Study of the root development of some *Musa* cultivars in hydroponics.

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ETUDE DU DEVELOPPEMENT RACINAIRE DE QUELQUES CULTIVARS DE *MUSA* EN CULTURE HYDROPONIQUE.
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RESUME - Etude en culture hydroponique des systèmes racinaires de dix cultivars de bananiers et de plantains ; 95 p. 100 des racines étaient saines. On distingue deux types de racines primaires: les nourricières et les pionnières ; les premières sont fines et fortement couvertes, sur 90 p. 100 de leur longueur, de racines secondaires plus petites ; les deuxièmes ont des racines secondaires sur 70 p. 100 de leur longueur. De ce fait les nourricières sont estimées plus importantes pour l'alimentation en eau et en éléments nutritifs que les pionnières : elles entrent, respectivement, pour 2/3 et 1/3 dans la longueur totale des racines primaires.
Le système racinaire du plantain est moins ramifié que celui du bananier : pour le premier 46 p. 100 de la longueur totale revient aux racines secondaires contre 77 p. 100 dans le cas du bananier.

INTRODUCTION

Plantain bananas, hereafter called «plantains» form a special but economically important subgroup of AAB-banana cultivars (Simmonds, 1966). A very frequent problem in plantain fields is the quick decline in productivity (Wilson, Swennen and De Langhe, 1985). This is in sharp contrast with many other popular dessert bananas (*Musa* cv. AAA) which are normally perennial. Yet, there has been little research on plantain in the past. Only recently have some studies been performed on plantain roots, in order to find explanations for the quick decline in productivity of the plantain (Weckx, 1982; Janssen, 1983). Initial studies showed that plantains have a shorter and less dense root system than bananas (Weckx, 1982). While mulching improved the plantain root system, it was still inferior to that of the banana. This different root pattern of plantains and bananas may be the factor responsible for the different suckering behaviour of the two (Swennen, 1984).

Roots in the genus *Musa* are formed in groups of 3-4 by the cambium in the corm. They are adventitious and grow through the cortex where a process of cytolysis takes place in order to give space. Before the roots break into the soil near the surface of the corm, the root tips broaden abruptly (Skutch, 1932).

Most of the banana roots are present in the topsoil (Sioussaram, 1968; Champion and Sioussaram, 1970) and they grow horizontally; this also applies to plantain roots

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especially when the soil is rich in organic matter (Irizarry, Vicente-Chandler and Silva, 1981).

Besides the laterally spreading roots there are a large number of roots that grow vertically downwards (Summerville, 1939; Simmonds, 1966). New roots are formed continuously until flowering occurs (Beugnon and Champion, 1966).

When the plant ages, newly formed roots may also appear above the soil (Moreau and Le Bourdelles, 1963). These roots will grow geotropically and, depending on growing conditions, will enter the topsoil or die-off before reaching the soil surface.

Banana roots are white and fleshy when young, but corky when old. The mature roots have prominent lacunae in the cortex and have large vessels and phloem strands in the central portion of the stele. Xylem elements mature at a level in the root at which elongation has ceased (Riopel and Steeves, 1964). Root hairs appear 4-6 cm behind the apex and reach their mature size at 8-12 cm proximal to their place of origin. Their length may exceed 2 mm. Lateral roots are initiated in a non-random dispersed pattern (Riopel, 1966).

For *Musa acuminata* cv. Gros Michel, the daily growth of large and small (larger and smaller than 15 cm respectively) roots is 2.6 cm and 1-2 cm respectively (Riopel and Steeves, 1964). Beugnon and Champion (1966) observed the growth rate of the primary roots of the Poyo banana to be 3-4.2 cm a day, and also that this growth rate was not constant or regular. Various factors, such as soil properties, climatic conditions and pest and diseases, influence the growth rate (Lassoudière, 1971).

The plant crop of a Poyo banana can have 300 to 500 primary roots with a total length of 230 m (Robin and Champion, 1962; Beugnon and Champion, 1966). Most of these primary roots have appeared between 2 and 4 months after planting (Robin and Champion, 1962; Laville, 1964).

The above mentioned studies on root development had serious limitations such as, for example, difficulties in extracting undamaged roots from the soil. This is a very time-consuming process and explains why quantitative observations have been limited to the primary roots. Studies of roots growing in a nutrient solution (hydroponic conditions) have several advantages including the following: (1) Roots can develop in a uniform medium, (2) they can be separated more easily with negligible damage and (3) plants grow more vigorously in hydroponics.

The present paper discusses the results of study on roots of different *Musa* cultivars grown in a hydroponic culture.

MATERIAL AND METHODS

Cultivars and the Nutrient Culture.

Peepers of 11 *Musa* cultivars were collected from plants grown in soil in the greenhouse, and transferred to a hydroponic solution. This was repeated several times so that by the time of observation, there was a wide range in the age of the plants (between 85 and 164 days). The peepers were washed and placed on a rockwool base in the hydroponic solution (Fig. 1) at a depth of approximately 3 cm. The depth of the solution was about 5-7 cm. The composition of hydroponic solution is indicated in Table 1. 400 ml of stock solution A, 40 ml of stock solution B, 50 ml of stock solution C and 100 ml each of stock solutions E and F were added to 10 l. distilled water. This solution was then adjusted to a pH of 5.5 and an E.C. (Electrical Conductance) of 6.0 mS. The solution was renewed every 2 months and pH and E.C. were monitored twice a week. The solution was aerated for 15 minutes every 30 minutes. A plate of Isomol was suspended above the solution so that the roots could grow in complete darkness. A hole was made at the pseudostem location. The hole was widened regularly in order to avoid the plant being strangled, the plants being tied to supports (Fig. 1).

The plants were illuminated for 12 hours, using 400 W high pressure mercury HPL-N (Philips) lights providing 23,00 lumen. The relative humidity was kept between 60-80 % and temperature ranged between 20 and 35°C. The following *Musa* cultivars were studied:

1. False Horn plantain known as Agbagba (AAB)
2. Horn plantain (AAB)
3. French plantain (AAB)
4. Paranta or Pome (AAB)
5. Silk (AAB)
6. Bluggoe (ABB)
7. *Musa velutina*
8. Pisang lilin (AA)
9. Pisang nangka (AAA)
10. Robusta (AAA)
11. Dwarf Cavendish (AAA)

Root observations and measurements.

After careful removal of the rockwool, roots were separated from each other. This could be done quite easily and with almost no damage. The length of every primary root was measured; the width at the proximal end was also measured, using a vernier caliper.

Taking two representative roots per plant, of the root type with the highest density of secondary roots, the length

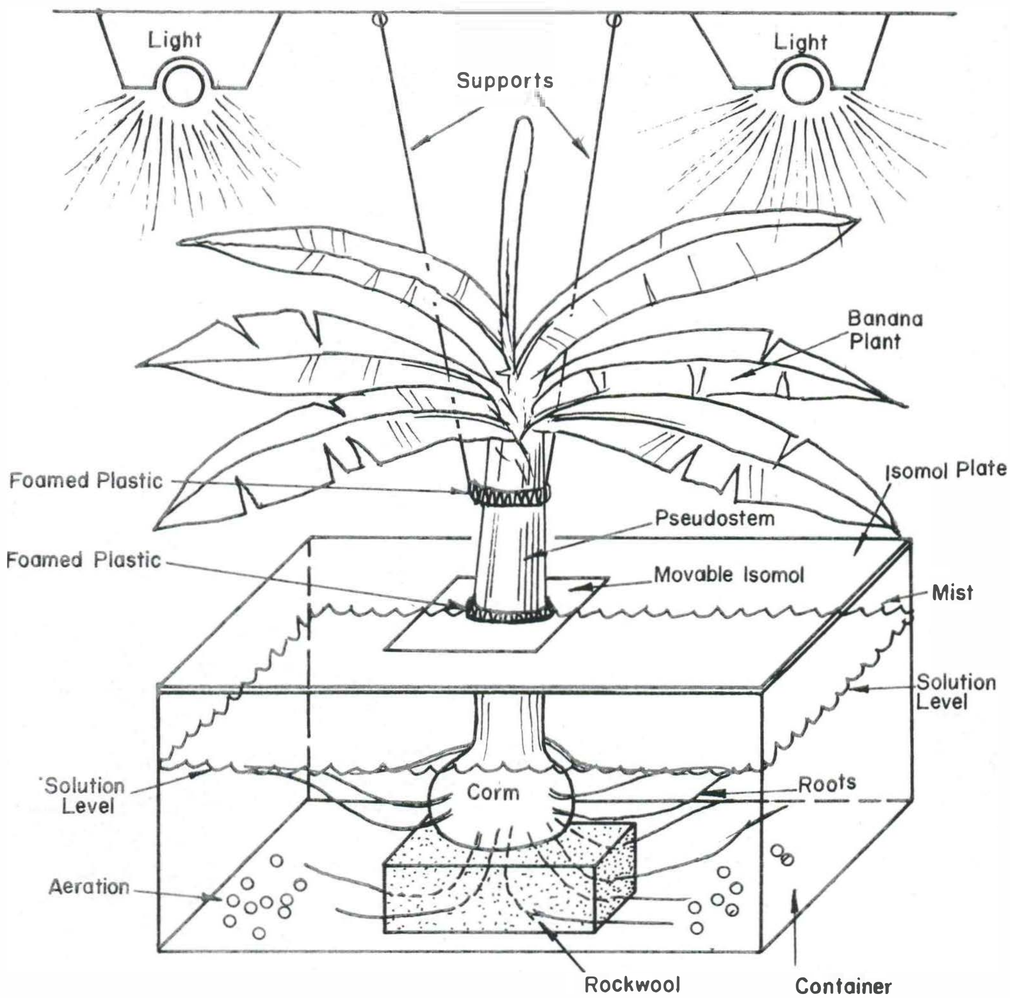

Figure 1. Schematic view of a banana plant growing in hydroponic culture.

and density of secondary roots were measured over a 5 cm length of primary root. Five roots were selected from these secondary roots and the number of tertiary roots over 5 cm of secondary root was counted, to assess the density. It was noted that tertiary roots are not found on all secondary roots in all varieties. The total root length of the root system was calculated. This is an over-estimation, as the primary root type with the highest density of secondary roots, i.e. feeder roots (see results and discussion) was used for the calculation.

The mean length of a tertiary root is approximately 0.3 cm. The length of the root hairs was not considered although they are very important. Since this study was very time-consuming, only 1 or 2 plants per cultivar were analysed. Sometimes not all the measurements described were taken for an individual plant. This will be specified in the results where necessary.

RESULTS AND DISCUSSION

Growth.

All *Musa* cultivars, except Silk and Pome grew vigorously. The root system developed profusely and was floating in the solution. Part of the secondary root system protruded out of the solution, and secondary and tertiary root formation near the corm was also well developed in the misty air (Fig. 2).

On average 94.5 % of the root system of all cultivars growing in the hydroponic solution was healthy, if Silk is excluded. This is in sharp contrast with the situation in the field.

In an Ultisol Decoene indicated that during the first 3 weeks after planting about 75 % of the roots of the

Figure 2. Dense root system near the corm of *Musa* cv. AAB in misty air.

TABLE 1 - Composition of the 5 stock hydroponic solutions for *Musa* cultivars.

Solution	Substance	g/10 L.
A	KNO_3 K_2SO_4 $MgSO_4.7H_2O$ $MgCl_2.6H_2O$	455.00 435.00 44.02 45.31
B	sequestreen	120.00
C	H_3BO_3 $MnSO_4.H_2O$ $ZnSO_4.7H_2O$ $CuSO_4.5H_2O$ $Na_2MoO_4.2H_2O$	2.28 5.40 0.46 0.32 0.14
D	KH_2PO_4 NaH_2PO_4	194.28 306.43
E	$Ca(NO_3)_2.4H_2O$ $CaCl_2.2H_2O$	463.50 105.00

plant crop of plantain and cooking banana is healthy (Decoene, 1985). This declines until the 7th week after planting and reaches then a level of about 40 % being healthy, due to die-off of the roots which were already formed before planting («racines préformées») (Beugnon and Champion, 1966). 20 weeks after planting again about 75 % of roots were healthy (Decoene, 1985).

In the same Ultisol, Weckx established that only 42 % and 49 % of the root system of the *first ratoon* (15 months after planting) of plantain and banana cultivars respectively were found to be healthy (Weckx, 1982).

During flowering the root system of the *second ratoon* of the Giant Cavendish in an andosol is even worse off. Less than 20 % are healthy (Gousseland, 1983).

The low rate of necrosis of primary roots in the hydroponic culture which results in increased extension of secondary roots (Laville 1964; Lassoudière, 1971) is also a feature of sound growth. The cultivars Silk and Pome grew less vigorously; it is not known what factor determines this, as both grew in the same container.

Description of a root.

A healthy root is white and fleshy and originates on the corm. The main primary root normally has an active growing tip of 7-8 cm long covered with short root hairs of about 2 mm long (Weckx, 1982); this is called zone 1, and is not presented in Fig. 3. Close to the primary root tip, there is a zone devoid of root hairs which varies in length (zone 2). The adjacent proximal zone, which is the longest zone, contains the secondary roots. Towards the distal end of this zone, the secondary roots decrease in length and density (zone 3a), the rest of the zone containing a high density of secondary roots of uniform length (zone 3b). At first sight the density of the secondary roots appear quite uniform, but detailed observation reveals that this zone consists of clusters of secondary roots of uniform density. Development of tertiary roots on the secondary roots showed the same pattern as indicated above.

TABLE 2 - Differences between pioneer (P) and feeder (F) roots of the entire root system for different cultivars.

Cultivar	Mean diameter at proximal end (mm)		Mean length of primary root (cm)		Length of P and F occupied by secondary roots (%)		Primary root length of P and F as percentage of total primary root length (%)	
	P	F	P	F	P	F	P	F
Agbagba (2) * (Plantain)	8.37**a	4.15b	40.7a	71.8b	75.2a	97.2b	35.4a	64.6b
Horn Plantain (2)	7.98a	4.63b	30.4a	62.6b	67.0a	95.4b	18.1a	81.9b
Pome (1) (Banana)	7.27a	3.89b	36.4a	116.0b	71.6a	93.8b	28.9a	71.1b
P. nangka (2) (Ditto)	7.30a	5.25b	38.4a	78.3b	73.0a	93.9b	34.7a	65.3b
Robusta (1) (Ditto)	8,00a	4.39b	45.2a	120.6b	74.9a	94.4b	36.8a	63.2b

* - Figures in brackets are numbers of plants observed.

** - Values in the same row of the same variable followed by a different letter are significantly different at 5% based on T statistics.

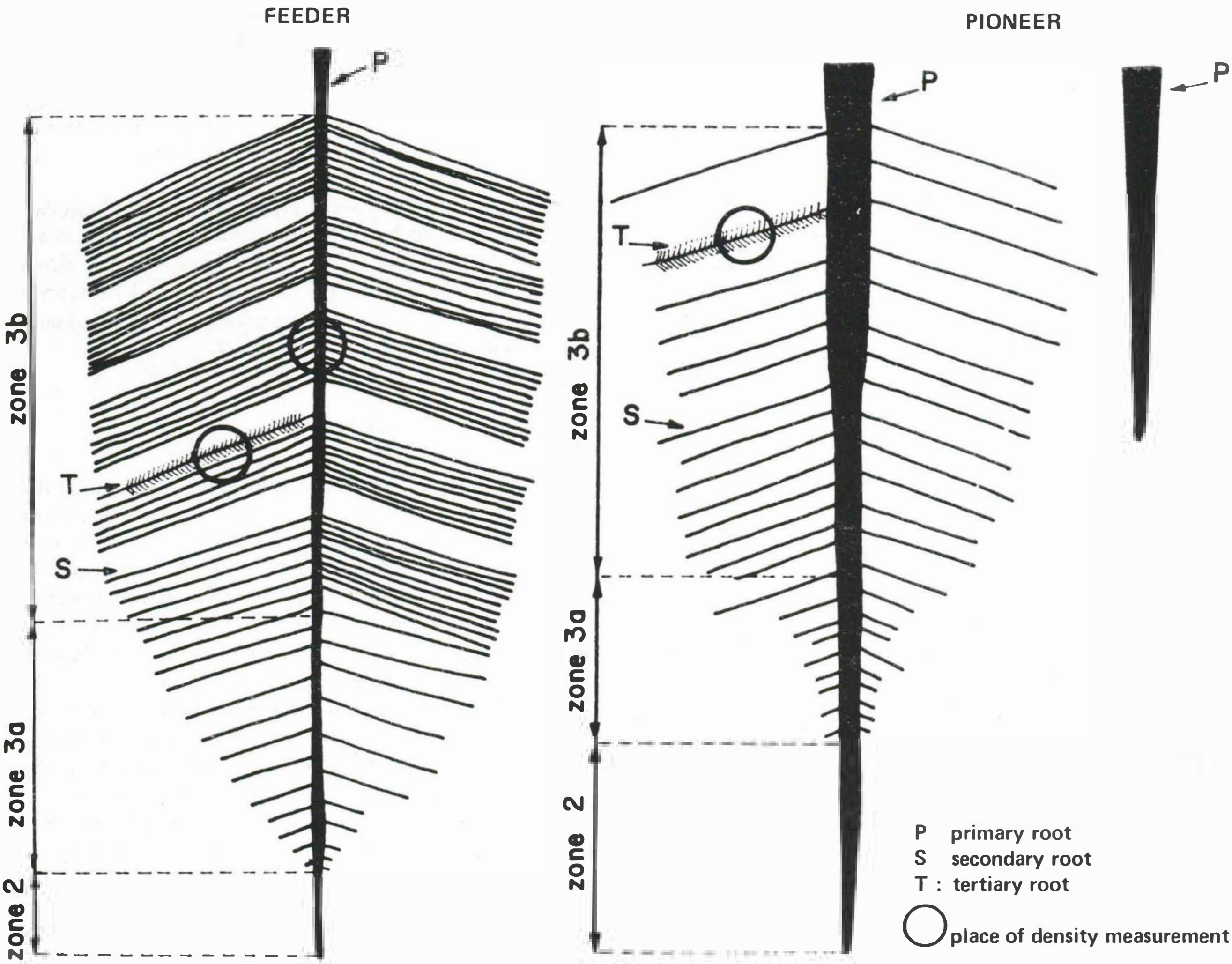

Figure 3. Schematic view of the two types of primary roots.

Root types.

The primary roots can be classified into two groups which can be called feeders and pioneers. Feeders are significantly longer but thinner than pioneers (Table 2) and have a higher density of secondary roots, although this was not measured.

Since the bare zone (zone 2) is much smaller in the primary root of the feeder than that of the pioneer (Fig. 3), the percentage of total root length occupied by secondary roots is about 20 % greater for feeders than for pioneers (Table 2).

The total length of the pioneers and feeders is about one third and two thirds, respectively, of the primary root system (Table 2). Thus it is suggested that the feeders seem to be more important for the water and nutrient uptake than the pioneers. Some *Musa* cultivars observed had sword suckers, all the roots of which were of the pioneer type.

It should be noted that the primary roots of the feeders are of uniform diameter over their whole length, but that pioneers are conical in shape (Fig. 3). Since the solution level was very shallow, and all roots spread laterally, it could not be established whether the distinction between feeders and pioneers coincides with the distinction which many authors mention between the laterally spreading roots (crown roots) and the vertically orientated roots

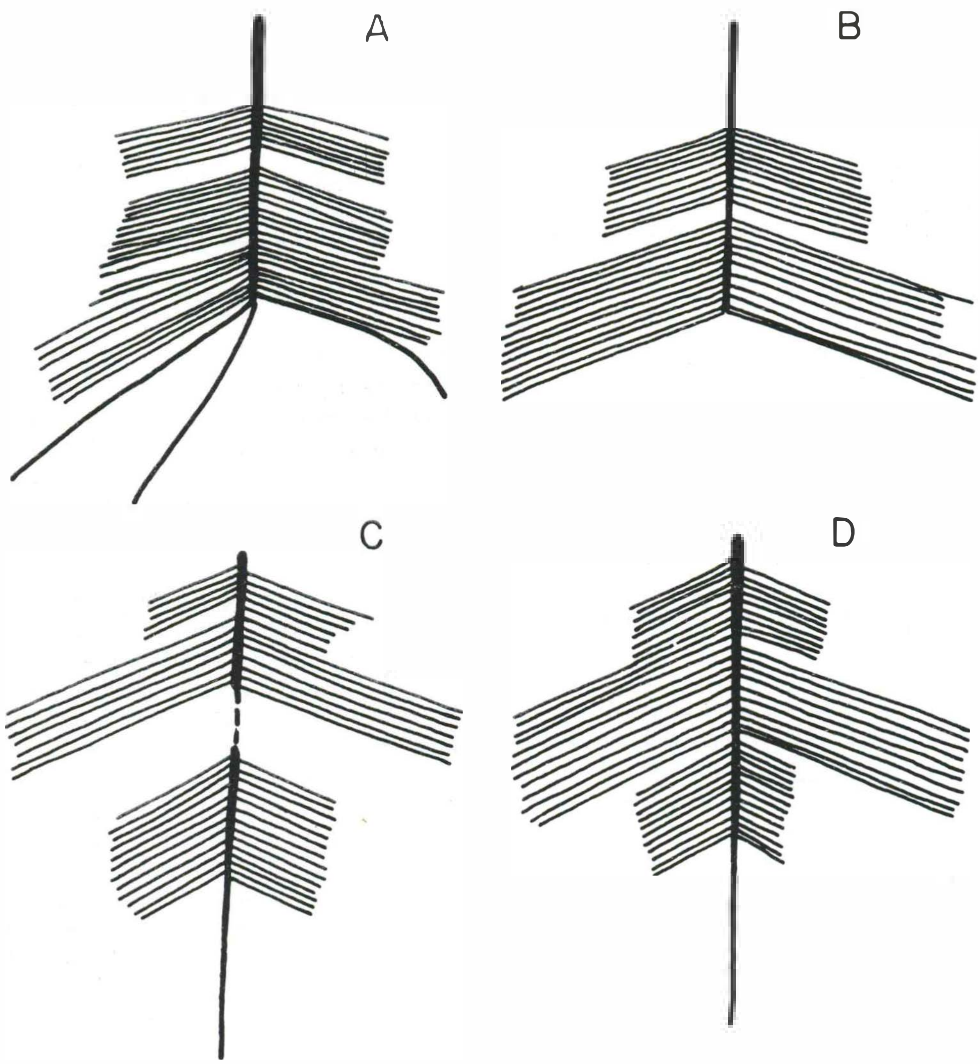

Figure 4. Four types of increased secondary root development.

(Kervégant, 1935; Summerville, 1939; Simmonds, 1966). An understanding of whether the functions of these two root types differ would be very useful.

The existence of feeders and pioneers under hydroponic conditions was recently confirmed (Winderickx, 1985). However under field conditions this was not the case (personal observation).

Secondary branching of root tip.

5 percent of the roots did not grow vigorously in the nutrient solution. It was observed that such roots showed a distinct elongation of part of the secondary roots in three ways:

(1) Increased branching of the primary root after necrosis of the root tip. Each branch (secondary root) near the root tip apparently became a primary root (Fig. 4A) due to its thickness and length. This was also observed in the field (Laville, 1964; Lassoudière, 1971).

(2) Increased elongation of secondary roots after necrosis of the root tip or root cortex (Fig. 4 B-C). The part of the primary root showing increased elongation of secondary roots, is limited approximately to 2-3 cm behind the point of necrosis. The extent of elongation varied considerably, with a maximum length of 101.4 cm.

(3) The same secondary root elongation, as discussed under item 2, but no necrosis could be ascertained at the distal

TABLE 3 - Proportion of primary, secondary and tertiary roots as a percentage of total root length.

Cultivars	Primary roots (%)	Secondary roots (%)	Tertiary roots (%)
diploids + acuminata triploids (AAA)	0.32	22.40	77.29
AAB plantain	0.68	53.44	45.88
AAB bananas	1.45	72.46	26.09

end of the increased elongation zone (Fig. 4D).

Proportion of primary, secondary and tertiary roots of total root length.

Calculation of the proportion of primary, secondary and tertiary roots of the total root length reveals that the *Musa* cultivars considered may be arranged in 3 groups: diploids + acuminata triploids (AAA), AAB plantains and AAB bananas (Table 3).

Tertiary roots are present in each group but their degree of significance varies (Fig. 5). In diploids and acuminata triploids (AAA) their proportion of the total root length is 77% as against only 46% for plantain (Table 3) since almost all the secondary roots of the diploids and acuminata triploids (AAA) considered have tertiary roots as opposed to only about 70% for the secondary roots of the plantains (Table 4). In contrast, the contribution made by the secondary roots is greater for plantains than for bananas, 53% as opposed to 22%, (Table 3). The contribution of the primary roots to the total root length is negligible.

As mentioned above, Silk and Pome, two AAB bananas, did not grow very well. Their roots were less developed, and the contribution made by the tertiary roots to the total root length was only 26% against 72% for the secondary roots. The following hypothesis is suggested: every cultivar has a different capacity to form primary, secondary and tertiary roots. In general, the capacity to form tertiary roots is greater in bananas than in plantains. Under less favorable conditions there is a shift in the largest proportion of the total root length from the tertiary roots towards the secondary and from the secondary towards the primary roots (Table 3). The results of field work indicate the same (Weckx, 1982).

Although the root branching may depend to a certain extent on environmental factors such as temperature, pH, etc. of the solution and the optimal growth conditions for plantain could be different from the ones for banana, it is very likely that the above mentioned differences in branching pattern between plantain and banana depend primarily on the genotype.

It should be noted that, in absolute terms, the root formation capacity of bananas seems also to be greater than that of plantains, since a comparison of two plants of the same size (length = 154 cm) gives the following total length of the root system (root hairs excluded): 9.2 km for Agbagba (Plantain) and 41.3 km for Robusta (Banana).

The other cultivars could not be compared in the same way because they differed in age and size, but the total root length calculated for each of these cultivars suggests that the total root length of bananas is at least twice that of plantains.

TABLE 4 - Percentage (%) of secondary roots occupied by tertiary roots and mean length of secondary roots.

Cultivars	Percentage (%)	Mean length (cm)
False Horn plantain (2) *	71.8	12.6
Horn plantain (2)	66.1	11.0
French plantain (1)	67.7	8.7
P. lilin (2) (banana)	100.0	3.8
P. nangka (2) (ditto)	100.0	12.4
Robusta (1) (ditto)	97.1	11.6
Dwarf Cavendish (2) (ditto)	97.7	5.2

* - Figures in brackets are the numbers of plants observed.

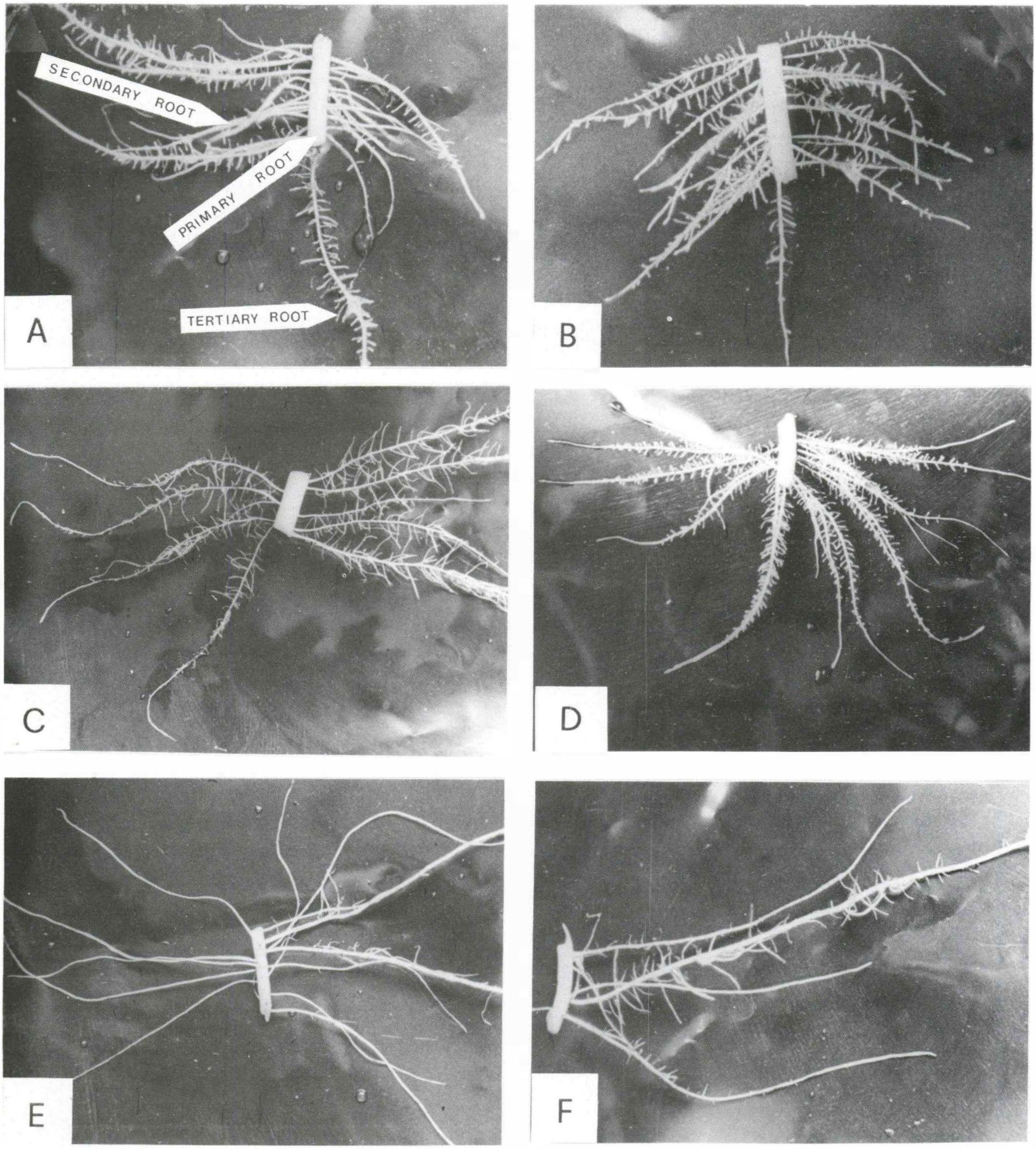

Figure 5. Different branching of 6 *Musa* cultivars

A - *Musa velutina*
B - Pisang lilin (AA).
C - Pisang nangka (AAA).
D - Dwarf Cavendish (AAA).
E. Agbagba (AAB).
F - Horn plantain (AAB).

Intervarietal differences in root form have been noted in several crops (Hackett 1968; Chang, Loresto and Tagumpay, 1972). The number of plants per *Musa* cultivar analysed, however, was two small for this to be verified.

CONCLUSION

Growing *Musa* cultivars in hydroponics seems to be a promising method for studying root development due to the high percentage (95%) of healthy roots. This method also made it possible to distinguish two root types. The type with secondary roots at a high density over about 90% of its entire length was called feeder as it is believed to be far more important for the nutrient and water uptake than the second type, called pioneer. The latter manifests secondary roots at a low density over about 70% of its entire length. Feeders make up two thirds of the primary root length, pioneers only one third.

Measurement of the secondary and tertiary roots on the feeder roots showed that the total length of the secondary and tertiary roots, was different for bananas and plantain. The secondary and tertiary roots of plantain were respectively 53% and 46% of total root length, against 22% and 77% for banana roots.

The smaller root length especially due to the lower proportion of tertiary roots could be a contributing factor to the lower productivity of plantains compared to bananas. Therefore further research should focus on field techniques such as mulching which stimulate branching.

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