf age for placement in a ring around the palms. From figure 1 it is evident that the greatest part of the phosphate and calcium taken up during the experimental period, was transported to the youngest leaves. This picture may change entirely, however, if the fertilizer is placed in one point, as illustrated by figures 2 and 3 for phosphate and calcium respectively. In these figures the phylotaxis of the oilpalm, which is $^3/_8$, has been represented by a circle, in which the numbers of the leaves are indicated.

The increase in P and Ca content of the leaves, has been plotted on the extrapolated radius, connecting the leaf number and the centre of the circle. The dotted lines represent the uptake after 12, the drawn lines after 33 days. The heavy black dots indicate the places where the fertilizers were applied in one point (A and B in figure 2 and A in figure 3).

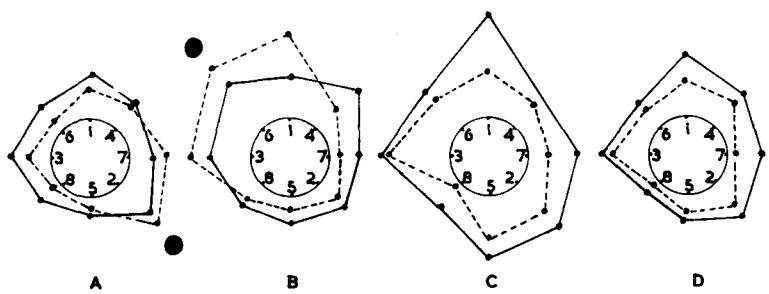

FIG. 2 THE DISTRIBUTION OF P^{32} IN PALMLEAVES.
- - - - - - - after 12 days; A and B, placement in one point.
——— after 33 days; C and D, placement in a ring around the palm.

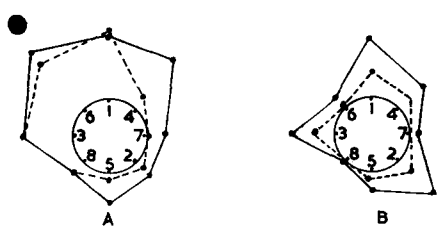

FIG. 3 THE DISTRIBUTION OF Ca^{45} IN PALMLEAVES.
- - - - - after 12 days; A, placement in one point.
——— after 33 days; B, placement in a ring.

It may be seen that after 12 days, the application of fertilizers in one point induced high P and Ca contents in the leaves growing at the same side as where the application was made, irrespective of the leaf age. After 33 days however, phosphate appeared to have translocated to the other leaves, as is suggested by the decrease in P content of the leaves growing at the same side as the placement and an increase of the P content of the leaves growing opposite that point (figure 2). Ca was not translocated, as after 33 days the position of the innercircle in the diagram in figure 3 A was still excentric and the Ca content of the leaves at the side of the placement remained high.

Placement at a depth of 20 cm reduced both P and Ca uptake to a very low level, but the distribution pattern appeared to be similar to those in figures 2 and 3.

The effect of placement at 20 cm depth as compared with placement on the surface is given in table 1. The differences are significant at P = 0,05.

Table 1 The average uptake of P and Ca after 33 days.

Placement	μC P^{32}/100 g DM	μC Ca^{45}/100 g DM
on surface	2.47	1.82
at 20 cm depth	1.24	0.76

3 *Conclusions*

The following conclusions can be drawn from the data :

1 The highest proportion of both P and Ca supplied as $Ca(H_2PO_4)_2$ is found in the youngest leaves.
2 Placement in one point results in an uneven distribution of Ca and P in the palm ; the leaves nearest of the placement have the highest P and Ca content. In the latter stages P is translocated to other leaves, but this is not the case for Ca.
3 Placement on the surface results in a greater uptake of both P and Ca, than placement at 10–20 cm depth.
4 With regard to a future sampling technique for placement trials, the present experiment has shown that only the composition of leaves of similar age many be compared as a measure for differences in uptake by entire palms.
5 It is not possible to estimate the uptake from radio-active fertilizer, given in one point, unless the element in question is rapidly translocated to other parts of the palms.

Therefore, if the effect of placement at certain distances or depths on nutrient uptake has to be investigated in placement trials, using radio-active fertilizer, the application should preferably be made in a ring around the palm.

C Radiation damage to roots

Prior to any experiments with radio-isotopes the effect of radiation of the isotope on the magnitude of the uptake should be investigated. As was shown by Scott Russell et al. (2) radiation damage to plants is a function of the

specific activity of the fertilizer and also depends or the extend to which radio-isotopes may accumulate in certain tissues.

It is of importance to know whether the radiation of P^{32} contained in the fertilizer, may reduce the uptake of P^{31}. Various kinds of damage might occur:

1 A direct effect of P^{32} in the fertilizer.

2 An effect of the accumulated P^{32} in the meristems of the roots.

3 An indirect effect, caused by a reduced or altered metabolism of the palm.

An experiment was carried out to investigate this problem for the oilpalm, with a view to studying P^{32} uptake as a function of the specific activity of the fertilizer.

1 *Description of the experiment*

10 palms of approximately similar size were selected in a 9 months old nursery. Two series of 5 palms received a solution of 200 g mono-sodium-phosphate, labeled with resp. 0.5, 1.0, 1.5, 2.0 and 2.5 mC P^{32}. Leaf samples were taken from the three youngest leaves and analysed after 2, 9 and 14 days for P^{32} content. In addition micro-autoradiographs were made of root sections in order to determine whether accumulation of P^{32} would have induced an abnormal tissue formation or cell distortion.

The leaves were dried at 105° C and 5 g of dry matter was ashed, followed by a digestion in a mixture of concentrated sulfuric and nitric acid, to remove the last traces of carbon. The digest was made up to 25 ml with distilled water and silica was filtered off.

The activity of the solutions was determined with a halogen quenched liquid counter, type M 6 H.

2 *Results*

The uptake of P^{32}, expressed as counts/min., was found to be a linear function of the specific activity of the fertilizer.

The results of the analysis of variance which was carried out for the data, have been given in table 2.

Table 2 Analysis of Variance of the Radiation Damage Experiment. (F test Snedecor)

Factor	Degrees of freedom	F_2 days	F_9 days	F_{14} days
Interclass	4	1.9	4.4	10.6
Linear regression	1	6.5*	15.8**	31.2**
Curvature	3	0.5	0.6	3.7

* sign. at P = 0.05.
** sign. at P = 0.01.

From this table it may be seen that the curvature effects were insignificant, i.e. the regression lines may be considered as linear. In other words, the uptake of phosphate was not affected by radiation damage from P^{32} for the range of specific activities used in the experiment.

In addition, micro-autoradiographs were prepared from transverse and longi-

tudinal sections of the root tips which had been in contact with the stripped photographic emulsion for exposure to β radiation during 3 days.

The location of the blackening, produced by P^{32} was observed under a microscope and appeared to be concentrated in the apical meristems of the roottips and in some cases in the young vascular strands, immediately behind the apical meristem, in the exodermal layers of the roots. Some P^{32} was found in the disorganized tissues of the root cap. No abnormal cell formation or cell distortion could be observed.

The results of this experiment indicate clearly that phosphate uptake is not affected by internal and external radiation of P^{32}, because in all cases, the regressions were linear, and curvature effects were small and insignificant.

It may not be concluded however, that radiation from P^{32} did not have any effect on cell metabolism, but, even if such an effect existed, in the present case it did not interfere with phosphate uptake by the palms for the duration of the experiment.

The final choice with regard to the specific activity of the phosphate in subsequent placement experiments was never taken higher than 3 mC/kg NaH_2PO_4, which corresponds approximately to the lowest specific activity used in the radiation damage experiment.

D Isotopic dilution

If the top layer of the soil would contain a quantity of labile phosphate which would differ considerably from the labile phosphate content at $\pm$ 20 cm depth, the uptake from radio-active fertilizer phosphate would be underestimated in the case of the highest labile phosphate concentration of the soil as a consequence of isotopic dilution of fertilizer phosphate with soil phosphate.

However, previous soil chemical analysis of the area under investigation (red latosol) had shown that labile phosphate was practically nonexistent. Even 1% citric acid failed to remove any detectable quantity of P (Broeshart (3)).

Under these conditions, it would be unlikely that isotopic dilution of fertilizer phosphate with the labile pool of P in the soil would be of any importance.

For the determination of isotopically exchangeable P (E value) many difficulties were encountered. The concentration of P^{31} in the equilibrium solution was too low to be accurately determined. Increasing the amount of added P^{31} rendered the determination of the E value, being a small difference of two high figures, very unreliable.

PART II THE RESULTS OF FIELD EXPERIMENTS

A Introduction

In experiments, employing radioactive fertilizers, the uptake of the element in question is determined from the amount of radio-activity in the youngest palm leaves, shortly after the applications have been made.

If the same quantity of fertilizers of a particular specific activity has been applied according to various placement methods, the best method will correspond to the highest radio-activity in the leaves.

In order to determine the best method of placement, a series of experiments were carried out in plantations of 1–11 years old. The experiments were of

similar design ($3^n \times$ m factorial) and included combinations of the following treatments :

1 Placement at three distances from the base of the stem.
2 Placement at various depths and on the surface (n).
3 Fertilizers of different solubility (m).

In one case the effect of spraying dilute fertilizer solution on the palm leaves was compared with ordinary placement on the soil.

In addition, the effect of rainfall on fertilizer uptake was studied in plantations of various ages.

Experiments were laid down in a nursery of 9 months and in plantations of 1, 2, 3, 4 and 11 years after planting out in the field. In the plantation of 4 years old, the palms were coming into production ; in the plantation of 11 years old, the palms were all well in the productive stage and the crowns were overlapping, causing complete shadowing of the soil.

Sodium and calciumphosphates, tagged with P^{32} or both P^{32} and Ca^{45} were employed as fertilizers. Mono- and dicalciumphosphate were prepared by precipitation from solutions of calciumchloride and phosphoric acid, previously tagged with the appropriate isotope. Monosodium phosphate was dissolved in water and tagged with P^{32} solutions.

As a considerable health hazard is involved in handling quantities of P^{32} of the order of 100–300 mC, appropriate safety precautions had to be taken. These consisted of protective screening during the preparation and application of the fertilizers, the use of long handling equipment and frequent checks with monitors for the detection of personal and laboratory contamination.

Approximately 1 week after the fertilizers were applied in the field, the central part of the youngest leaves were sampled for the determination of the radio-activity. Bulk samples of the leaflets from two or three whirls of young leaves were taken with weekly intervals. After drying at 90°, the leaves were digested in concentrated sulfuric and nitric acids and the activity of the digest was determined by means of a liquid Geiger counter. In the case that the sample contained both Ca^{45} and P^{32} the counting was done with an end window counter, according to the technique described in part I.

B Experiment in nursery

1 *Description of experiment*

One liter of a suspension, containing 200 g of monocalciumphosphate, tagged with 1.2 mC P^{32} and 0.44 mC Ca^{45} was supplied to each of 6 palms. Each palm was surrounded by 4 neighbour palms. As the distance between the palms was 1 m, and the phosphate applied in a square at 50 cm from the base of the palms, each neighbour palm was therefore automatically supplied with one quarter of the application, or 50 g of monocalcium phosphate, located in a strip of 1 m. The fertilizer was applied on the surface, at a depth of 5 cm and at a depth of 10 cm.

Leaf samples were taken at weekly intervals, starting on the 3rd day after the application was made.

2 *Results*

Table 1 shows the average uptake of P^{32} and Ca^{45} during the course of the experiment. It may be seen that for both elements the uptake was considerably greater in the case of surface application than for placement at a depth of 5 or 10 cm.

Table 1 Average uptake of P^{32} and Ca^{45} in $\mu C/100$ g dry matter.

Element	Placement	Weekly samplings			
		1st sampling	2nd sampling	3rd sampling	4th sampling
P	Surface	1.27	0.57	0.57	1.08
	5 cm depth	0.43	0.17	0.25	0.27
	10 cm depth	0.40	0.17	0.12	0.23
Ca	Surface	0.20	0.38	0.57	0.53
	5 cm depth	0.10	0.07	0.10	0.13
	10 cm depth	0.07	0.07	0.05	0.22

The P^{32} content of the leaves was relatively high in the beginning and at the end of the experiment. This was not the case for the Ca^{45} content, which showed a steady increase for the surface placement and only an increase at the end of the experiment for the placement at 5 or 10 cm depth. This different behaviour of P^{32} and Ca^{45} is the result of the different mobilities of P and Ca in the palm and the irregular water supply during the course of the experiment. The fertilizers were supplied as a suspension shortly after a rainy period, which resulted in an initial rapid uptake of P and Ca. The following rain obtained shortly before the 3rd sampling. The variation in water supply during the course of the experiment may be illustrated by the moisture content of the soil (table 2) at various depths.

Table 2 Moisture content of the soil at the experimental site.

Depth	1st sampling	2nd sampling	3rd sampling	4th sampling
0– 5 cm	9.4	6.3	13.6	13.7
5–10 cm	9.6	8.3	12.4	13.5
10–15 cm	9.8	9.7	13.4	13.4

The high initial moisture content of the soil at the time the fertilizer was applied, accounts for the rapid uptake op P^{32} and Ca^{45}. It may be seen however that the activity of P^{32} in the leaves decreased when the soil dried out during the first part of the experiment and only increased towards the end of the experiment. This was not the case for Ca^{45}, which showed an increase in activity, particularly when the fertilizer had been applied on the surface. The behaviour of P^{32} and Ca^{45} suggests that the uptake of these elements was reduced when the soil was dry and translocation of P^{32} to other leaves and growing tissues caused a net decrease of the activity in the three youngest leaves. As it was shown that Ca is not or very little translocated from the leaves where it has accumulated, the Ca^{45} activity in the leaves did not decrease.

The effect of placement in a strip is shown in table 3. In the table, the position of the leaves at the same side as the strip in represented by A, the opposite side by B and the leaves parallel to the strip by AB. The activities of P^{32} and Ca^{45} have been expressed as a percentage of the content of the leaves in the A position, receiving the fertilizer on the surface.

Table 3 The distribution of P^{32} and Ca^{45} in palms receiving the fertilizer in one strip (expressed as a % of surface placement A).

Element	Placement	A same side as placement	AB parallel placement	B opposite of placement
P^{32}	Surface	100 %	68	46
	5 cm depth	25	10	18
	10 cm depth	9	3	9
Ca^{45}	Surface	100	121	75
	5 cm depth	25	17	21
	10 cm depth	17	0	4

The data in table 3 confirm the findings of the sand culture experiment, that placement of calcium phosphate in one point, or in this case, in one strip, induced an irregular distribution of P^{32} and Ca^{45} in the leaves.

3 *Conclusions*

Placement of $Ca(H_2PO_4)_2$ on the surface resulted in a much higher uptake of Ca and P than at 5 or 10 cm depth.

Placement in one strip resulted in an uneven distribution of Ca and P in the palms; the leaves bordering to the side of the placement showing the highest Ca and P uptake.

Rainfall had a pronounced influence on Ca and P uptake. The uptake was retarded when the moisture content of the soil was low.

C EXPERIMENTS IN YOUNG PLANTATIONS

1 *1 year old palms*

This experiment compared the following treatment combinations:

a Placement of fertilizers close to the base of the stem (A) at crown diameter (B) or outside crown diameter (C).

b Placement on the surface or howing the fertilizer into the top 5 cm of the soil.

c The application of very soluble monosodium phosphate or of less soluble monocalcium phosphate.

All palms received 500 g monosodium phosphate or an equivalent quantity of monocalcium phosphate, tagged with 3 mC of P^{32}.

The experiment comprised 36 palms and was layed out in 3 randomized blocks, each containing the 12 treatment combinations.

In addition, 5 palms were sprayed with 1 liter of a 3 % solution of monopotassium phosphate, of the same specific activity as the fertilizer which was used in the above experiment. From each palm only half of its leaves were

sprayed, by deviding the leaves into two parts by means of a polytene sheet and spraying at one side of the sheet only. The object of this experiment was to find out whether translocation would take place to the non sprayed leaves and how this would be quantitatively related to normal uptake after placement of 500 g of fertilizer of the same specific activity in a ring around the palm.

If all the leaves of the palms would have been sprayed, it would not have been possible to differentiate between the activity of phosphate absorbed by the leaf and the phosphate still sticking on the surface of the leaves.

Results

From figure 4 it may be seen that placement inside crown diameter resulted in the greatest phosphate uptake, whereas placement outside crown diameter compared very unfavourably with the other two distances.

The difference between surface placement and howing in, as demonstrated in figure 5, appeared small and insignificant. The difference in solubility of the phosphate had very little effect on the uptake as is suggested by figure 6. Although the uptake of monocalcium phosphate was slightly more than that of monosodium phosphate, the difference was not significant at $P = 0.05$. The translocation of P from the sprayed to the non-sprayed leaves has also been given in figure 6. It may be seen that the translocation of P was much less than the uptake of P through the roots. On the other hand, it should be born in mind that only 1 liter of 3% monopotassium phosphate was sprayed on the leaves, whereas the palms of the experiment received 500 g of phosphate.

After approximately 1 month, the translocation rate decreased, presumably due to the fact that rainfall had removed the phosphate from the leaf surface.

The activity of the leaves of all palms, including the sprayed ones, decreased after the first sampling. This may be explained by the fact that the second sampling was carried out after a period of 10 days dryness. Consequently, the translocation of P from the youngest leaves to other parts of the

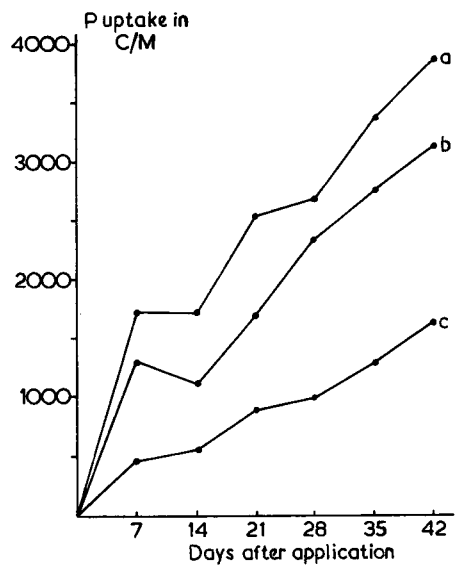

FIG. 4 THE EFFECT OF PLACEMENT INSIDE CROWN DIAMETER (a), AT CROWN DIAMETER (b) AND OUTSIDE CROWN-DIAMETER (c) ON PHOSPHATE UPTAKE OF ONE YEAR OLD PALMS.

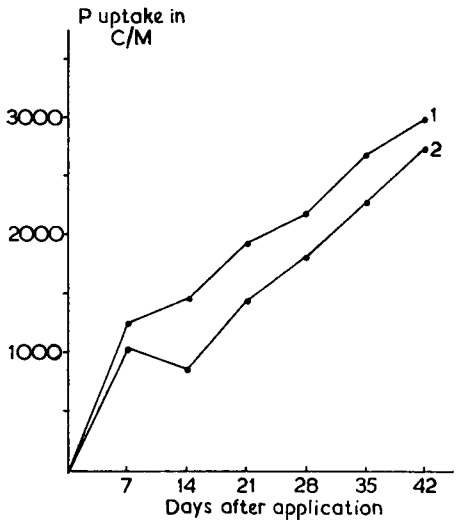

FIG. 5 THE EFFECT SURFACE PLACEMENT (1) AND HOWING IN OF THE FERTILIZER (2) ON PHOSPHATE UPTAKE OF ONE YEAR OLD PALMS.

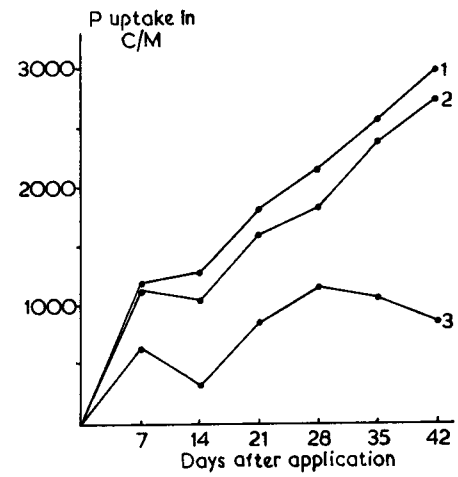

FIG. 6 THE INFLUENCE OF THE SOLUBILITY OF THE FERTILIZER ON PHOSPHATE UPTAKE OF ONE YEAR OLD PALMS.

1 Monocalciumphosphate.
2 Monosodiumphosphate.
3 Spraying of monopotassium phosphate.

palms, exceeded the uptake of P through the roots. It is somewhat surprising that the same phenomena was observed in the case of the sprayed palms.

2 *2 years old palms*

The experiment was of similar design as the previous one and compared the following treatment combination :

a Placement close to the stem, at crown diameter and outside crown diameter.

b Application on the surface and howing in.

There were 3 replications in blocks of 6 palms. Each palm received 500 g monocalcium phosphate, tagged with 3 mC of P^{32}.

Results

The effect of distance of placement has been given in figure 7 ; in figure 8 surface application and howing in have been compared.

Although the placement close to the stem resulted in a slightly higher uptake than placement at crown diameter, the difference was not statistically significant. Placement outside crown diameter is very unfavourable as compared with the other distances.

There was no effect from howing in the fertilizer. Figure 8 shows that the uptake from fertilizer placed on the surface and howed in fertilizer was about equal.

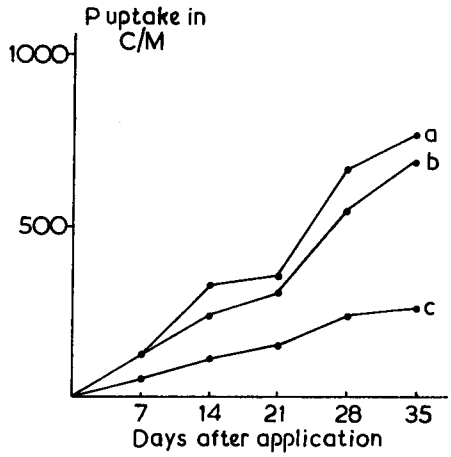

FIG. 7 THE EFFECT OF PLACEMENT INSIDE CROWN DIAMETER (a), AT CROWN-DIAMETER (b) AND OUTSIDE CROWN-DIAMETER (c) ON PHOSPHATE UPTAKE OF 2 YEAR OLD PALMS.

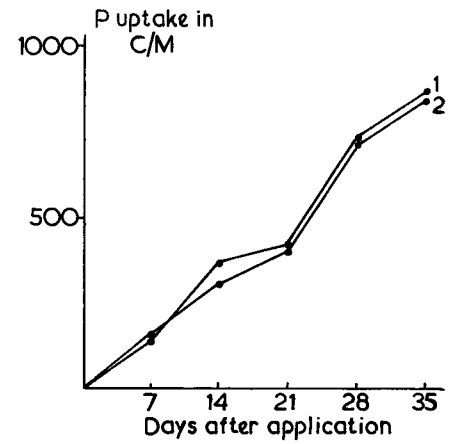

FIG. 8 THE EFFECT OF SURFACE PLACEMENT (1) AND HOWING IN OF THE FERTILIZER (2) ON PHOSPHATE UPTAKE OF 2 YEAR OLD PALMS.

3 *3 year and 4 year old palms*

The treatments and lay out of these experiments were similar to the previous experiments. In this case, all palms received monosodium phosphate. Instead of the howing in treatment, the fertilizer was placed in fisures which had been made at ± 10 cm depth with a spade.

Results

The results of the experiment on 3 year old palm have been given in figure 9 and 10. The placement of phosphate on the surface at crown diameter appeared by far the best method of placement (sign. at P = 0.01). Placement at a depth of 10 cm reduced the uptake considerably. The experiment on 4 year old palms gave similar results as the one on 3 year old palms (figure 11 and 12). In this case the application of phosphate on the surface outside crown diameter resulted in a higher P uptake than placement close to the stem, which suggests that the active part of the roots, which is mostly involved in nutrient uptake, is gradually moving in a direction away from the stem, when the palm grows older.

4 *11 years old palms (adult plantation)*

The last experiment of the series was carried out on adult palms, with a view to determining whether the findings for young palms were equally valid for palms in production. With regard to distance of placement, it is obvious that the treatments "outside crown diameter" and „inside crown diameter" were not possible in adult plantations, in which the crowns are overlapping. Instead of the treatments which were given in the previous experiments, the distances of placement were as follows:

a inside the clean weeded ring,
b at half the distance between two adjacent palms,
c in between a and b.

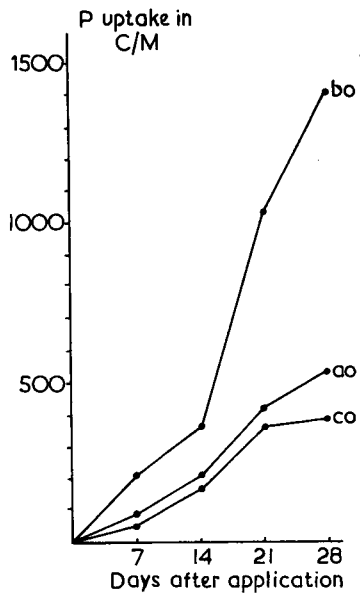

FIG. 9 THE EFFECT OF PLACEMENT ON THE SURFACE INSIDE CROWN DIAMETER (ao), AT CROWN DIAMETER (bo) AND OUTSIDE CROWN DIAMETER (co) ON PHOSPHATE UPTAKE OF 3 YEARS OLD PALMS.

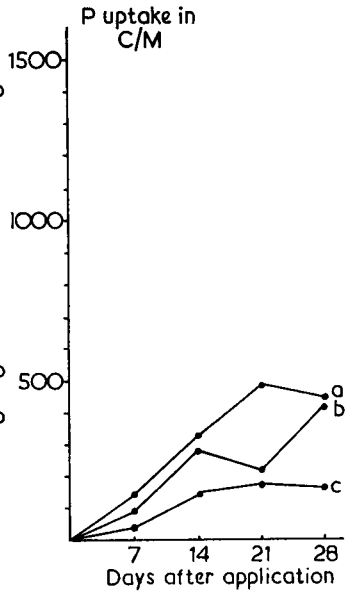

FIG. 10 THE EFFECT OF PLACEMENT AT 10 CM DEPTH INSIDE CROWN DIAMETER (a), AT CROWN DIAMETER (b) AND OUTSIDE CROWN DIAMETER (c) ON PHOSPHATE UPTAKE OF 3 YEARS OLD PALMS.

These distances were compared for each of the following ways of applications: placement on the surface, howing in and at 15–20 cm depth.

All palms received 1 kg of bicalciumphosphate, labeled with 5 mC of P^{32}. Prior to the fertilizer application the area around the palms were slashed. The experiment comprised 27 palms and was laid down in 3 randomized blocks, each containing the 9 treatment combinations. The fertilizer was applied at the end of the rainy season.

Results

The main effects of distance and depth treatments have been given in figure 13 and 14.

With regard to the distance of placement, no significant differences could be observed. The placement inside the clean weeded ring (figure 13) resulted in a reduced fertilizer uptake, but the difference with the other distances was not significant. Apparently an optimal distance of placement does not exist in adult plantations. Placement in the surface was highly significantly better than placement at a depth of 15–20 cm.

Surface placement compared favourable with howing in, but the difference was not significant at $P = 0.05$. The results of this experiment showed that there was a rapid uptake of P from bicalciumphosphate even during the dry season. Despite the dry periods during the course of the experiment and the fact that a rather insoluble source of phosphate had been applied, the palm leaves showed a steady increase in leaf P. This would suggest that adult palms

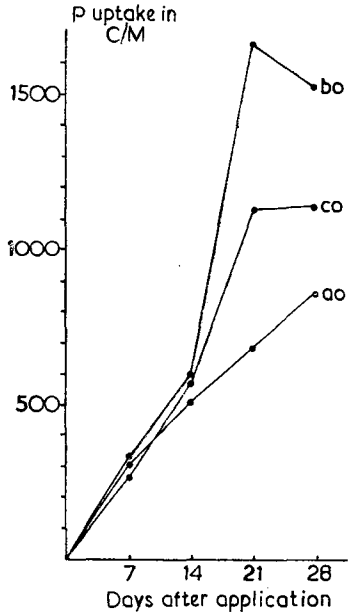

FIG. 11 THE EFFECT OF PLACEMENT ON THE SURFACE INSIDE CROWN DIAMETER (ao), AT CROWN DIAMETER (bo) AND OUTSIDE CROWN DIAMETER (co) ON PHOSPHATE UPTAKE OF 4 YEARS OLD PALMS.

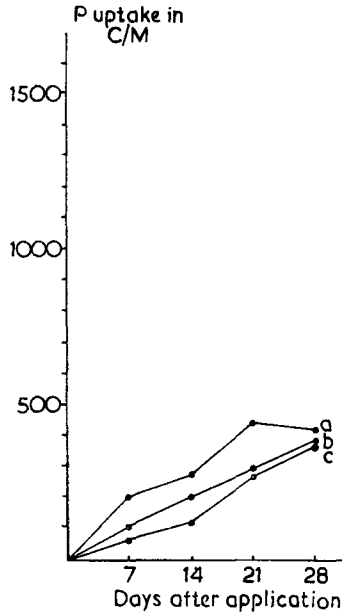

FIG. 12 THE EFFECT OF PLACEMENT AT 10 CM DEPTH INSIDE CROWN DIAMETER (a), AT CROWN DIAMETER (b) AND OUTSIDE CROWN DIAMETER (c) ON PHOSPHATE UPTAKE OF 4 YEARS OLD PALMS.

which have a more extended root-system than young palms, are less sensitive to dry periods in respect of nutrient supply.

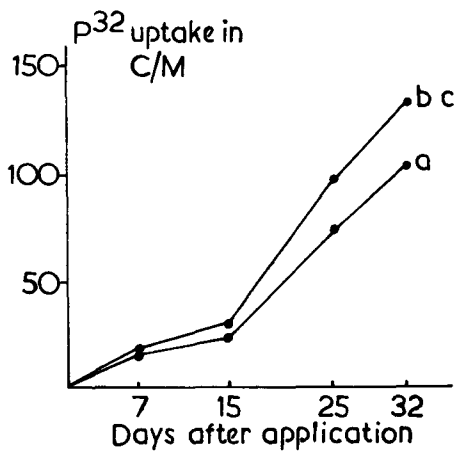

FIG. 13 THE EFFECT OF PLACEMENT INSIDE THE CLEAN WEEDED RING (a), AT HALF THE DISTANCE BETWEEN 2 PALMS (b) AND BETWEEN (a) AND (b), ON PHOSPHATE UPTAKE OF 11 YEARS OLD PALMS.

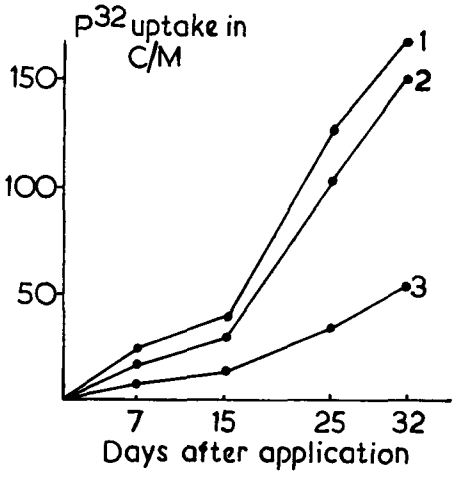

FIG. 14 THE EFFECT OF PLACEMENT ON THE SURFACE (1), HOWING IN (2) AND PLACEMENT AT 15–20 CM DEPTH (3) ON PHOSPHATE UPTAKE OF 11 YEARS OLD PALMS.

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