# 6.2

# Effects of Soil Physical Properties and Tillage Methods on the Growth and Development of Pineapple Roots

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## 6.2.1. INTRODUCTION

A study has been made of soils used for production of pineapples at Bongua in the Ivory Coast. Soil physical conditions have been measured, and the influence of tillage on soil properties. The effects of physical conditions on root growth of pineapples are discussed.

## 6.2.2. SOIL CHARACTERISTICS

The soils of the plantation are yellow 'sols ferralitiques', with pH between 4 and 5, total exchangeable cations less than 1.5 meq/100g, organic matter about 1.5 per cent, and developed on tertiary sand. They have a sandy to clayey sand texture, with some clay enrichment at depth, but are weakly structured. Particle size analysis of the 0–50 cm layer is given as: coarse sand 55 per cent, fine sand 25.5 per cent, coarse silt 3.5 per cent, fine silt 3.5 per cent, and clay 11 per cent (Bonzon, 1969).

## 6.2.3. STRUCTURAL CONDITIONS CREATED BY CULTIVATION

The treatments differ essentially in the depth to which the residue of the previous crop is buried in the soil.

- $T_1$ Superficial tillage: using a rotovator to a maximum depth of 10 cm; this allows the maintenance of a true mulch.
- $T_2$ Medium tillage: the rotovator is at a maximum depth of 25 cm; this forms a homogeneous mixture between the residue of the last crop and the soil.

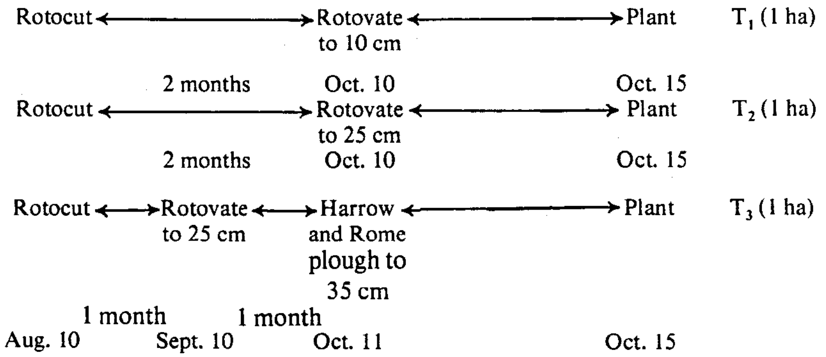
- $T_3$ Deep tillage: incorporates the following methods of tillage: burying the residue of the last crop with a rotovator (25 cm); deep working (to 35 cm) with a coulter plough; breaking of the surface layer with a harrow.

For all treatments the preceding cultivation cycle involved rotovating to 25 cm.

$T_3$ is the usual cultivation method employed in the plantations in the south of the Ivory Coast.

Observations were made on the cultivated profiles before planting. A point of discontinuity was found in treatments $T_1$ and $T_2$ where at about 10 cm and 25 cm respectively a smeared surface separated the higher layer, with a fragmented and particulate structure, from the lower layer, with a bulky and continuous structure. In treatment $T_3$, the soil layer turned over by the harrow was very swollen compared with the underlying layer, which tended to be more bulky. There was a clear horizontal discontinuity seperating these two soil layers of treatment $T_3$.

The timing of these different treatments was as follows:



The level of decomposition of the residues of the (previous) cultivation at planting time differentiates treatments $T_1$ and $T_2$ from $T_3$. About 70 per cent of the residues 'rotocut' (35 tonne/ha) persists on $T_1$ and $T_2$ two months later. For $T_3$ the quantity of residues at the time of ploughing is almost 20 per cent of the mass rotocut: burial by rotovator has led to rapid decomposition in the period between rotovating and ploughing.

### 6.2.4. PHYSICAL PROPERTIES OF THE CULTIVATED SOILS

To characterize the different structural states:

(a) a densitometer was used to determine the compaction of the different horizons;
(b) a penetrometer was used to detect horizon discontinuities and to measure cohesion differences between the horizons;
(c) an infiltrometer was used to characterize water movement in the cultivated soil.

### 6.2.5. DENSITOMETER MEASUREMENTS

These were made to a depth of 18 cm, at the end of the cultivation cycle (16 months after planting) on the treatments $T_1$, $T_2$, and $T_3$, and at the start of the new cycle $T_1^1$, $T_2^1$, and $T_3^1$. The mean results (five repetitions as a minimum) are given in Table 6.2.

Table 6.2 Bulk densities of soils 24 hours and 16 months after different cultivation treatments

| Depth (cm) | Apparent dry density (g/cm³)<br>24 hr after cultivation | | | 16 months after cultivation | | |
|---|---|---|---|---|---|---|
| | $T_1^1$ | $T_2^1$ | $T_3^1$ | $T_1$ | $T_2$ | $T_3$ |
| 0–18 | 1.25 | 1.09 | 1.25 | 1.31 | 1.21 | 1.25 |
| 10–28 | 1.37 | — | — | 1.45 | — | — |
| 20–38 | — | 1.43 | 1.25 | — | 1.52 | 1.35 |
| 30–48 | 1.49 | — | — | 1.57 | — | — |
| 40–58 | — | 1.47 | 1.49 | — | 1.55 | 1.58 |

The lack of particle size analyses for the soil when the trial restarted prevents a strict comparison being made between the corresponding treatments in the two trials. The observations on the cultivated profiles indicate that to a depth of 40 cm $T_1$, $T_2$, and $T_3$ were richer in clay than $T_1^1$, $T_2^1$, and $T_3^1$. Allowing for this restriction, analysis of the results for this layer of soil (0–40 cm) underlines the existence of two kinds of profile:

A continuous profile for treatment $T_3^1$ at the beginning of the cycle. The two horizons (0–20 cm) and (20–40 cm) become slightly differentiated during the course of the cultivation cycle ($T_3$); in particular, an increase in bulk density at 20–38 cm is noted. This change is confirmed by the results for the horizons (10–28 cm) ($T_1^1$) and (20–38 cm) ($T_2^1$) which have not been reduced by cultivation.

A discontinuous profile for treatments $T_1^1$ and $T_2^1$ and $T_1$ and $T_2$ in relation to the depth of working by the rotovator; density increases sharply below this limit.

### 6.2.6. PENETROMETER MEASUREMENTS

The apparatus used is a small steel spike (diameter 1 cm) terminating in a conical point (diameter 1.2 cm) and carrying an anvil (block). The shaft is driven into the soil by consecutive blows from a weight of 1 kg dropped from a height of 1 m. The three treatments ($T_1$, $T_2$, $T_3$) were tested 35, 42, 112, and 146 days after planting in order to detect any change in the forces of cohesion. The median results are shown in Figure 6.1. The three treatments gave the following results:

$T_1$: the cohesive force increased from 10 cm to 40 cm; the horizon (0–10 cm) worked by the rotovator was not taken into account in the measurements, as the weight of the penetrometer led to the burial of the probe close to the discontinuity.

$T_2$: at the lower limit of the layer worked by the rotovator the soil separates into two horizons differentiated by the forces of cohesion, which are constant over the first 20 cm and increase in the horizon below.

$T_3$: the forces of cohesion are generally constant over all the cultivated layer, but there is a small increase with depth. There is a sharp increase at the base of the worked soil.

Although the four series of measurements were made at appropriate intervals, they did not enable the general sequence of changes with time to be established, because for $T_3$, the first series having been made more than a month after planting, it is possible that a slight increase in cohesion had already occurred in the 20–40 cm horizon, and the fourth series of measurements having preceded the main rains (May to June), the effect of climate on penetration could not be taken into account.

## 6.2.7. MEASUREMENTS OF THE RATE OF INFILTRATION OF WATER

The method chosen was that of Vergiere: infiltration rates were measured in the laboratory on undisturbed soil cores. The three treatments ($T_1$, $T_2$, $T_3$) were tested at the end of the cycle (16 months after the soil was cultivated). Samples were taken according to the existing horizon discontinuities. The infiltration rates ($K = 10^{-4}$ cm/sec) after 4 h of percolation are shown in Figure 6.2.

Soil permeability for the three treatments is high in the superficial layer ($K = 170 \times 10^{-4}$ cm/sec) and is greatly reduced as the depth increases ($K = 10\text{–}20 \times 10^{-4}$ cm/sec at 50 cm). The decline is more marked when the soil is not cultivated very deeply. $K$ ($T_3$) is twice as great at 25 cm ($K = 10 \times 10^{-4}$ cm/sec) and at a depth of 40 cm ($K = 50 \times 10^{-4}$ cm/sec) than $K$ ($T_1$ and $T_2$) at the same depths. At the base of the cultivated soil, for $T_2$ (20–30 cm) and $T_3$ (43–53 cm) the rate of infiltration is lower than in the underlying layer; in the plots worked by implements a 'polishing' seems to be the cause of this reduction in permeability. This is not apparent for $T_1$ (5–15 cm); the reduction of the rate of infiltration is cancelled out by the important macroporosity caused by roots.

## 6.2.7. CONCLUSIONS FROM THE PHYSICAL MEASUREMENTS

Each of the cultivation methods has produced a well-typified (0–45 cm) cultural profile. For $T_1$ and $T_2$, two quite distinguishable horizons are separated by their

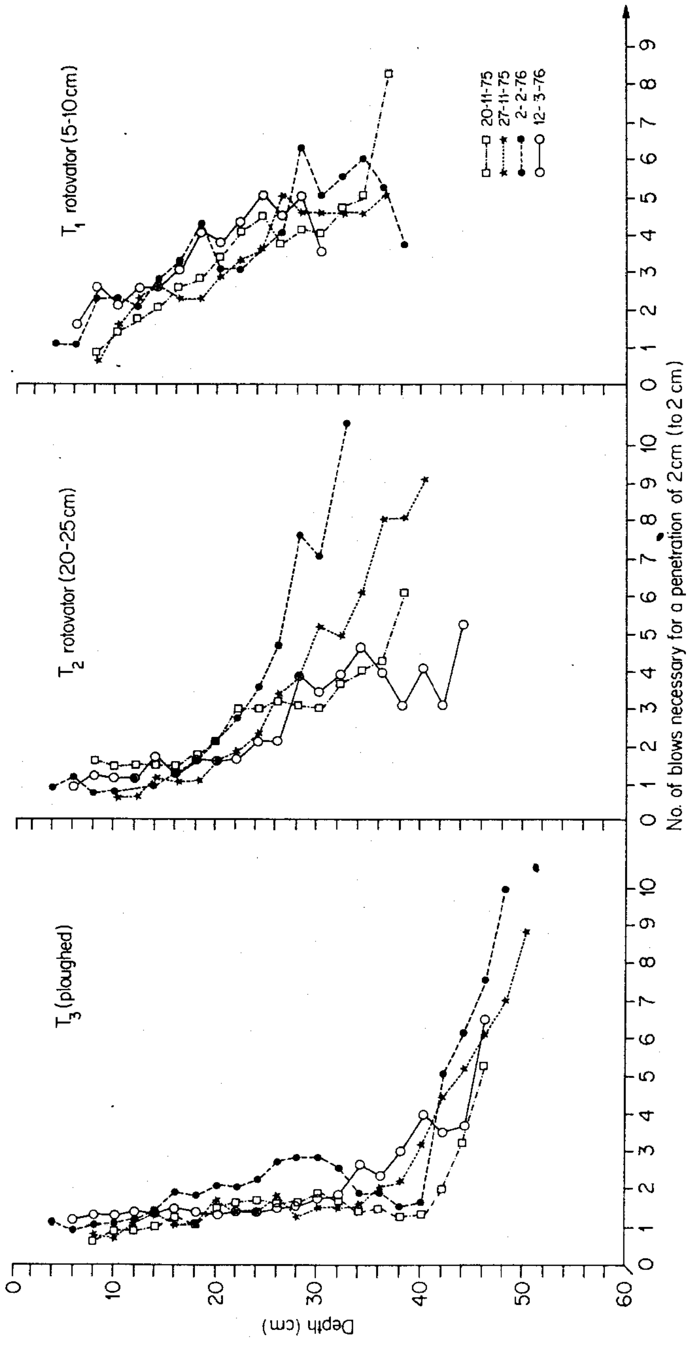


**Figure 6.1.** Penetrometer resistance profiles for the three cultivation treatments

apparent density, their cohesion, and their permeability. In the absence of deep ploughing for four years, the horizons (10–40 cm) for $T_1$ and (25–40 cm) for $T_2$ redevelop a massive structure.

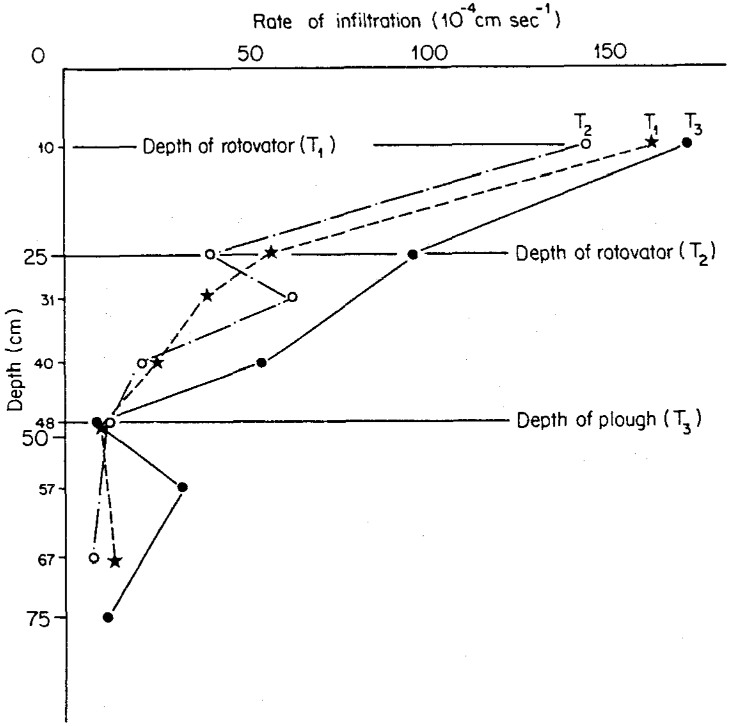


Figure 6.2. Infiltration rates at different depths (after 4 h)

In the case of $T_3$, there is the long-lasting effect of loosening of the soil by deep working: 16 months after the use of implements, the apparent density and permeability remained lower than on $T_1$ and $T_2$ in the horizons which had not been tilled. The absence of a real horizon discontinuity at the level of the base of harrowing (25 cm) confers on this profile a more homogeneous character for this layer of soil (0–45 cm).

Generally this superposition of different permeabilities can lead at times of heavy rainfall to the accumulation of free water, more important where the worked zone is restricted. Temporarily insufficient aeration of the soil can arise: alternation of oxidation and reduction (pseudo-gleying) has been observed. Such conditions are unfavourable to the root system (Stolzy, 1974), a deficit of $O_2$, an excess of $CO_2$, and toxic products of the decomposition of organic matter arising.

### 6.2.8. DEVELOPMENT OF THE ROOT SYSTEM OF THE PINEAPPLE

The behaviour of pineapple is typical of vegetative material planted in soils after cultivation. The development of the root begins at the base of the axis. Roots are initiated along the length of the axis up to the junction with the leaves, at the same rate of development as the aerial parts.

In the absence of literature on the subject, it was considered important to follow the development of the root system, as this partly determines the extent to which the cultivated soil is exploited.

### 6.2.9. ROOT DEVELOPMENT DURING THE FIRST SEVEN MONTHS OF THE CULTIVATION PERIOD

Root counts were made on the three treatments, $T_1$, $T_2$, and $T_3$. The morphology of the pineapple shoots led us to distinguish two types of emergent roots:

roots in contact with the soil;

roots at the angle of the leaves and turning more or less around the axis.

Figures 6.3 and 6.4 show respectively the emergence curves of the total number of roots, and the number of roots in the soil. On Figure 6.3 the growth curve of the plants of treatment $T_3$ is also traced. No effect of cultivation on the rhythm of root emergence was detected during the period under study. Three distinct phases

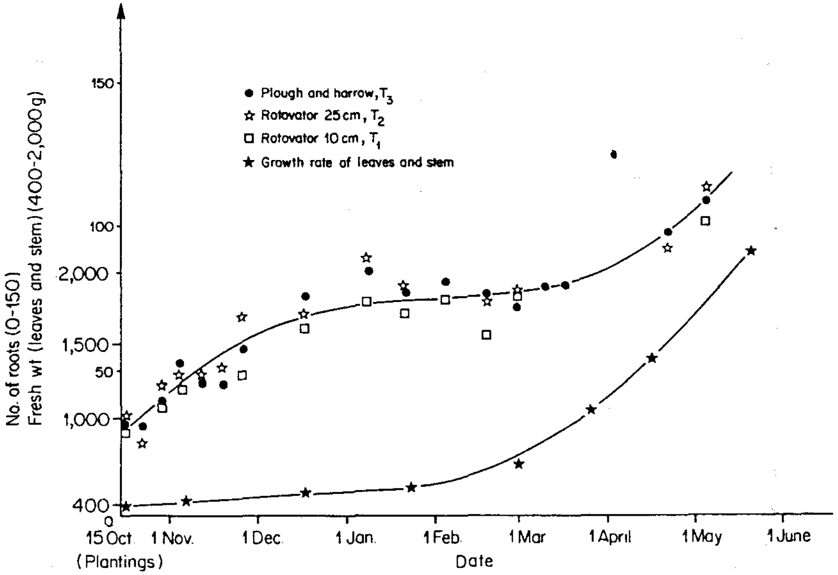


Figure 6.3. Total number of roots emerging per plant

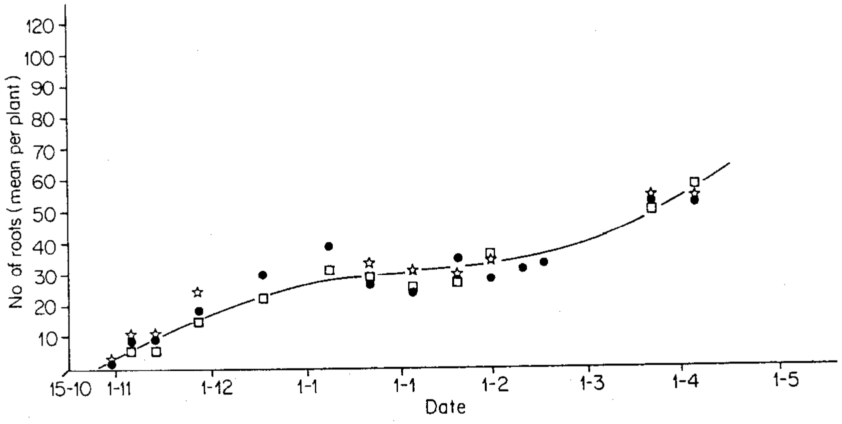


Figure 6.4. Number of roots found in the soil (mean per plant). Symbols as in Figure 6.3

are brought to light by these curves for total root initiation, which show a strong resemblance. From Figure 6.3, the phases appear to be:

First phase—duration two months—intense growth, conveyed by the doubling of the initial stock: 30 roots at planting and 70 roots two months later.

Second phase—(three months)—no root emergence was noted. The lack of root initiation corresponded to the growth of the aerial parts: the levels of development of these were insufficient to sustain further root initiation.

Third phase—recovery of root emergence occurs in parallel with active growth of the above-ground parts of the plant.

Observations on the emergence of roots in the soil (Figure 6.4) are as follows:

the first roots in the soil developed 15 days after planting;

two months later, their number was around 30–40, and remained constant during the following three months.

Exploitation of the cultivated profile following planting of the slip is therefore controlled by a restricted number of roots; this poses problems of maintenance of their growth and activity.

## 6.2.10. GROWTH AND DEVELOPMENT OF THE ROOT SYSTEM DURING THE FIRST FIVE MONTHS OF THE CULTIVATION CYCLE

The rooting of the pineapple is of the fascicular type, concentrated in the superficial soil layer (0–30 cm). Samplings were made using special boxes in order that the total root system of the plant was obtained as far as the discontinuity of $T_1$. The dimensions of the cube of soil sampled were 25 cm high, 30 cm long, and 17 cm deep.

In view of the delay which occurs in development of roots in the soil the sampling was started one month after planting (12 replicates for each treatment on each date). Some samples were taken from 25–40 cm, at the last two sampling dates. The results from the samples obtained with the aid of the boxes are given in Table 6.3. The overall amounts of roots, supported by a certain soil volume ($25 \times 30 \times 17$ cm$^3$), are shown in Figure 6.5.

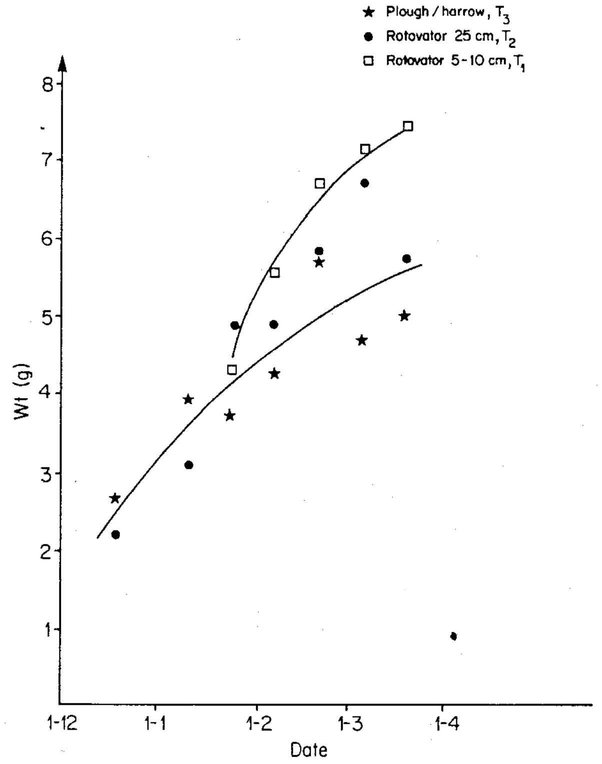


Figure 6.5. Root dry weight in the 0–25 cm horizon

### 6.2.10.1. Total Roots, 0–25 cm

A greater number of roots were measured on $T_1$ than on $T_2$ and $T_3$ during the initial period of root development. These results are opposite to the corresponding results for the growth of the above-ground parts; for these $T_1$ is less than $T_2$ and $T_3$. In order to explain these results the following hypotheses are put forward. Three months after planting, the morphology of the root samples for $T_1$ was distinctly different than for $T_3$. On $T_3$ the roots were swollen with a layer of soil at

Table 6.3 Relative weight of roots by horizons (g, and % of total)

| Treatments | Horizons (cm) | Sampling dates | 18.12.75 | 9.01.76 | 23.01.76 | 5.02.76 | 20.02.76 | 4.03.76 | 18.03.76 |
|---|---|---|---|---|---|---|---|---|---|
| $T_3$ | 0–10 | wt (g) | 0.735 | 1.323 | 1.343 | 1.440 | 2.210 | 1.827 | 2.186 |
| | | % | 28 | 34 | 36 | 34 | 38 | 39 | 43 |
| | 10–25 | wt | 1.935 | 2.611 | 2.403 | 2.799 | 3.644 | 2.882 | 2.841 |
| | | % | 72 | 66 | 64 | 66 | 62 | 61 | 57 |
| | 0–25 | wt | 2.670 | 3.934 | 3.746 | 4.239 | 5.854 | 4.709 | 5.027 |
| $T_2$ | 0–10 | wt | 0.703 | 0.719 | 1.601 | 1.289 | 1.918 | 1.745 | 2.061 |
| | | % | 32 | 23 | 33 | 26 | 50 | 26 | 36 |
| | 10–25 | wt | 1.513 | 2.393 | 3.284 | 3.591 | 3.852 | 5.004 | 3.673 |
| | | % | 68 | 77 | 67 | 74 | 50 | 74 | 64 |
| | 0–25 | wt | 2.216 | 3.112 | 4.885 | 4.880 | 5.770 | 6.749 | 5.734 |
| $T_1$ | 0–10 | wt | — | — | 3.024 | 3.009 | 2.885 | 4.005 | 3.642 |
| | | % | — | — | 70 | 54 | 43 | 56 | 49 |
| | 10–25 | wt | — | — | 1.272 | 2.560 | 3.839 | 3.173 | 3.737 |
| | | % | — | — | 30 | 46 | 57 | 44 | 51 |
| | 0–25 | wt | — | — | 4.296 | 5.569 | 6.694 | 7.178 | 7.379 |

their periphery, whereas on $T_1$ they were woody, like 'iron wire', without the attached soil, and showed symptoms of an attack by nematodes (Meloidogyne). It would, therefore, seem that when unfavourable environmental conditions occur they promote a proliferation of the root system, more or less in terms of root mass. These results and observations reassert the fact that the increase in weight of the root system cannot explain that of the above-ground parts of the plant. Concepts of activity have also to be taken into account.

### 6.2.10.2. Distribution of the Root System in the 0–25 cm Horizon

Four to five months after planting, about 40 per cent of the root mass of $T_1$ and $T_2$ was concentrated in the 0–10 cm horizon, against 50 per cent for $T_3$ (mean results relating to the last three samplings). If $T_3$ is used as a reference treatment it can be seen that a relative increase in rooting in the 0–10 cm horizon occurs with time: 28 per cent two months after planting as against 43 per cent at five months. Inforzato *et al.*, (1968) found 58 per cent in the 0–10 cm horizon and 75 per cent in the 0–20 cm horizon at 8 and 12 months respectively.

### 6.2.10.3. Rooting at Depth

The results of the two samplings (12 composite samples for each treatment) from the 25–40 cm horizon were:

*Root Mass (mg/kg of earth) (25–40 cm)*

| | $T_3$ | $T_2$ | $T_1$ |
|---|---|---|---|
| 4.3.76 | 21 | 8 | 5 |
| 18.3.76 | 16 | 10 | 6 |

Below the depth (25 cm) worked by the rotovator there was less root growth in $T_1$ and $T_2$ compared with $T_3$.

Exploitation of the soil layer (0–40 cm) by roots depends on the depth to which the soil was cultivated, the discontinuities created by the cultivations. The lower horizons, characterized by less favourable density, cohesion, and permeability than the higher horizons, are obstacles to a regular root growth at depth, and this much more so when the cultivation of the soil is superficial.

## 6.2.11. CONCLUSIONS

Rooting of pineapples is particularly sensitive to the differing structural states produced by cultivation. It has been suggested (O'Connell, 1975) that root development of plants is limited when the apparent dry density is above 1.5 g/cm$^3$. In the case of pineapple reduced root development occurs with a density below 1.4 g/cm$^3$. This sensitivity should be taken into account by relating the cultivation cycle to the climatic cycle. In the trial reported here no difference between rotovating to 25 cm ($T_2$) and rotovating and harrowing ($T_3$) in growth of the aereal parts was found. At the same time the increase of rooting over the first five months showed a remarkable similarity. The phase of active growth finished with the start of the rainy season. In contrast, in a previous trial the plants on $T_2^1$ and $T_3^1$, after showing similar development for five months, showed above-ground as well as root growth which was different at the end of the rainy season, root and surface growth having continued on $T_3^1$, whereas it had stopped on $T_2^1$.

Study of these related topics of structural condition and root growth is at present being pursued in new trials, in which more stress is placed on the 'activity' of the root system.

## ACKNOWLEDGMENTS

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## 6.3

# Effects of Bulk Density and Soil Moisture on Radicle Elongation of Some Tropical Crops

P. R. MAURYA and R. LAL

Soil physical characteristics that can be important in root penetration and development in tropical soils include: bulk density, soil moisture regime, soil temperature, gravel concentration, and nutrient imbalance including toxicity to Al and Mn and/or deficiency of Ca and other basic cations. Fertilizer-use efficiency and better crop growth cannot be attained without adequate and prolific root system development into the solum.

Whereas the interaction between soil temperature and moisture regime can be significant for root development (Maurya and Lal, unpublished), so may be the interaction between bulk density and soil moisture regime. Pore size distribution and bulk density are rather difficult to interpret for highly variable, shallow, gravelly soils which occur in many parts of the tropics (Collinet, 1969; Smyth and Montgomery, 1962). Size and shape of the coarse material also affect root distribution, over and above the adverse effects of gravel concentration (Babalola and Lal, 1977). Large concentrations of inert gravel material also dilute the nutrient and water retention capacity of the soil.

The influence of bulk density *per se* on root development has been investigated by many researchers. However, the information on the influence of interaction between bulk density and gravel concentration on root development of tropical crops is rather scanty. Even a slight increase in the bulk density can change root anatomy (Baliga *et al.,* 1975; Barley, 1963; Sheikh, 1976). Gravel concentration in soil has been shown to adversely affect root development of tree crops and arable crops (Babalola and Lal, 1977; Vine *et al.*, 1978). The mechanism of this adverse effect, either physiological, physical or both, has not yet been thoroughly investigated.

The resistance to root development is a function of the shear strength exerted by the soil. The shear strength is affected by soil moisture potential and soil bulk density. The latter, however, is influenced by texture and gravel concentration.

The objective of this study therefore was to investigate the influence of interac-

Vedette :

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