DETERMINATION OF ROOT ACTIVITY OF BANANAS (NAKYETENGU CULTIVAR OF THE COOKING TYPE) DURING WET AND DRY SEASONS AS MEASURED BY RADIOACTIVE PHOSPHORUS (P-32) UPTAKE.

by

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I, Henry Ssali, hereby declare that the work presented in this thesis has not been presented in any previous application to another University for a degree.

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ABSTRACT

The root activity of Nakyetengu, a local cultivar belonging to the cooking type of bananas, was studied using radioactive phosphorous (P-32). The study was conducted at the University Farm at Kabanyolo, on a clayey, highly weathered and leached well drained ferrallitic soil typical of the major banana growing region in Uganda. The study consisted of two experiments, one in a typical dry season and the other in a typical wet season.

The P-32 was injected into the soil at four different depths (0, 15, 30 and 60cm) below the soil surface and at four different distances (40, 80, 120 and 160cm) from the pseudostem of the plant. The banana plants used as experimental units were in the late vegetative phase, 7-9 months old. The radioactivity of the leaf samples from the third fully opened leaf of each treated plant was used to assess the amount of P-32 taken up by the plant from the treatment zone over a period of 40 days.

In the dry season, highest uptake of P-32 was recorded at the soil surface near the plant

(40cm. distance) but further away from the, highest uptake of P-32 was obtained from deeper placements of P-32. In the wet season, however, most of the P-32 uptake was in the top layers of the soil. (0 and 15cm. depth) especially further away from the plant. The uptake of P-32 in the wet season was much higher than that in the dry season, and, in both experiments, there was little uptake of P-32 from the 60cm. depth.

I N T R O D U C T I O N

The banana plant belongs to the genus *Musa*. The edible bananas originated from *Musa Acuminata* and *Musa Balbisiana* which are both members of the *Eumusa* section of the genus Musa. The plant is believed to have originated from South East Asia. In East Africa, the banana was first recorded at Mombasa around 1300 A.D. and it may have come from Java via Madagascar. Alternatively, it is thought that the Arabs introduced it to the Holy Land and Egypt from where it spread to equatorial Africa via the Nile valley. In Buganda, where this crop is the staple food, it is traditionally believed to have been brought by the legendary ancestor of the Baganda people, Kintu, from Mount Elgon. Hence as far as the Baganda people know, the banana was here with the formation of the Kingdom of Buganda.

Bananas in Uganda are classified on the basis of how the fruit of the plant is used. There are four main categories (Luganda names in brackets):

(a) Cooking bananas (Matoke).

The fruits from these plants are harvested when they are mature, but before they begin to ripen. Then they are boiled or steamed and mashed before being eaten.

(b) Roasting banana (Gonja).

The fruit from these may be harvested before they are ripe or after ripening, but they are normally roasted before being eaten.

(c) Beer bananas (Mbidde and Kisubi).

These are not normally eaten unless there is a famine. The fruit is normally harvested when mature and then kept in a warm place until ripe. The juice is then squeezed out and beer made by fermenting this juice with sorghum.

(d) Sweet Bananas (Sukali Ndizi, Bogoya).

The fruit from these plants have a higher sugar content than those of the other varieties. They are eaten raw when they are ripe.

There are a number of cultivars in each of the categories listed above, especially in

the cooking category, but the exact number of cultivars in East Africa has not been established. Shepherd (1957) pointed out that there are probably not more than 55 cultivars in East Africa, but these are represented by over 200 local names.

Simmonds (1957) noted that Uganda was the world's biggest producer of bananas for local consumption. In the most recent Uganda Agricultural Census, (1965/67) it was reported that the total area of the country devoted to bananas was 1,147,000 acres, second only to cotton. It was also reported that the percentage of holders who grew the crop in the country was 73.2. This was the highest percentage for all crops. This is due to the fact that the crop is the staple food in a number of districts in Uganda, especially those in the fertile crescent of Lake Victoria (the elephant grass zone). This includes East and West Mengo, Busoga, Bugisu, Ankole, Toro and Bunyoro. The crop is now spreading further north into Teso, Lango, Acholi and West Nile.

The above census showed that the percentage (acreage in brackets) of holders who grew bananas was 92% (552,000A) in Buganda, 82% (418,000A) in the West Region, 74% (188,000A) in the Eastern region and 27% (19,000A) in the Northern region.

The bananas are normally grown on small holdings near the homestead of the owner who normally has a plantation of cooking bananas with a few roasting bananas and then the sweet and beer-making bananas on the outside of the plantation to shield the more important food crop from wind and cattle damage. Since the banana plant is fairly resistant to seasonal changes, weeds, pests, and diseases, the small holder has taken the crop for granted since the introduction of cash crops. It has, however, been found that the banana plants make a very big demand on soil fertility (Rimington 1964). The small holder used to overcome this by planting only on fertile land and when fertility was exhausted, he would look for some new ground. This practice is

becoming increasingly more difficult to follow as the labour to land ratio increases.

In the agricultural census mentioned above, the average yield for the cooking type of bananas in West and East Mengo districts was estimated to be between 3 and 4 tons/acre/year. In other areas (eg. Honduras) where the bananas are grown commercially, yields are very high at around 20 tons/acre. When it is borne in mind that the bunches in these areas are harvested when only a half to three-quarters full, then this figure in Uganda would be 30 to 40 tons/acre (Parish 1969). This indicates the potential yield of the bananas and that if farmers in Uganda can improve their agronomic practices, more bananas could be produced on less land.

Before recommendations can be made to the farmers to improve agronomic practices, research has to be done to find out the exact requirements of the banana plants in East Africa. The department of soil science and agricultural chemistry at Makerere University, Kampala, in

conjuction with the research stations of the Governments of Uganda and Tanzania, have established manurial trials at five different sites distributed throughout the major banana growing region. At the University farm, Kabanyolo, a manurial trial has been established using a dwarf variety of banana, Nakyetengu. From the results of the manurial trials, the response to essential nutrients for the bananas will be established but, fertilizers are expensive and for their economic use, they must be well placed in the soil. The root systems of plants are essential organs by which nutrients and water are absorbed. A Knowledge of the distribution of active plant roots in the soil is therefore an essential pre-requisite to the rational use of fertilizers.

The investigations in the rooting habits of plants were previously done by direct visual observations of the root systems (excavation, root washing or root observatory methods) or by field experiments. The former method besides being

laborious if a number of replicates are to be used, only provides a picture of the root distribution without distinguishing between active and non-active roots. In the latter method, the efficiency of fertilizer placement methods was assessed by means of yield or growth measurements data or the chemical composition of plant materials. This method requires a lot of land and takes a very long time especially for perennial crops. With the development of radiotracer techniques, the activity of plant roots can be investigated *in situ* with very little soil disturbance and in a very short time.

The International Atomic Energy Agency (I.A.E.A.) in conjuction with the Food and Agriculture Organisation (F.A.O.) have established a series of projects to study the efficient use of fertilizers in a number of countries using radio isotopes. The research that has already been done on the efficient use of fertilizers has indicated that the distribution of active roots of various

plants depends on the supply of the moisture in the soil (Holiday and Draycott 1968, Balakrishnamurti 1970, and Huxley et al 1970).

The object of this project, therefore, was to study the distribution of active roots of "Nakyetengu" a dwarf variety of the banana during both the wet and dry seasons using radiotracer techniques.

LITERATURE SURVEY

In East Africa, very little research has been done on the bananas. Rimington (1964) reviewed available information about the banana in East Africa with particular reference to Kenya. He reviewed general agronomical practices and summarized some of the research that has been done especially in Kenya. In the report he mentions that in an irrigation trial at Jacaranda, Kenya (in 1955), five of the six varieties used in this trial gave better yields under irrigation. In a fertilizer agronomy trial at Malinduko, it was found that pit planting and mulching were advantageous. He noted that there were too many varieties in East Africa to mention individually. This question of varieties is not yet fully understood in East Africa. Baker and Simmonds (1952) made a survey of the banana cultivars in East Africa and they reported that some of the clones were identical to those in the West Indies, but that many of these clones were regarded as "alien" sorts by the East Africans. They reported that the majority

of cultivars found in East Africa were unfamiliar and that they were evidently distinct from those known from other banana-growing areas. They noted that native names could not help in classfying the clones because the names were of very limited distribution and often far exceeded the actual number of clones present. They estimated about 70 cultivars in East Africa represented by over 200 native names. Shepherd (1957) compared 51 clones from East Africa with a standard collection at the Imperial College of Tropical Agriculture, Trinidad. He reported that somatic mutation has contributed much to the diversity in the native names and that there are probably not more than 55 cultivars in East Africa altogether. He pointed out that the majority of these cultivars were types that originated from Musa Acuminata and that very few of them were yet known outside East Africa.

Simmonds (1966) reports on much of the work that has been done elsewhere on the bananas.

especially in the West Indies and Australia. Regarding the root system of the bananas in general, he reported that the roots usually arise in groups of fours at the junction between the central cylinder and the cortex of the corn and that these roots mostly spring from the upper parts of the corn and then spread laterally in the upper layers of the soil. He reported that the majority of the roots are normally found in the top 15cm. of the soil and that the banana root bears numerous laterals of a much smaller diameter than the main roots and that these, bearing root hairs, are believed to be responsible for the nutrient and water uptake by the plant. These are what are commonly referred to as "feeding roots". He further reported that according to Fawcett (1913) the laterally spreading roots extend to about 520cm. from the plant while the descending ones commonly go down to a depth of 75cm. in the soil. Summerville (1939) found that roots arising from the lower parts of the corn,

normally fewer in number than the crown roots, tend to grow downwards but that there was no sharp distinction between spreading and descending roots as all intermediates existed. He noted that the "feeding roots" referred to above mainly occurred in the distal portions of the main roots and recommended that fertilizers should not be placed too close to the mat. In 1944 he found that a healthy "Dwarf Cavendish" corm bore 200-300 roots.

Awuor-Okullo and Parish (1969) worked on the root system of the sweet and cooking (matoke) types of the banana. They found that for both types, there was a dense network of roots from 2-3cm. down to 50cm. below the soil surface. Below the 50cm. depth, they found a sharp decrease in the occurence of primary roots while the secondary roots gradually decreased to a depth of 75cm. They found that the roots that descended down to 75cm. and below mainly originated from the base of the corm and that they

were mainly vertical compared to the predominantly horizontal roots present in the top 50cm. They found that the sweet varieties of the banana studied had a well developed secondary root system descending down to 220cm. from the soil surface while the cooking varieties studied had roots descending down to only 140cm. at the most. They found that a banana plant has more living roots at flowering than at maturity and that after flowering and bunch formation, some of the roots start to die and decay. Awuor-Okullo (1969) found that for "Nakyetengu" (a cooking type) the longest lateral roots went out to about 450cm. while the maximum rooting depth was only 140cm. He found that a healthy corm of "Nakyetengu" bore 300-400 roots. He also found that the area of greatest root concentration for this particular cultivar was within a distance of 51cm. from the base of the plant.

Walmsley and Twyford (1968a) working in the West Indies found that for the Robusta Banana,

in the late vegetative phase or in the early fruiting stage, the maximum distance at which nutrients were taken up was 244cm. (8ft). Hence they recommended that fertilizers should be broadcast over the whole field since the normal spacing between the mats in this area is 244x244cm. (8 x 8ft). Radioactive phosphate was used in this experiment but no depth placements were involved.

Most of the work done above on the root system of the bananas was done using the jet-wash method. This method only reflects how the roots are distributed in the soil without indicating the most active portions of the roots. Radioactive tracer techiniques have been used successfully to study the activity of roots (Ahenkorah 1969, Balakrishnamurti 1970, Boggie and Knight 1960, Hall et al 1953 etc.). In this sort of study a number of radioactive isotopes can be used (eg. radioactive Rubidium Rb-86, phosphorous P-32, Sulphur S-35 etc.). A good

radioisotope to use for the study of root activity should have a convenient half-life time, high mobility within the plant, relatively mild health hazards, and should be immobile in the soil. The half-life time of the radio-active isotope should not be too long as this would introduce residual problems in the soil, but it should be long enough to cover the experimental period. In order to minimise health hazards, the particles emitted should be mainly low energy beta-particles. S-35 has a half-life time of 86.7 days and decays emitting mainly beta-particles of 0.167 Mev energy. Rb-86 has a half-life time of 18.7 days and decays emitting mainly beta-particles of 1.77Mev and 9% gamma-radiation. P-32 has a half-life time of 14.3 days and decays emitting beta-particles of 1.71 Mev. (Weast & Selby 1965-6). Huxley et al (1970 working on the Kikuyu Red loam type of soil in Kenya, found that Rb-86 (as the chloride) over a short time did not move more than 2-3cm. from the point of injection in this soil while P-32 moved an

even shorter distance. They found that ihitially Rb-86 was taken up more quickly than the P-32 but that with time the distribution of Rb-86 was rather more variable than that of P-32. Yu-Yuan (1970) working in Taiwan found that 99.9% of the P-32 solution injected into the soil did not move from the point of injection. There are certain experiments in which Rb-86 has been preferad to P-32. Jones (1963) working on the root distribution of elephant grass and chloris gayana at Namulonge, Uganda, found that P-32 was not suitable for use in the subsoil layers while Rb-86 was used successfully on the same soil down to a depth of 244cm. (8ft). He suggested that the failure of P-32 in the subsoil layers could have presumably been due to its rapid fixation into forms which are unavailable to plants. Nethsinghe (1970a) noted that systematic variation in the soil phosphate down the soil profile could occur under normal conditions or

due to previous fertilizer application. He noted that this variation in the soil phosphate could lead to erroneous interpretation of results in certain soils and suggested that errors arising from this could be minimised by injecting a P-32 solution with a high concentration of phosphorous.

Russel et al (1954) and Nye and Foster (1960) have shown that isotopic exchange between the applied radioactive phosphate and soil phosphate could occur and invalidate absolute estmates of fertilizer uptake by the plant. On this problem, Nethsinghe (1964) stated "isotopic exchange would not affect comparative estimates of fertilizer uptake by the plants from different placements on the same soil provided that (a) the content of isotopically exchangeable phosphate in the soil is the same at the different points of placement, and (b) the same quantity of labelled phosphate is applied according to the different

methods on equal surface areas of the soil. If condition (a) is not satisfied, the fertilizer uptake from locations where content of exchangeable phosphate is higher can be under-estimated".

In root activity studies involving use of radioactive tracers, it is assumed that the pattern of root activity using one tracer would be equally valid for other nutrient elements for the same plant. Nethsinghe (1970a) carried out an experiment to test the validity of this assumption using P-32 and N-15. The results from both experiments indicated a similar pattern of root activity and showed that there was no reason to doubt the validity of this assumption. Another assumption in the use of radioactive tracers to study root activity is that for maximum efficiency of fertilizer utilization, fertilizers should be placed in zones of highest root activity. Nethsinghe (1979a) carried out an experiment on mature apple trees to compare the results

obtained from the P-32 injection method with those obtained using P-32 labelled super - phosphate (20% P_2O_5). The labelled superphosphate was placed in an 8 cm band around the tree at the various positions tested. The results showed that in both techniques highest P-32 uptake was at the 20cm. depth and no significant differences were obtained between the distance placements in both techniques.

The methods of P-32 injection into the soil has varied depending on the plant whose root activity is being studied and the treatments involved. Walmsley and Twyford (1968 a&b) working on the nutrient uptake of the Robusta Banana, used the bund method for applying the labelled phosphate solution. In this method, circular bunds (61cm. diameter) were made around the banana plant. Water was poured into the bunds, allowed to soak in and then labelled phosphate (a carrier free P-32 solution as orthophosphate in dilute hydrochloric acid,

diluted in a phosphate solution prepared from sufficient triple super phosphate fertilizer to allow ½lb. to each plant) poured into the bunds. When the active solution had soaked in, more water was poured into the bunds to ensure that the active solution reached the rooting zone. In this experiment no depth placements were considered and the method is not satisfactory where such placements are to be considered. The commonly used method to study both distance and depth placements on tree plants is by injecting the P-32 solution in holes dug to the required depth at the appropriate distances. Lipps et al (1956) using P-32 to study the root activity of alalfa found that 36 equidistantly spaced holes (3.2cm. diameter) gave similar results to 9 equidistantly spaced holes (7.6cm. diameter). They considered the method with fewer holes better because there would be less soil disturbance and hence less chance of having root channeling. In the study of root activity of tree crops conducted in conjunction with the

I.A.E.A., 16 equidistantly spaced holes (2.5cm diameter) in a ring around the plant have been used. The main criticism with this method is that the holes might be too few especially for placements further away from the treated plant. If holes are made in concentric circles around a plant (16 equidistantly spaced holes in each circle) the distance between any two holes in the furthest concentric circle, will be much greater than the distance between any two holes in the concentric circle near the plant. This would mean that further away from the plant there would be fewer roots in contact with the labelled phosphate. Nethsinghe (1970a) carried out an experiment on mature apple trees to test the effect of using 16 and 32 injection points at the 50cm. and 100cm. distances using 9 replicates. He found no advantage in using the 32 injection points treatment. He also reported that this conclusion has been supported by data from coconut experiments in Ceylon. Further support comes from the experiment mentioned above where the labelled superphosphate (20% P_2O_5) and

the P-32 injection method were used to show the pattern of root activity. The results were similar for both methods. In this experiment the labelled superphosphate was applied in a band (8cm. wide) at all distances around the tree while 16 injection points were used in the second method at all distances. In both methods the coefficient of variation for a tree was in the order of 40%. If the high variation was due to variations in the P-32 coming into contact with the roots, then the band application should have given a considerably lower variation.

Some workers (eg. Walmsley and Twyford 1968a&b) using P-32 as a radiotracer have applied it as a carrier-free solution or powder of the orthophosphate. As it has been mentioned before, owing to the possible systematic variation in the soil phosphate down the soil profile, Nethsinghe (1970a) recommended injecting a P-32 solution with a high concentration of phosphorous in order to try and mask the possible effects of phosphate variation down the profile. As a result of this the I.A.E.A. recommends

applying P-32 with 4mg. P per injection point.

The dosage of radioactivity should depend on the resistence of the particular plant to radiation damage. Russel et al (1949) observed that young barley plants were affected by radiations when exposed to levels of P-32 above 0.8 microCuries per 1500gm. of soil for one week in pot culture studies. Hence a preliminary experiment should always be done to determine a safe dose to use for the particular plant. The dosage of radioactivity, however, should be big enough to ensure that there is sufficient P-32 absorbed by the plant for quantitative assay. Walmsley and Twyford (1968b) working on the uptake of P-32 by the Robusta Banana reported "Assuming that a count rate of at least twice the background count is desirable before a reliable estimate can be made, then fertilizer with an activity of at least one millicurrie per plant would be necessary in the experiments using this technique."

Various methods have been used for placing the

P-32 solution into the holes. Huxley et al (1970) after making the hole to the desired depth inserted a fitting rigid plastic tube which was partly crimped at the bottom end. The tube was then withdrawn after insertion approximately 3-5cm. to leave a small soil "chamber" into which the ampoule contents could drain. The ampoule was then dropped down the tube and then crushed by means of a pointed spike. The tubes were kept corked and they were not removed from the holes. There was no evidence for root channeling. Jones (1969) used larger holes (7.5cm. diameter) filled with sand (25cm. thick) at the bottom of the hole. He then put polythene tubes (1.2cm external diameter) in the middle of the hole down to 2.5cm below the surface of the sand. The channel around the polythene tube was then filled with a slurry of subsoil and water and, the upper 10cm. were packed with moistened top soil. The results showed a high degree of variability and he dug pits adjacent to the placement holes to investigate whether there was any evidence of root channeling.

He reported "In many of the holes it was found that roots had grown between the slurry and the undisturbed soil of the sides of the hole. Apparently the slurry had cracked away from the sides of the hole as it dried. Roots which had grown down the hole in this way proliferated in the sand if they reached it and these effects combined to give a false impression of the root density in the placement zone." Nye and Foster (1960) have also mentioned that there was a possibility that disturbance of soil during injection of isotopes into the soil might allow easy access for roots to reach the treated zones. Hall et al (1953) suggested that to minimize the possibility of root channeling, holes should be made 60° to the horizontal. Nye and Foster (1960) tried this method but did not find it advantageous. The IAEA recommended method is to dig holes (about 2.5 cm diameter) to the desired depth and the P-32 solution, dispensed in ampoules, is placed into the hole by means of a hollow brass tube with a crushing device. After crushing an ampoule in

each hole 10 ml of water are poured down the hollow brass tube so that any P-32 solution which might have been adhering to the sides of the tube is washed down. Then the hole is filled with dry soil. There has been no evidence of root channeling reported.

In experiments using radiotracers to determine the activity of roots, single plants are used as experimental units. Therefore, these experimental units should be as uniform as possible. Wethsinghe (1970a) reported that in an experiment on coconut trees in Ceylon, there was a marked negative correlation between leaf P-32 content and the girth of the tree trunk at all the four dates of sampling. By eliminating the effects of girth, the variation was reduced by about 12% for all dates of sampling. A similar effect was observed, in the same experiment for number of fruits. Apart from the girth measurements and the height of the plant, the physiological stage of the plant plays an important part in the uptake of nutrients. Walmsley and Twyford (1968a &b)

found that the most rapid uptake of fertilizer phosphorous by the Robusta banana occured in the period of vegatative growth from 2-3 months after planting to flower initiation. Huxley et al (1970) noted that the seasonal changes in uptake of P-32 by the Arabica coffee were related to the physiological condition of the plants (eg. flowering and fruiting phases).

The P-32 taken up by the plant has been determined, mainly, by foliar analysis. The type of leaf to sample depends on the particular plant. The leaf sampled should be of the same age and from a similar position on all the plants. For plants which have a number of leaves in the same position (eg. Coffee and Oranges), it is better to take a number of subsamples (eg. a number of leaves from the lower or upper crown) than to take a single leaf. Nethsinghe (1970a) reported "it seems then that the greatest contributory factor to the high variability between individual trees is in errors in leaf sampling arising out of non-uniform distribution of P-32 even between leaves in similar

position and age. Considerable reduction in error should be possible by taking a number of subsamples. All other sources of error discussed above are comparatively small, and subordinate to leaf sampling error."

After leaf sampling the samples are processed depending on whether the wet counting method or the Geiger-Muller end window method is to be used. Walmsley and Twyford (1968a &b) used the wet counting method. Huxley et al (1970) used both the wet counting method and the dry ash counting method using the Geiger-Muller end window method. They did not find any advantage in the use of a wet counting method. The recommended IAEA method (Nethsinghe 1970, Huxley et al 1970, Yu-Yuan 1970, etc.) is to dry the samples (at 70°C), grind and then ash the ground samples. Then the ash is used for P-32 counting using the Geiger-Muller end window method. Alternatively a liquid counting procedure may be adopted where the ash is extracted with 2N HCl and the filtered extract used for liquid Geiger-Muller counting. All counts should be corrected for the contribution of radiation from the naturally occuring radio-

active isotopes in the soil. Talibudean (1964) reported that in the Great Russian plains, two-thirds of total radioactivity of soils were due to the contribution of radioactive potassium (K-40) and thorium (Th) while radioactive carbon (C-14) contributed less than 0.5% and rare earths and other elements had negligible contributions. Of these the beta-emitting isotopes are K-40, Rb-86 and C-14 and, from the findings above K-40 seems to be the most important radioactive isotope to consider in these experiments. Nethsinghe (1964) traced the natural radioactivity in leaflets of the cocconut palm to radioactive potassium (K-40). The counts are normally corrected for the naturally occuring K-40 by either determining K-40 count rate in "blank" samples from untreated trees or double counting of P-32 samples (eg. after 14 days) and calculating the amount of K-40 in each sample after allowing for P-32 decay.

Results have been expressed as counts per minute per mg. of phosphorous (cm./mg.P) or as counts per minute per gm. of dry leaf.

Nethsinghe (1970a) reported that a green house experiment carried out in Seibersdorf in 1967 with barley did show a reduction of error from 24% to 12% when P-32 uptake was expressed as cpm./gm.P. but that data from cocoa experiments in Ghana showed no advantage in expressing results in terms of cpm./mg. P. Huxley et al (1970) also found no advantage in expressing results in terms of cpm./gm.P. The final results are usually adjusted to the date of P-32 application.

By the nature of the experiment, a high coefficient of variation is usually expected and some workers have warned against the use of statistical analysis to interprete data of such experiments. In many of the tree experiments done in conjunction with the I.A.E.A. the coefficient of variation between individual trees was observed to be in the order of 100%. However, treatment differences were large enough to show statistical significance in most of the experiments. Nethsinghe (1970a) using data from experi-

ments to test the validity of the assumption that the P-32 of a particular leaf is directly proportional to the total P-32 uptake by the tree and that the proportionality constant is the same for a similar type of leaf for all root positions, showed that absolute quantitative interpretation of the results for such experiments is not appropriate. The results from these experiments showed a highly significant interaction between the root position and the type of leaf sampled for both distances and depths. This sort of interaction would imply that the above assumption is not valid. This would mean that the roots in a particular position supply more P-32 to certain types of leaves than roots in other positions and that the rates of translocation of P-32 between different types of leaf are dependent on the P-32 content of the leaf. Wethsinghe (1970a) used six different tables of data to show that a closer examination of the data shows that the P-32 uptake can for all practical purposes be considered independent of the leaf type. (ie. if orange tree leaves from the lower canopy are used, they will show a pattern of root activity

similar to that obtained by using leaves from the upper canopy.) The data used was from experiments on Citrus in Taiwan, Cocoa in Ghana and Apple trees at Seibersdorf. He concluded "Even though the interactions observed may be real effects, they are not large enough to invalidate the technique. But one should be guarded about giving an absolute quantitative interpretation to the results which anyway is not the objective of the programme."

EXPERIMENTAL

(a) MATERIALS AND METHODS

(i) Experimental Site. The experiments were carried out at the University Farm located at Kabanyolo. Kabanyolo (0°28' N, 32°37' E) is about 17 Km north of Kampala (Atlas of Uganda, 1962). The Farm covers 206 hectares and straddles two north - south ridges. The elevation on the highest point of the west ridge is 1195m. (3920ft), on the east ridge 1168m. From the rounded and narrow ridge tops, the land grades at 5-6% on the east - facing slopes, and 7-9% on the west slopes, until at the valley edge, it grades abruptly at 15-20% to the narrow flattish bottomlands. The climate is moist tropical with moderate temperatures (Van Eck, 1970). Maxima occasionally exceed 30°C while minima may fall below 15°C. Minimum value for relative humidity may fall to 40% in a dry season. Solar radiation varies from a maximum of over 600 langleys/day to minima of under 100 langleys/day but the monthly average is approximately 400 langleys/day. There is wide daily variation in

both intensity and duration of sunshine.. Annual rainfall is about 1300mm with up to 150 rain-days, with moderate annual, and considerable seasonal variation. Wet seasons follow the solar equinox, but storms of any intensity may occur in any months. Periods of soil water deficit for farm crops occur frequently during dry spells, most often in January to February and July to August.

The elevation, land form, relief and climate at Kabanyolo are typical for the major banana growing region in Southern Uganda.

The experiments were carried out on field A3, in the manurial trial plantation. Field A3 is situated on the Southern end of the mid-eastern slope of the Western ridge. The plant-ation was established in November 1968 and covers an area of 0.89 hectares (2.2 acres). The plantation consists of a dwarf variety of banana (Nakyetengu). The original spacing of the banana plants was 2.14 x 2.14 (7 x 7ft).

The soils of the experimental site are part of the upland cultivated soils of Kabanyolo belonging to the Buganda catena. The soils are sandy clays or clays developed from precambrian schists and quartzites. They are deep, highly weathered and leached, well drained ferrallitic soils with a low cation exchange capacity (8 - 12 - me). They are dark brown soils at the surface changing to dark reddish brown and then red with depth. A soil profile description is given in table 1=A. The soil profile described was situated about 2m. away from the northern end of the banana manurial trial plantation. The organic matter (3%) in the top soil is the main source of the cation exchange capacity. The type of soil described above is widespread in the banana growing regions of Southern Uganda.

The results of the chemical and physical analyses of the soil sampled from the banana manurial trial plantation are shown in tables 1 B; C&D. The soil samples were taken from the twelve plots, used throughout this study

TABLE 1

A Soil Profile Description (At the northern end of the plantation, just outside of the experimental site).

HORIZON	DEPTH CM	COLOUR	STRUCTURE	TEXTURE	ROOTS & FAUNA
A	22	5 Yr 3/4 Dark reddish brown	Moderate crumbs	Clay Loam	Roots abundant Fauna few
B_1	105	2.5Yr 3/6 Dark red	Strong granular	Clay	Roots and Fauna abundant
B_2	From 127+	10R 4/6 Red	Weak massive	Clay	Few Roots and Fauna

(diagram 1 of the appendix). The method used in the chemical analysis of soil samples is the one used at Kawanda Research Station which is based on the method described by Robinson and Semb (1968). In the analysis of soil samples for P, Ca, Mg and K, the soil was extracted with a dilute ammonium lactate-acetic acid solution (AL). The concentrated AL solution was prepared by mixing together 1250 ml of hydrolysed lactic acid, 1125 ml of glacial acetic acid and 350 ml of concentrated ammonia, in a 5 litre volumetric flask. The volume was then made up to the mark with water. The dilute AL solution was then prepared by measuring out 1 litre of the concentrated AL solution into an aspirator and then adding 9 litres of water. The solution was mixed and the pH of the solution adjusted to 3.8 using either acetic acid or ammonia. Air-dry soil (5gm) which had passed a 2mm sieve was shaken with 100 mls of the dilure AL solution for 1.5 hours. After 30 minutes the extract was filtered using No. 5 filter paper.

TABLE 1

B Chemical Analyses.

(Means of twelve replicate samples)

DEPTH (cm)	PH	O.M. %	Available nutrients P (PPM)	Ca (mg/100g)	Mg (mg/100g)	K (mg/100g)	Total N %
0-20	5.4	2.8	5.5	105.7	30.4	25.5	0.110
20-40	5.4	2.8	4.1	123.3	29.1	17.4	0.110
50-70	5.5	1.2	1.2	63.3	29.1	18.7	0.072

The P in the extract was then determined by adding 10ml of 1% chloromolybdic acid and 5ml of 40% chlorostannous acid to 25ml of the extract and then measuring the optical density of the solution in an Evans Electoselenium Limited (EEL) flow-through colorimeter at 650 millimicrons, 15 minutes after the addition of the chlorostannous acid. The amount of P in the solution was then obtained from a phosphate calibration graph. The Ca and K in the extract were determined by adding 5ml of lanthanum chloride solution (2.5%) to 20ml of the extract and then readings taken on an EEL flame photometer. The amounts of K and Ca present in the solution were obtained from calibration graphs. The Mg in the extract was determined by adding 5ml of lanthanum chloride solution (2.5) to 5ml of the extracted solution in a 50ml volumetric flask. The volume was made up to the mark with distilled water. Then readings were taken on the EEL atomic absorption spectrophotometer using a magnesium lamp. The amount of Mg in the

solution was then obtained from a calibration graph. The total nitrogen in the soil samples was determined using the macro-Kjeldahl method (Bremner, 1960 and A.S.A. 1960). The organic matter in the soil samples was determined by measuring the percentage of organic carbon in the soil samples (Walkey, 1947 and Watson, 1956). The organic carbon in 2mm of soil that had passed a 2mm sieve was oxidised with chromic acid (10ml of 4N sodium dichromate and 20ml of concetrated sulphuric acid). Optical density readings were then taken on the EEL flow-through colorimeter at 600 millimicrons. The percentange of organic carbon in the soil sample was obtained by multiplying the meter readings by a factor obtained from a calibration graph. The soil particle size distribution analysis was performed using the Bouyoucos Hydrometer method (Black et al, 1965). The pH of the soil was determined at the moisture saturation point (Jackson 1958). The moisture saturation point was reached by adding

demineralised water to the soil until the soil was fully wetted, yet a hole made by a rod was only slowly closed. The soil pH was then determined at this point using the Pye Universal pH meter.

The moisture at field capacity was determined gravimetrically using the method described by Reynolds (1970). Soil samples were taken three days after a heavy storm (32.5mm). After the storm, the areas to be sampled were covered with polythene paper to minimise evaporation. Undisturbed cores were used in the determination of bulk density and permanent wilting point (Hosegood). The permanent wilting point was determined using the suction plate method (pF 4.2). (Baver, 1948).

(ii) Selection of plots and Mats. Individual mats of banana plants were used as experimental units. The mats were selected in subplots within the manurial trial at Kabanyolo (diagram 1 of the

TABLE 1

C Physical analyses

(Means of twelve replicate samples)

		Moisture content by volume			
DEPTH (mm)	BULK DENSITY	F.C. %	P.W.P. % (pF 4.2)	Available water %	Available water (mm)
0-20	1.38	39.58	20.20	19.38	38.76
20-40	1.50	39.96	21.30	18.68	37.36
40-60	1.52	39.71	24.30	15.41	30.82

Total available water (0-60cm) = 106.94

	Particle size distribution		
DEPTH (cm)	Clay %	Silt %	Sand (by difference)
0-20	42.8	5.8	51.4
20-40	44.2	5.3	50.5
50-70	54.8	5.0	44.7

appendix). Table 2 shows which subplots were selected. The sub-plots selected were those where no phosphorus fertiliser had been applied since the establishment of the plantation. In each sub-plot four mats were selected. The contact mats were not selected as experimental units. The mats in this plantation are pruned so as to leave a maximum of three plants (one mother plant, one follower and one sucker) per mat. Hence the mats used in this study usually consisted of one mother plant and one or two younger plants. The mats were selected on the basis of uniformity, mainly of the mother plant in the late vegetative phase (7-9 months old). Girth (circumference at a height of 1m) and height measurements for each banana plant in the manurial trial are recorded once a month and this information was used in the selection of the mats.

(iii) P-32 Application. The method of application of P-32 was based on the I.A.E.A. method (Nethsinghe 1970b). This is a suitable

method to be used where both distance and depth of placement of labelled fertilizers are to be considered. Sixteen equidistantly spaced holes were made in each selected mat in a ring around the mother plant. The holes, made with a soil probe (screw type), were 2.5 cm in diameter and were dug at the appropriate distances to the required depths. The holes were all prepared in advance and were plugged with wooden rods prior to treatment application to prevent filling up with soil. The p-32 was prepared and supplied by the I.A.E.A. at Vienna, and it was dispensed in glass ampoules ready for placement in the field. Walmsley and Twyford (1968b), found that in field experiments involving soil application of labelled fertlizer to bananas, a minimum of one milliCurie per plant was required in order to obtain a reliable estimate of P-32 uptake. Since the mats in the

Table 2

Plots used in the experiments during the dry and wet seasons.

Replicate	I	II	III
Main Plots	M	MD	D
	Sub-plots	Sub-plots	Sub-plots
	2	11	14
	22	17	31
	35	38	43
	55	51	62

plantation are pruned to leave a maximum of three plants per mat, each mat would require at least three milliCuries. It was decided to use approximately five milliCuries per mat taking into account the time lost between the preparation of the labelled phosphate and its application into the soil. At the time of preparation, in Vienna, each ampoule contained 300 microCuries in 4ml. of 1000p.p.m. phosphorus solution (as KH_2PO_4).

The P-32 was injected into the soil by placing and then crushing one ampoule in each hole. To do this, a specially made crushing device was used (plate I). This consisted of two hollow brass tubes one inside the other. The inner tube, A, (100cm long) was attached to the outer tube, C, by means of a set screw, B. The set screw fitted into a slot, D, in the inner tube. This prevented any vertical movement of the inner tube, but allowed it to rotate. The upper end of the inner tube protruded 10cm above the outer tube so that the inner tube could be rotated separately. By rotating the inner tube A, the opening at the

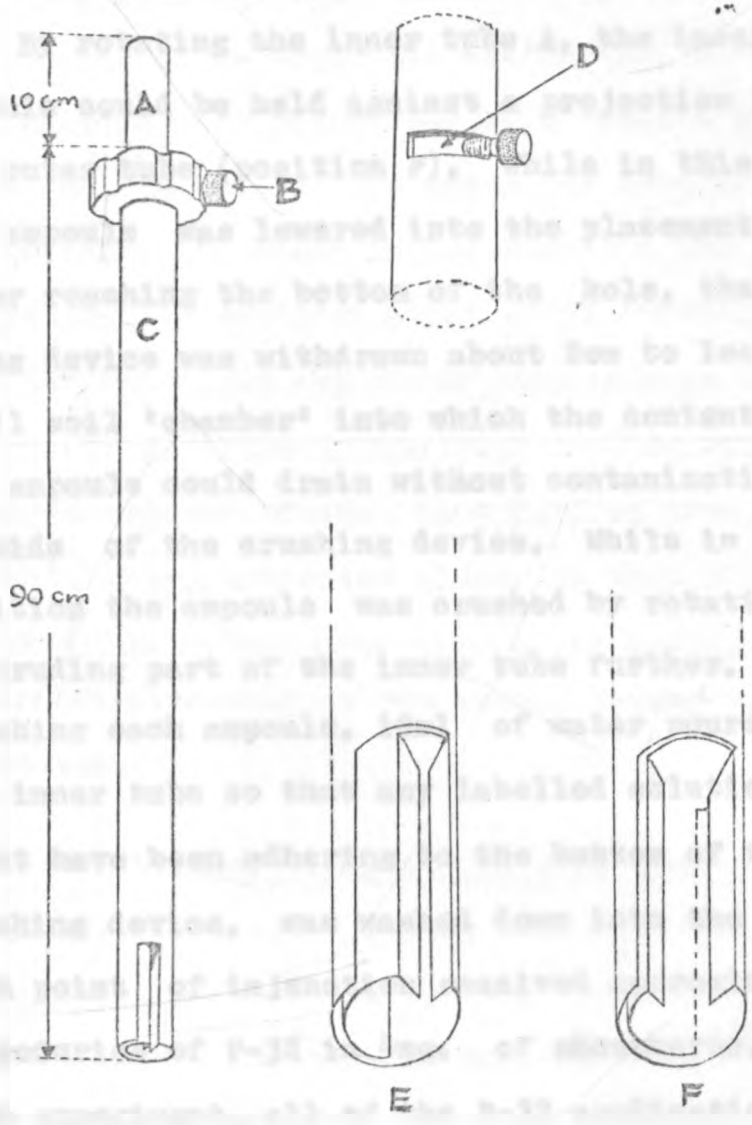


PLATE I

Device used for placement and crushing of ampoules containing the radioactive phosphorous solution.

bottom end of the device could be widened so that the glass ampoule could be inserted (position E). By rotating the inner tube A, the inserted ampoule could be held against a projection in the outer tube (position F). While in this position, the ampoule was lowered into the placement hole. After reaching the bottom of the hole, the crushing device was withdrawn about 2cm to leave a small soil 'chamber' into which the contents of the ampoule could drain without contaminating the outside of the crushing device. While in this position the ampoule was crushed by rotating the protruding part of the inner tube further. After crushing each ampoule, 10ml of water poured down the inner tube so that any labelled solution which might have been adhering to the bottom of the crushing device, was washed down into the soil. Each point of injection received approximately 300 microCuries of P-32 in 4mg. of phosphorus. For each experiment, all of the P-32 applications were completed on the same day, proceeding block by block.

(iv) Leaf Sampling. Leaf samples were obtained by taking eight strips of leaf from a

banana leaf of the treated plant. The strips were about 5cm wide and were taken from either side of the mid-rib to cover the entire leaf sampled. Leaf samples were taken from each treated plant at 10, 20, 30 and 40 days after the date of P-32 application. On these banana plants a new fully opened leaf is produced about every fortnight so that the same leaf was never sampled more than twice. In addition to the leaf samples taken from the treated plants, leaf samples were also taken from six untreated plants so that radioactivity due to the contribution of naturally occurring radioisotopes in the banana leaves could be assessed.

(v) Leaf analysis and P-32 assessment. The I.A.E.A. recommended drying leaf samples at 70°C overnight. (Nethsinghe 1970b). When this procedure was followed, however, it was found that at least 36 hours were required for the banana leaf samples to dry. In the leaf analyses for the manurial trial, a temperature of 105°C has been used successfully for drying banana leaf samples over-

night. Hence all leaf samples were dried at 105°C The dry leaf samples were then ground to pass a 1mm sieve using a Christy and Norris 5" Junior Laboratory mill. A ten gm. aliquot of the ground leaf material was then ashed in a muffle furnace at 450°C for six hours. After cooling, the ash was weighed and then a 0.250gm aliquot of the ash was used for assessing the radioactivity using the Geiger-Muller end window method. The counts were made in a mica window type of Geiger-Muller tube connected to a Phillips PW 4302 electronic counter. The ash was weighed into a counting container and the surface was levelled with a spatula. Then the container was placed into the Geiger-Muller tube and counts were taken for two minutes. Where counts were very low (less than 100 counts per minute), a longer counting period (five minutes) was used. All counts were made on the same day for each sampling date following the order in which blocks were sampled. The background counts were taken for five minutes at the beginning and at the end of each days counting.

(vi) Data handling. All total counts were reduced to counts per minute (cpm) and then corrected for the background count. Using the counts obtained from the 0.250gm ash aliquot, cpm per gm of ash were calculated. The cpm per gm of dry leaf were calculated as shown in table 2 of the appendix. These were then corrected for the contribution of natural radioactivity (mainly K-40) by subtracting off the average cpm per gm of dry leaf from the six samples taken from untreated banana plants. All counts were then adjusted to the date of P-32 application using the following formula:

$$A_t = A_o e^{-\lambda t}$$ (Friedlander and Kennedy 1956)

Where:

A_o = counts per minute at the date of P-32 application

t = number of days from the date of application of P-32 to the date of radioactivity counting.

A_t = counts per minute at the date of radioactivity counting.

e = natural base of logarithms.

λ = radioactivity decay constant for P-32 (0.04846 per day).

An anlysis of variance was carried out on each set of data using the methods described by Snedecor (1967).

(vii) COMPUTATION OF AVAILABLE SOIL WATER BALANCE.

The method used was similar to the one described by Slatyer (1960). In this method there are a number of assumptions in order to draw up the relevant equations:

(i) That run-off was negligible.

(ii) That when rainfall was excessive, the complete root zone profile would first be recharged up to field capacity and any excess would be drained off below this zone and completely lost.

(iii) That there would be no appreciable upward movement of water into the root zone.

(iv) That the rate of water use or actual transpiration rate would be reduced to

about half the potential rate, when the soil water balance fell low near the wilting point level (to one-third of the total available level) and rainfall did not occur.

(v) If rainfall occured, then the transpiration rate would be restored to its full potential transpiration rate, even though the total available soil moisture was below a third of its full capacity.

(vi) That the calculations would start when the soil profile within the effective rooting zone was fully charged.

Since treatments went down to a depth of 60cm in this experiment, this was taken as the effective rooting zone for plant nutrient uptake. From the results in Table 1 c, the total available water to a depth of 60cm is 106.94mm. Hence 110mm was used as the total available moisture for this experiment.

The potential evaporation rate (E_T) was taken as 0.85 Eo. Where Eo is the open pan evaporation (Class A pan). The ratio E_T/E_o ('f' value)

was taken as 0.85 since this was the value commonly used for crops at Kabanyolo. There was no available lysimeter information.

The calculation of the soil water balance was started at the end of April 1970 when the soil profile was taken as fully charged (March 127.7.mm, April 143.0mm). When the profile was fully charged the following equation was used:-

(110mm to 37 m) + Rainfall - 0.85Eo = Soil water balance (SWB).

When the SWB dropped to below a third of the total available level (37mm), and rainfall did not occur, the following equation was used:-

(37mm to 1mm) + zero rainfall - 0.45Eo= SWB

If rainfall occured (1mm or above in a day) at this low level of available soil moisture, then the following equation was used:-

(37mm to 1mm) + Rainfall - 0.85Eo = SWB

(b) PRELIMINARY EXPERIMENT

(i) Introduction. The purpose of this experiment was to test the I.A.E.A. recommended method of applying P-32 under local conditions and to determine the best banana leaf to sample for the radioactive assay.

(ii) Method. For the purpose of this study, four mats were selected within the manurial plantation. Four mats (two mats per plot) with the mother plant in the late vegetative phase (7-9 mother), were selected in two plots (sub-plots 22 and 55) where no fertilizer had been applied since establishing the plantation in November 1968. Sixteen equidistantly spaced holes were made around the mother plant. The holes were each 10cm deep. The P-32 solution was applied on 7 July 1970. Leaf samples were taken from the 1st, 3rd, 5th and 7th fully opened leaf from the mother plant and from the first follower in each mat. The leaves are numbered in increasing order of maturity with the first leaf being the first fully opened leaf. The leaf samples were taken at 10,20, 30, and 39 days after the date of P-32 application. The leaf samples

were dried, ashed and assayed for radioactivity as described above, except that the counts per minute were adjusted to the date of the second sampling (20 days after the date of P-32 application) and that the counts were not corrected for the contribution of the radioactivity due to the naturally occuring radioisotopes in the banana leaves. Due to a malfunction of the muffle furnace, the first set of leaf samples (10 days after the date of P-32 application) was lost during the ashing.

(iii) Results and Discussion. Walmsley and Twyford (1968b) working on the uptake of P-32 by the Robusta banana in the West Indies, assumed that a count rate of at least twice the background is desirable Before a reliable count can be made. The average background count in our laboratory is about 25cpm. Hence for reliable estimates the count rates should be 50cpm and above. All count rates, except two, in the preliminary experiment were above 50cpm. (table 3). The count rate increased with time (table 3 and 4). This was due to the accumulation of P-32, from the soil applied P-32 in the above ground parts of the plant especially the leaves

(Patel 1971). Difference between the mats were significant at the 5% confidence level. This was probably due to the fact that in this preliminary experiment, no specific attention was given to the girth and height measurements of the plants of the mats treated in this experiment. There were no significant differences between the counts from leaves of the same plant. The mean of the third fully opened leaf, however, was higher than the means of the other leaves. The results from the first folowers (not shown in the tables) were more variable. This was due to the fact that the followers had greater age differences since selection of mats was based on the uniformity of the mother plants. The results from the first followers however, were all higher than the corresponding results from the mother plants and the means of the third fully opened leaf were again higher than the other leaf means. Walmsley and Twyford (1968b), found that the highest rate of uptake of P-32 occured in vigorously developing banana plants

TABLE 3

PRELIMINERY EXPERIMENT

Actual radioactivity of dry leaf material from mother plants corrected to 20 days after P-32 application (cpm/gm over-dry leaf)

NUMBER OF DAYS	LEAF	MAT 1	MAT 2	MAT 3	MAT 4	LEAF MEANS
20	1st	46	452	93	93	159
	3rd	182	27	73	180	116
	5th	121	7	95	183	112
30	1st	278	240	280	321	280
	3rd	365	244	591	591	449
	5th	298	441	512	512	441
59	1st	343	225	581	893	511
	3rd	645	212	1131	1172	790
	5th	544	175	974	1319	753
MAT	MEANS	314a	225b	481a	580a	400*

*General Mean.

Means followed by the same letter are not significantly different at the 5% confidence level

TABLE 4

Preliminary Experiment

Summary of Treatment Effects

Cpm. per gram of dry leaf material from mother plants.

(mean of four replicates).

TIME after P-32 application	LEAF 1	LEAF 3	LEAF 5	TIME MEANS
20	159	116	112	125
30	280	449	441	390
39	511	790	753	685
LEAF MEANS	316	452	432	400*

*General

during the vegetative phase. Their results showed that young plants (2 to 5 months old), had higher P-32 uptakes than plants in the late (5 months to flowering) vegetative phase. This could explain why higher results were obtained with the younger plants and it indicated the need for treating plants of the same age in this type of experiment. There were no obvious symptoms of radiation damage noted on the treated plants. From this experiment, the third fully opened leaf was selected as the best one to sample. The same leaf is used for nutrient analysis in the manurial trial experiment.

(c) EXPERIMENT DURING THE DRY SEASON.

(i) Method. For the purpose of this experiment 48 mats were selected paying specific attention to the age and the girth and height measurements of the mother plants. The treatments were four distances (40,80, 120 and 160cm from the mother plant) and four depths (0, 15, 30 and 60cm below the soil surface). The design of the experiment was a 4 x 4 factorial completely randomised block replicated thrice. The P-32 was applied on November 1970. At each sampling date, leaf samples were taken from the third fully opened leaf of all the treated plants plus six untreated plants in order to assesss the contribution of radioactivity from the naturally occuring radioistopes in the banana leaves. Sample preparation and radioactivity assay was conducted in the manner described above.

(ii) Results and Discussion

This experiment was conducted during the dry season from 24 November 1970 to 4 January 1971. Figure 2 shows the distribution of rainfall (10 day totals) immediately before and during the experimental period. The actual daily rainfall recorded is shown in table 9 of the appendix. The table shows that there were only 9 raindays (where 1 mm or more of rain was recorded) over the 40 days of the experiment and the total rainfall over the same period was 50.6mm. This gives an average figure of 1.3 mm of rain per day. The average figure for the daily potential evaporation (Penman Eo) over the experimental period was 4.2 mm (Van Eck 1970). This shows that on the average there was a daily water deficit throughout the experimental period. The calculated available moisture in the soil throughout the 40 days of the experiment is shown in figure 3. The calculations were based on a total storage capacity of 110 mm of water when the soil is at

FIGURE 2

Rainfall distribution during the experimental period (10 day Totals) October 1970 to June 1971

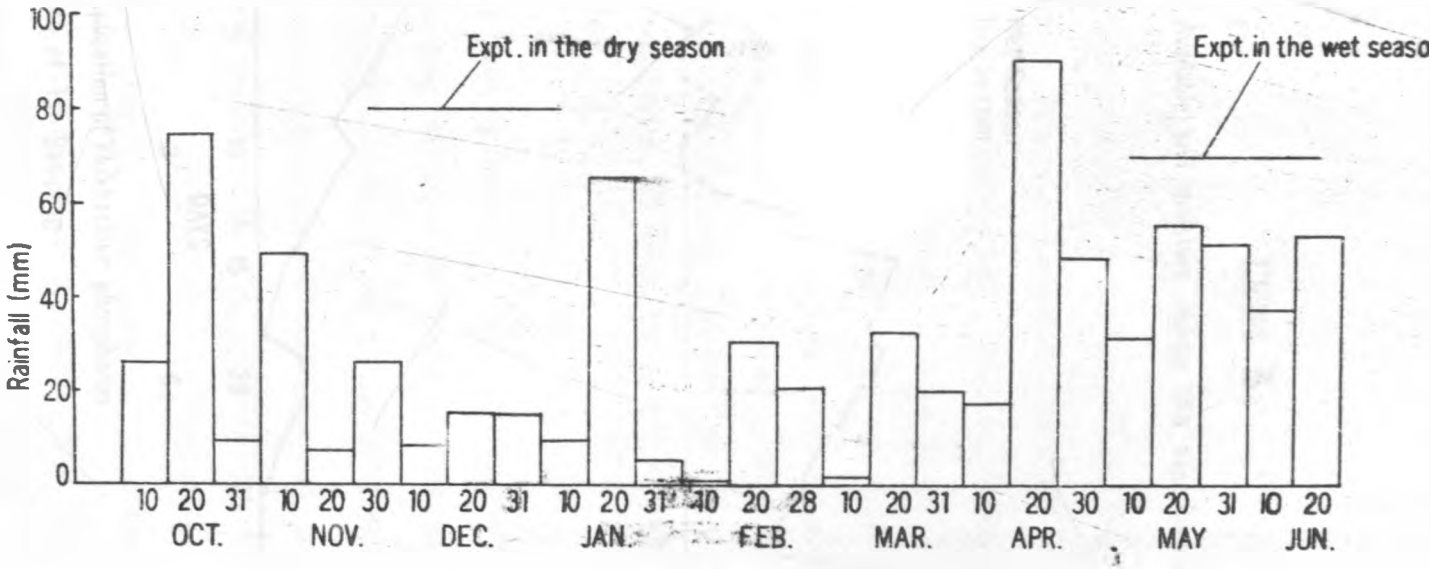
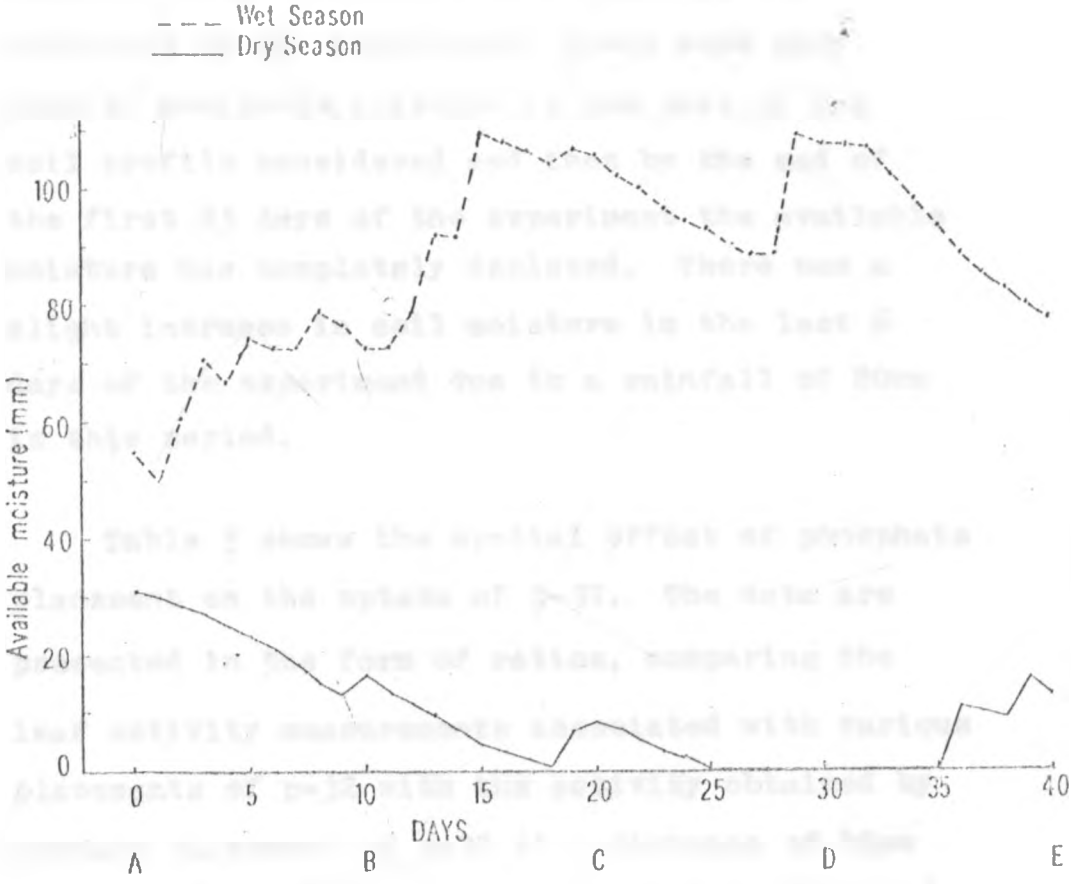


FIGURE 3

Available soil moisture during the experimental periods



A — Application of radioactive phosphorus

B — Date of 1st Sampling

C — " " 2nd "

D — " " 3rd "

E — " " 4th "

field capacity from the soil surface down to a depth of 60cm. Figure 3 shows that at the beginning of the experiment, there were only 30mm of available moisture in the part of the soil profile considered and that by the end of the first 25 days of the experiment the available moisture was completely depleted. There was a slight increase in soil moisture in the last 6 days of the experiment due to a rainfall of 20mm in this period.

Table 5 shows the spatial effect of phosphate placement on the uptake of p-32. The data are presented in the form of ratios, comparing the leaf activity measurements associated with various placements of p-32 with the activity obtained by surface placement of p-32 at a distance of 40cm from the pseudostem. The actual counts obtained from the individual leaf samples are shown in table 3 of the appendix. An analysis of variance showed a highly significant interaction between the treatments (table 4 of the appendix) but there were no significant differences between the replicates. The range of the coefficient of vari-

EXPERIMENT DURING THE DRY SEASON

TABLE 5

Relative radioactivity of leaf samples collected during the dry season (expressed as a ratio of the activity at the soil surface at the 40cm distance).

Time (days)	DEPTH (cm)	DISTANCES (cm) 40	80	120	160
	0	1.00	0.72	0.03	0.10
	15	0.13	0.12	0.04	0.26
10	30	0.04	0.05	0.25	0.11
	60	0.06	0.01	0.02	0.003
	0	1.00	0.67	0.01	0.09
	15	0.37	0.28	0.16	0.46
20	30	0.13	0.09	0.73	0.17
	60	0.11	0.06	0.04	0.01
	0	1.00	0.99	0.04	0.16
	15	0.68	0.51	0.19	0.60
30	30	0.27	0.18	1.42	0.41
	60	0.18	0.02	0.04	0.05
	0	1.00	0.54	0.06	0.14
	15	0.51	0.74	0.24	0.88
40	30	0.21	0.39	1.12	0.47
	60	0.25	0.26	0.04	0.005

action was between 29 and 40 per cent. The data for each sampling date shows a similar pattern of P-32 uptake. Near the pseudostem (40 and 80cm distances), the highest uptake of P-32 was recorded at the soil surface while further away from the pseudostem, highest uptake of P-32 was obtained from deeper placements of P-32 into the soil. At the first two sampling dates, the highest uptake of P-32 for each set of data was recorded at the soil surface near the pseudostem (40cm distance), but at the last two sampling dates, the highest uptake of P-32 for each set of data was recorded deeper into the soil at a depth of 30cm at the 120cm distance.

Table 6 presents the relative changes which took place in the P-32 uptake from various placements over the experimental period. The data are presented in the form of ratios comparing the leaf activity measurements made at each successive sampling dates with the measurement at the first sampling date. Increases in the radioactivity of

EXPERIMENT DURING THE DRY SEASON

TABLE 6

Relative radioactivity of leaf samples collected during the dry season (expressed as a ratio of the activity at the first sampling date).

DEPTH (cm)	TIME (days)	DISTANCE (cm) 40	80	120	160
0	10	1.00	1.00	1.00	1.00
	20	1.16	1.09	0.60	1.05
	30	1.23	1.69	1.67	1.95
	40	1.20	0.91	2.34	1.64
15	10	1.00	1.00	1.00	1.00
	20	3.16	2.64	3.97	2.05
	30	6.16	5.03	5.15	3.27
	40	4.46	7.23	6.28	4.05
30	10	1.00	1.00	1.00	1.00
	20	3.59	2.24	3.41	1.72
	30	7.69	4.58	7.00	4.38
	40	6.49	8.49	5.42	4.93
60	10	1.00	1.00	1.00	1.00
	20	2.21	6.79	2.05	5.17
	30	3.69	2.89	2.26	17.17
	40	4.98	27.05	1.95	1.67

samples with time are expected due to the accumulation of the soil applied p-32 into the above ground parts of the plant especially the leaves but large increases in activity over a period of time are assumed to be associated with the activity of the roots in the placement zone. Table 6 shows that the activity of leaf samples taken from plants where P-32 was applied deep into the soil increased much more with time than did the activity of leaf samples from plants where P-32 was applied at the soil surface. These observations are probably due to the soil profile drying out downwards with time. At the 60cm depth, the increase in activity of leaf samples with time was rather erratic especially further away from the plant. This was probably due to the low uptake of P-32 at this depth throughout the experiment.

It is unlikely that the large increase in the uptake of P-32 with time was due to roots growing down the placement holes (root channelling).

Jones (1969) using P-32 to study the root system of maize plants at Namulonge, Uganda, found that his results showed a high degree of variability and he attributed this to root channelling. In this experiment, holes of 2.5cm diameter were used and after the application of P-32, the holes were filled with dry soil. There were no significant differences between the replicates. If root channelling had occurred in this experiment, the variation of p-32 uptake with time (table 6) would have been expectedt to be more erratic. Huxley et al (1970) using p-32 to study the root system of coffee on the Kenya Kikuyu red loams, inserted plastic tubes in the holes (2.5cm diameter) made in the soil. These were used for four consecutive seasons and at the end of the fourth season excavations did not reveal any root channelling. Root channelling would have been expected to occur more easily in the heavy Kikuyu red loams (70-80% Halloysite-Kaolimite clay fraction) than in the soils of this experiment

(40-50% clay fraction). Root channelling observed by Jones (1969) at Namulonge could have been due to the disturbance of the soil as a result of the relatively large holes (7.5cm diameter) used.

At the 40cm distance, highest uptake of p-32 was recorded at the soil surface although the uptake of p-32 from deeper applications at this distance increased significantly with time. The treatments at this distance (40cm) were within the area shaded by the leaves of the banana plants in the mat. The soil under this shaded area, therefore, would take a considerably longer period to dry out than the soil which was not shaded at all. This would explain why, at this distance, the highest uptake of p-32 was recorded at the soil surface. With time, the uptake of of p-32 at the soil surface, at this distance, would have been expected to decrease but it remained almost constant. This might be due to the precipitation during the experiment.

The precipitation might not have been much but the funnelling effect of the leaves of the plants would concentrate it in the area immediately around the mat so that this area did not dry out completely.

At the 80cm distance, at the first three sampling dates, highest uptake of p-32 was recorded at the soil surface. But, the uptake of p-32 from the deeper applications of p-32 at this distance increased rapidly with time so that at the date of the fourth sampling the uptake of p-32 at the 15cm depth was higher than that at the soil surface. The treatments at this distance (80cm) were roughly at the edge of the area shaded by the leaves of the plants in the mat so that the soil at this distance would dry out slowly due to the partial shading of the leaves though more rapidly than the soil at the 40cm distance which was completely shaded.

At the 120cm distance, the highest p-32 uptake was recorded at the 30cm depth throughout the experiment and the uptake in the surface layers

of the soil (0, 15cm depth) at this distance, was very low. The uptake of p-32 at the 30cm depth at this distance increased rapidly with time and by the third sampling it was greater than the uptake of p-32 at the soil surface near the plant. This area is not shaded by the leaves of the plants so that the soil in the surface layers would dry out much more rapidly than that at the 40 and 80cm distances. The low uptake of p-32 in the surface layers could be due to lack of moisture hence shifting root activity downwards where there is more moisture.

At the 160cm distance, there was an increase in the uptake of p-32 from the surface layers of the soil compared to that at the 120cm distance and the highest uptake of p-32 at this distance was recorded at the 15cm depth. Although the original spacing of the plants in the manurial trial plantation was 214x214cm, the banana mats grudually spread out and by the time this experiment was conducted the spacing between the adjacent mats was considerably less than 214cm.

Hence most of the treatments at this distance (160cm), were very near the neighbouring mats (four of them). The treatments, therefore, were within the area shaded by the leaves of the plants in the neighbouring mats. This would explain the increase in uptake of P-32 in the surface layers of the soil at this distance.

The uptake of P-32 at the 60cm depth was very low at all distances throughout the experiment. On the root system of the bananas, Simmonds (1966) reported that the majority of the roots were normally found in the top 15cm of the soil profile. Awuor-Okulo and Parish (1969) using the jet-wash method, found that the lateral roots which made up the majority of the roots from the corm of the Nakyetengu cultivar, were mainly in the top 50cm of the soil. This probably explains the low uptake of P-32 at the 60cm depth. Another contributing factor could be the fixation of the applied phosphorus, at this depth, into other forms unavailable to the plants (Jones 1963)

although a high dosage of phosphorus was deliberately applied at each injection point to try and mask the phosphorus variation down the soil profile.

In the original siting of the experiment (table 2), treatments in two of the three replicates were in plots which had been mulched at the establishment of the manurial experiment and two replicates were in plots where farm yard manure (dung) had been applied at the planting time. The farm yard manure was applied only once at the planting time and it was placed only in the planting holes. It was unlikely that the farm yard manure would have any effect on the phosphorus uptake when this experiment was conducted (two years after planting). By the time this experiment was conducted, mulch had not been applied for a period of approximately 9 months so that the soil in most of the plots in the mulched blocks were as bare as those which had not been mulched at all. This would explain why there were no significant differences between the replicates.

(d) EXPERIMENT DURING THE WET SEASON.

(i) Method

The design of this experiment was exactly the same as that of the previous experiment during the dry season. New mats (48) were selected within the same 12 plots used in the previous experiment. Particular attention was again paid to the age of the plant (7-9 months), girth, and height measurements. The p-32 was applied on 6 May 1971. Leaf samples were taken from the third fully opened leaf at 10, 20, 30 and 40 days after the date of p-32 application. Leaf samples were also taken from six untreated plants for assessing the contribution of the soil natural radioactivity. All counts were adjusted to the date of p-32 application.

(ii) Results and Discussion

The experiment was conducted a month after an exceptionally long dry season. In the month immediately preceding the experimental period (April 1971) there was a high amount of precipitation (147mm, table 9 of the appendix). During the 40 days of the experiment there were 176.3mm

of rain with 20 rain days. This gives an average figure of 4.4mm of rain per day over the experimental period. The average figure for the daily potential evaporation (Penman Eo) over this experimental period was 3.51mm. Hence on the average there was a daily water surplus during the experimental period. The calculated available moisture in the part of the soil profile considered (0 to 60cm) depth) throughout the 40 days of the experiment is shown in figure 3. The figure shows that at the beginning of this experiment there were 60mm of available soil moisture in the effective zone of the soil profile (down to 60cm) This was double the amount of available moisture at the beginning of the previous experiment. Figure 2 shows the distribution of rain-fall (10 day totals) over the two experimental periods while the actual daily rainfall is shown in table 9 of the appendix.

Table 7 shows the spatial effect of p-32 placement on the uptake of p-32 at each sampling date. The data are presented in ratios as in the previous experiment. The actual counts obtained from the individual leaf samples are shown in

EXPERIMENT DURING THE WET SEASON

TABLE 7

Relative radioactivity of leaf samples collected during the wet season (expressed as a ratio of the activity at the soil surface at the 40cm distance).

TIME	DEPTH	DISTANCE (cm)			
(days)	(cm)	40	80	120	160
10	0	1.00	0.29	0.26	0.38
	15	0.22	0.10	0.25	0.17
	30	0.66	0.21	0.16	0.02
	60	0.02	0.01	0.01	0.004
20	0	1.00	0.32	0.49	0.69
	15	0.58	0.20	0.69	0.31
	30	0.65	0.47	0.21	0.06
	60	0.06	0.02	0.01	0.009
30	0	1.00	0.34	0.31	0.67
	15	0.69	0.33	0.99	0.33
	30	0.88	0.57	0.29	0.10
	60	0.12	0.03	0.02	0.02
40	0	1.00	0.31	0.39	0.68
	15	0.81	0.36	0.90	0.30
	30	0.86	0.56	0.24	0.12
	60	0.22	0.02	0.03	0.02

table 6 of the appendix. The actual counts showed a big increase over those recorded in the previous experiment. The coefficient of variation in this experiment was low (13.8 to 22.1 per cent, table 4 of the appendix). This was mainly due to the high level of P-32 uptake in this experiment. The large increase in the total uptake of P-32 was undoubtedly due to the improved soil moisture condition. Simmonds (1966) reported that the lateral roots bearing root hairs (feeding roots) are believed to be responsible for the nutrient and water uptake by the banana plant. It is possible that during a long dry season (like the one which preceded this experiment) the "feeding roots" die off, especially those in the surface layers of the soil, due to lack of moisture and that when there is an ample supply of moisture in the soil new "feeding roots" develop. In this experiment there was an ample supply of soil moisture, therefore, new "feeding roots" would develop especially in the top fertile layers of the soil.

In this experiment, highest uptake of P-32 at three different distances (40, 120 and 160cm) was recorded within the top 15cm of the soil profile (table 7). At the 80cm distance, the highest uptake of P-32 was recorded at the 30cm depth. This could be due to the development of new roots from the corm of the plant passing through this region. This could also explain the high uptake of P-32 at the 40cm distance from the soil surface down to the 30cm depth. The P-32 uptake in the top layers of the soil (0 to 15cm depth) was high near the plant (40cm distance), decreased at the 80cm distance and then increased at the 120 and 160cm distance (table 7 and plate II). Awuor-Okulo (1969) found that the area of highest root concetration of this particular banana cultivar, was within 50cm distance from the plant and within the top 50cm of the soil. This would explain the high uptake of P-32 at the 40cm distance. Summerville (1939) noted that the "feeding roots" on the main roots of the banana plants occurred mainly in the distal portions of the main roots. This would explain the observation above that P-32 uptake in the

surface layers of the soil increased further away from the plant (at the 120 and 160cm distances). At the 60cm depth, there was a considerable increase in the uptake of P-32 at the 40cm distance but further away from the plant (80, 120 and 160cm), the uptake of P-32 was relatively low and comparable to the uptake during the dry season (table 6 of the appendix and plate II). The increase in uptake of P-32 near the plant (40cm distance) at this depth, could have been due to the development of new roots extending downwards from the base of the corm and passing through this region.

Table 8 presents the relative changes that took place in the P-32 uptake from various placements over the experimental period. The data are presented in ratios as in the previous experiment. Large increases in activity over a period of time are again assumed to be associated with the activity of the roots in the placement zone. Very large increases in activity with time were obtained at the 60cm depth. This was again due to the low

EXPERIMENT DURING THE WET SEASON

TABLE 8

Relative radioactivity of leaf samples collected during the wet season (expressed as a ratio of the activity at the first sampling date).

DEPTH (cm)	TIME (days)	DISTANCE (cm) 40	80	120	160
0	10	1.00	1.00	1.00	1.00
	20	1.38	1.56	2.58	2.50
	30	1.90	2.23	2.29	3.34
	40	2.17	2.36	3.25	3.84
15	10	1.00	1.00	1.00	1.00
	20	3.52	2.85	3.68	2.44
	30	5.77	6.31	7.28	3.60
	40	7.76	7.95	7.51	3.72
30	10	1.00	1.00	1.00	1.00
	20	1.39	2.98	1.79	3.47
	30	2.59	4.99	3.52	7.25
	40	2.87	5.57	3.34	9.65
60	10	1.00	1.00	1.00	1.00
	20	3.72	1.82	1.55	3.06
	30	9.29	3.81	3.63	11.12
	40	19.94	3.44	6.10	13.65

uptake of P-32 at this depth. In this experiment there were large increases in activity even at the soil surface whereas in the previous experiment there was very little increase in activity at the soil surface with time (table 6). The little increase in activity at the soil surface in the previous experiment was explained by the soil profile drying out. In this experiment there was an ample supply of soil moisture throughout the period of the experiment and the large increases in activity with time can be best explained by the proliferation of the newly developed "feeding roots" in the placement zones.

A summary of the results of the two experiments is shown in plate II. This plate was based on tables 5 and 8 of the appendix. The data in these tables were obtained by totalling up the counts per minute per gram of dry leaf for each of the four sampling dates for each treatment and then calculating the mean of each total. This was based on the fact that for each experiment, the data for each sampling date reflected a

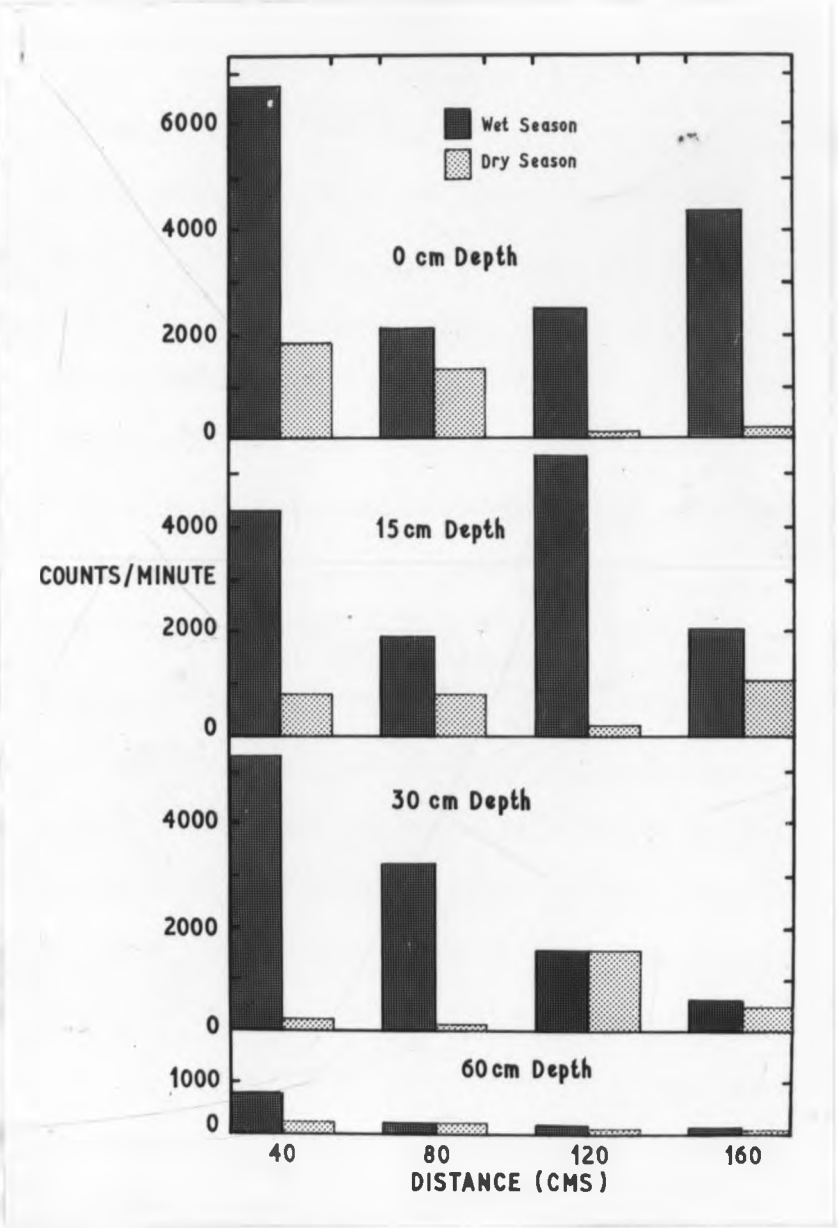


PLATE II

Effect of location of P-32 placement in the Soil on radioactivity of banana leaf samples.

A Summary of results for both the dry and wet seasons.

similar pattern of P-32 uptake. The plate is meant to reflect an average view of what was happening throughout the two experiments. The plate shows that during the dry season, near the plant (40 and 80cm distances) the uptake of P-32 was mainly near the soil surface whereas further away from the plant (120 and 160cm distances) high uptake of P-32 was obtained from deeper placements of P-32 in the soil. In the wet season there were large increases in the uptake of P-32 over that measured in the experiment during the dry season. The plate shows that these increases were mainly in the top 15cm of the soil. This increase in uptake has been explained above to be due to the proliferation of the newly developed "feeding roots" as a result of the improved soil moisture condition. The plate further shows that there was an increase in uptake of P-32 in the wet season over that measured in the dry season, at the 40 and 80cm distances at the 30cm depth and only at the 40cm distance at the 60cm depth. Both of these increases were near the plant which

indicates that roots might have developed from the base of the corm of the plant extending downwards through this region. The uptake of p-32 at the 60cm depth in both experiments was low. This could be due to the few roots at this depth or due to the phosphate fixation as explained above.

SUMMARY AND CONCLUSION

The extent of the active root zone of Nakyetengu, a local cultivar belonging to the cooking type of bananas, was determined using radioactive phosphorus (P-32). The study was conducted on a clayey, highly weathered and leached well drained ferrallitic soil typical of the major banana growing region around Lake Victoria in Uganda. The study consisted of two experiments. The first experiment was conducted during a typical dry season while the second experiment was conducted in a typical wet season.

The P-32 was injected into the soil at four different depths (0,15,30 and 60cm below the soil surface)and at four different distances (40, 80, 120 and 160cm from the pseudostem of the plant). The banana plants used were in the late vegetative phase (7-9 months old). The radioactivity of the leaf samples from the third fully opened leaf of each treated plant was used to assess the amount of P-32 taken up

by the treated plants from the different treatment zones over a period of 40 days. The P-32 uptake was assumed to be associated with the activity of the roots in the placement zone.

The uptake of P-32 from different depths in the soil at different distances over the two seasons was related to soil moisture availability. In the dry season, highest P-32 uptake was recorded at the soil surface near the plant (40cm distance) but further away from the plant, highest uptake of P-32 was obtained from deeper placements of P-32 into the soil. In the wet season, most of the P-32 uptake was in the top layers of the soil especially further away from the pseudostem of the plant. The uptake of P-32 in the wet season was much higher than that in the dry season. In both experiments there was little uptake of P-32 from the 60cm depth at all distances.

The customary practice of placing fertilizers in an established banana plantation in Uganda

has been to spread the fertilizer immediately under each plant (Rimington 1964). With an original spacing of banana plants of 214 x 214cm, "feeding roots", especially in the wet season, seem to extend throughout the established field. It would be advisable, therefore, to apply the fertilizers uniformly over the entire established field. Deeper placement of fertilizers would only be benefitial in the dry season, but the uptake of nutrients in the dry season is low and deep placement of fertilizers would involve considerably higher costs of labour. Hence it would be more economical to apply the fertilizers at the surface of the soil. The deeper layers of the soil would gradually be supplied with the fertilizers applied at the soil surface through leaching.

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University of Nottingham 1968 p.413.

Yu-Yuan Yeh (1970).

Estimation of functional root distribution of Citrus taken by radiotracer techniques.

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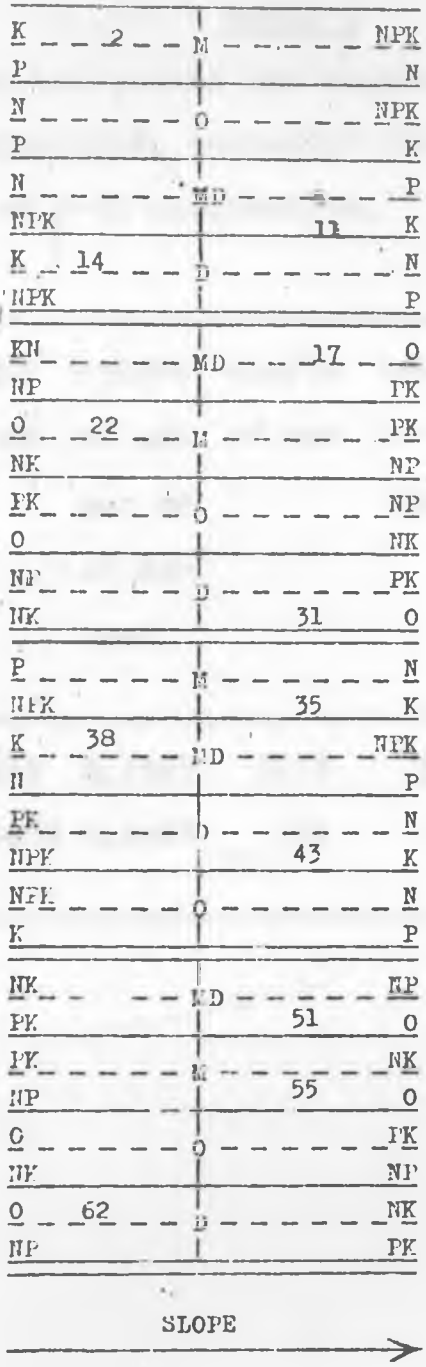
APPENDIX

DIAGRAM 1

Plot diagram of the manurial trial plantation at Kabanyolo.



MAIN PLOTS

O = No mulch and dung
M = Mulch to 6" with grass
MD = Mulch & dung
D = Dung, well rotted cattle manure 3 tins per hole.

SUB-PLOTS

N = 1 lb of K/plant
P = 1 lb of P/plant
K = 1 lb of K/plant
NK = 1 lb of N&K/plant
NP = 1 lb of N&P/plant
PK = 1 lb of P&K/plant
NPK = 1 lb of N,P&K/plant
O = No fertilizer.

TABLE 1

Table showing how counts per minute (cpm) per gm of dry leaf were calculated, corrected for K-40 and adjusted to the date of P-32 application.

Sample number	Weight of ash	Weight of ash per gm of dry leaf	cpm/gm of ash	cpm/gm of dry leaf	cpm/gm of dry leaf corrected for K-40	counts adjusted to the date of P-32 application.
1.	1.017	0.1017	3718	378	361	2066
2.	0.0968	0.0968	351	34	17	97

TABLE 2

PRELIMINARY EXPERIMENT

Analysis of variance.

SOURCE	DF	SS	MS	F
Total	35	4,044,048.31	-	
Replicates	3	694,398.69	231,466.23	4.61*
Treatments	8	2,143,320.06	267,915.01	5.33**
A (time)	2	1,878,902.73	939,451.37	18.69***
B (leaf)	2	128,194.89	64,097.45	1.28^{NS}
AxB	4	136,222.44	34,055.61	0.68^{NS}
ERROR	24	1,206,329.56	50,263.73	

* = Significant at the 5% confidence level

** = " at the 1% " "

*** = " at the 0.1% " "

NS = Not significant.

TABLE 3

Measured radioactivity of leaf samples during the dry season expressed as counts per minute per gm of dry leaf (means of three replicates) corrected for K-40 and adjusted to the date of P-32 application.

TIME (days)	DEPTH (cm)	DISTANCE (cm) 40	80	120	160	DEPTH MEANS
	0	1590	1149	55	169	741a
	15	219	201	75	417	228c
10	30	70	80	398	185	183c
	60	99	19	43	6	42b
Distance Means		494a	362c	143c	194b	298*
	0	1848	1247	33	178	826a
	15	693	530	298	856	594c
20	30	251	179	1356	318	526c
	60	219	129	88	31	116b
Distance Means		753a	521b	444bc	346c	516*
	0	1958	1943	92	332	1081a
	15	1344	1011	386	1365	1027a
30	30	538	366	2787	810	1153a
	60	365	55	97	103	155b
Distance Means		1052a	844a	840a	652b	847*
	0	1913	1045	129	278	841c
	15	977	1454	471	1688	1147a
40	30	454	762	2156	912	900c
	60	494	514	84	10	276b
Distance Means		958a	772ab	710b	722b	791*

Means followed by the same letter are not significantly different at the 5% confidence level.

* = General Mean.

TABLE 4

Experiment during dry season

Analysis of variance

Source	DF	SS	MS	F
Total	47	9.277.281.0	-	-
Replicates	2	19,436.3	9,718.1	0.6NS
Treatments	15	8.817.615.3	587.841.0	40.0***
Depth(A)	3	3.357.877.2	1.119.292.4	76.2***
Distance (B)	3	931.973.7	310,657.9	21.1***
AxB	9	4.527.764.3	503,084.9	34.2***
Error	30	440,229.2	14,674.3	
Coefficient of variation =40.6%				
		20 Days		
Total	47	14.315.101.4	-	-
Replicates	2	127.274.6	66,637.3	2.1NS
Treatments	15	13.305.492.1	887,032.8	30.1***
Depth (A)	3	3.145.872.7	1.048,624.2	35.6***
Distance(B)	3	1.083.872.0	361,290.6	12.2***
AxB	9	9.075.747.3	1.008,416.3	34.2***
Error	30	882,334.6	29,411.1	
Coefficient Variation = 33.2%				
		30 Days		
Total	47	32.586.254.9	-	-
Replicates	2	331,246.2	165,623.1	2.5NS
Treatments	15	30.279.355.6	2.018,623.7	30.6***
Depth (A)	3	7.720,096.0	2.573,365.3	39.0***
Distance(B)	3	956,855.2	318,951.7	4.8**
AxB	9	21,602,404.3	2,400,267.1	36.4***
Error	30	1.975,653.0	65,855.1	
Coefficient of variation = 30.3%				
		40 Days		
Total	47	23.219,076.6	-	-
Replicates	2	77,680.6	38,840.3	0.7NS
Treatments	15	21.549,460.6	1.436,630.7	27.0***
Depth (A)	3	4,882,699.1	1.627,566.3	30.6***
Distance (B)	3	479,953.8	159,984.6	3.0*
AxB	9	16.186,807.6	1.798,534.1	33.8***
Error	30	1,591,935.3	53,064.5	
Coefficient of variation = 29.1%				

NS = Not Significant

* = Significant at the 5% confidence level

** = " " " 1% " "

*** = " " " 0.1% " "

TABLE 5

Experiment during the dry season

Means of the totals for each treatment for the four sampling dates expressed as counts per minute per gm of dry leaf.

DEPTH	DISTANCES (cm)			
(cm)	40	80	120	160
0	1827	1346	77	239
15	808	799	308	1082
30	328	175	1674	556
60	294	179	78	38

TABLE 6

Measured radioactivity of leaf samples during the wet season expressed as counts per minute per gm of dry leaf (means of three replicates) corrected for K-40 and adjusted to the date of P-32 application.

TIME (days)	DEPTH (cm)	DISTANCE (cm) 40	80	120	160	DEPTH MEANS
	0	4169	1212	1093	1602	2019a
	15	951	420	1083	731	798b
10	30	2713	916	673	113	1104c
	60	103	68	49	17	61d
	Means	1985a	654b	726b	616b	995*
	0	5747	1889	2830	3997	3616a
	15	3348	1197	3990	1785	2587b
20	30	3763	2727	1208	392	2022c
	60	383	124	76	52	159d
	Means	3318a	1483c	2026b	1557c	2096*
	0	7927	2701	2514	5356	4625a
	15	5488	2551	7886	2629	4664a
30	30	7039	4575	2367	819	3700b
	60	957	259	178	189	396c
	Means	5353a	2547c	3236b	2248c	3346*
	0	9033	2852	3572	6146	5401a
	15	7383	3339	8132	2719	5393a
40	30	7786	5102	2245	1091	4056b
	60	2054	234	299	232	705c
	Means	6564a	2882c	3562b	2567c	3889*

Means followed by the same letter are not significantly different at the 5% confidence level.

* = General mean.

TABLE 7

Experiment during the wet season

Analysis of variance

SOURCE		SS	MS	F
10 DAYS				
Total	47	55.454.483.9		
Replicates	2	84.507.1	42.253.5	1.9NS
Treatments	15	54.733.249.9	3.648.883.3	171.9***
Depth (A)	3	23.667.718.9	7.889.239.6	371.7***
Distance (B)	3	15.755.139.0	5.251.713.6	247.4***
AxB	9	15.310.391.9	1.701.154.6	80.1***
Error	30	636.726.8	21.224.2	
Coefficient of variation =14.64%				
20 DAYS				
Total	47	143.680.158.0	-	-
Replicates	2	423.019.5	211.509.7	0.9 NS
Treatments	15	136.809.761.3	9.120.650.7	42.4***
Depth (A)	3	75.698.641.5	25.232.880.5	117.4***
Distance (B)	3	25.969.709.8	8.656.569.9	40.2***
AxB	9	35.141.410.0	3.904.601.1	18.1***
Error	30	6.447.377.2	214.912.5	
Coefficient of variation = 22.1%				
30 DAYS				
Total	47	337.199.382.5	-	-
Replicates	2	334.952.0	167.476.0	0.7NS
Treatments	15	330.207.197.1	22.013.813.1	99.2***
Depth (A)	3	146.403.034.2	48.801.011.4	219.9***
Distance (B)	3	70.608.775.2	23.536.258.4	106.0***
AxB	9	113.195.387.7	12.577.265.3	56.6***
Error	30	6.657.233.4	221.907.7	
Coefficient of variation =14.08%				
40 DAYS				
Total	47	413.356.332.7	-	-
Replicates	2	334.332.9	176.166.4	0.5NS
Treatments	15	404.374.511.0	26.958.300.7	93.5***
Depth (A)	3	176.592.266.7	58.864.088.9	204.2***
Distance (B)	3	120.916.880.4	40.305.626.8	139.8***
AxB	9	106.865.363.9	11.873.929.3	41.1***
Error	30	8.647.488.8	288.249.6	
Coefficient of variation =13.81%				

NS = Not significant

*** = Significant at the 0.1% confidence level.

TABLE 8

Experiment during the wet season

Means of totals for each treatment for the four sampling dates expressed as counts per minute per gm of dry leaf.

DEPTH	DISTANCE (cm)			
(cm)	40	80	120	160
0	6719	2164	2402	4275
15	4300	1902	5273	1966
30	5325	3329	1623	604
60	874	171	151	123

TABLE 9

Rainfall(mm) during the experimental periods.

	Oct.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
1.	2.9	-	-	-	-	0.1	9.0	0.3	-
2.	0.4	-	-	9.5	-	1.6	0.5	0.9	-
3	1.2	-	-	-	0.6	-	0.7	-	2.0
4.	-	5.9	-	-	-	-	-	-	32.1
5.	-	26.4	2.4	-	-	-	6.5	0.4	0.2
6.	-	7.9	-	-	-	-	-	2.7	1.7
7.	-	-	-	-	-	-	-	0.2	0.1
8.	-	3.0	-	-	-	-	-	13.0	-
9.	18.0	8.9	-	-	0.2	-	-	12.6	-
10.	3.6	-	-	-	-	1.7	0.7	1.3	-
11.	-	-	-	-	-	-	-	9.8	-
12.	-	3.2	-	-	-	-	2.3	-	0.1
13.	25.4	-	9.9	-	-	16.8	10.3	2.4	-
14.	2.7	0.3	4.6	11.7	-	-	5.6	10.9	1.4
15.	-	-	-	-	-	-	2.2	-	-
16.	19.5	3.9	0.5	34.3	-	-	8.3	0.7	-
17.	-	-	0.2	3.6	-	14.6	52.5	3.4	52.2
18.	15.9	-	-	16.1	-	-	0.6	9.0	-
19.	10.2	-	-	-	-	1.3	-	15.6	-
20.	1.0	-	-	-	30.8	-	8.6	3.7	-
21.	-	-	-	0.2	19.1	-	1.9	40.9	-
22.	0.3	-	-	4.9	1.5	2.2	13.0	1.8	0.2
23.	-	-	-	-	-	-	-	1.3	4.1
24.	-	23.4	1.0	-	0.2	8.1	-	0.4	-
25	-	0.4	-	-	0.1	-	1.1	4.4	-
26.	-	1.5	-	0.1	-	3.0	18.2	-	0.1
27.	0.4	0.5	-	-	-	-	7.5	0.6	0.6
28.	6.1	0.2	-	-	-	-	-	-	-
29.	1.4	-	0.5	-	-	4.1	6.8	-	-
30.	-	-	13.5	-	-	0.6	-	-	12.7
31.	0.9	-	-	-	-	2.2	-	2.3	-
Tot.	110.9	82.5	38.5	80.4	52.6	65.2	147.6	138.3	107.5
Rain-days	12	9	6	6	3	10	14	16	7
Ten yr. Means	164.5	201.7	102.6	55.1	99.6	150.3	201.0	123.8	78.4