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Some Aspects of Shoot and Root Growth of Avocado Under Lowland Tropical Conditions

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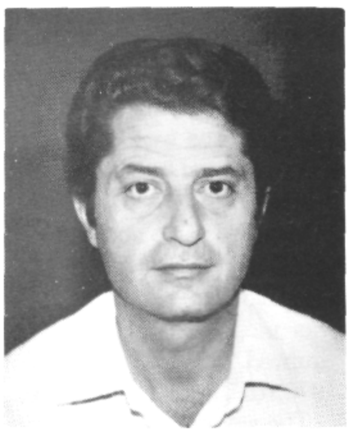

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Introduction

Avocado [*Persea americana* L.] is cultivated on a large scale ranging from the hot humid tropics of Latin America and Africa to the warm subtropics of North and South America, Australia, South Africa, and parts of the Mediterranean. In addition to widespread consumption within these areas, the value of this fruit as export commodity is of considerable economic potential; and in certain countries, it is grown principally for export.

While considerable work has been done in some areas such as flowering, diseases, cultivar selection, post-harvest handling, and marketing there are other areas in which more information is required. One such area is vegetative (shoot and root) growth, about which there is still relatively little information available in the literature.

In the present work, therefore, an attempt has been made to characterize the annual pattern of shoot and root growth of avocado when cultivated under the tropical lowland conditions of Trinidad.

Materials and Methods

The following two experiments were carried out between April 1978 and August 1979:

Experiment 1: Shoot and cambial growth of bearing plants.

Five plants of avocado (Simmonds variety on unknown West Indian rootstock) five years old were selected for the present studies. The plants had been growing at the University Field Station, on cambered beds and the soil type was River Estate loam (Brown and Bally, 1970). The plants were uniform in size and vigour and had been given uniform cultural care. No irrigation was applied.

To determine shoot growth flushes, twenty buds (ten apicals and ten axillaries) were selected at random in each selected plant and labeled. The extension growth of the leader shoots, developed from the selected buds, was measured and the number of leaves greater than 2 cm long was counted. Records were taken at weekly intervals from the 3rd of June, 1978, to the 30th of June, 1979.

The same plants used for the previous observations were also used for measuring the cambial growth of the trunk at weekly intervals. The girth of the trunk was measured at a fixed point at 8 a.m. every Saturday. The point was made 15 cm above the bud union. The recording period was from the 3rd of June, 1978, to the 30th of June, 1979.

Experiment 2. Shoot and root dry weight accumulation and root distribution.

Eighteen grafted avocado plants (Pollock variety on unknown West Indian rootstock) nine months old growing in plastic bags were used for the experiment. These were planted at the University Field Station on a cambered bed (River Estate loam) on the 16th of June, 1982, and had been given uniform cultural care. No irrigation was applied.

Sampling was at two-monthly intervals, and the first sample was taken two months after planting. Sampling extended over a one year period so a total of six samples was taken, three in the wet and three in the dry season. During each sample, shoot and root growth parameters were measured on three plants chosen at random.

To assess shoot growth the following parameters were used:

Height of the plant: This was the vertical distance from the graft union to the highest point of the crown.

Canopy-spread: The diameter of the canopy was measured in four directions: north-south, east-west, northeast-southwest and northwest-southeast and the mean of these was used.

Fresh and dry weights of shoots: The plant was cut at the soil surface and leaves and stems were separately weighed to determine fresh weights. Subsequently, leaves and stems were separately oven dried at 80° C until constant weight was obtained and their dry weights recorded. By adding the weights of the leaves and the stems the total weight of shoots was obtained.

The other objective of this experiment was to determine root growth by measuring total root weight and root distribution. In order to achieve this objective the following excavation method was used:

Cylindrical blocks of soil (with the plant as the center of the circle) were sequentially excavated and the excavated soil carefully searched for roots.

The order in which the blocks were excavated was as follows:

Block	Distance from the trunk-cm	Depth from soil surface-cm
1	0-50	0-50
2	0-50	50-100
3	0-50	100-150
4	0-50	150-200
5	50-100	0-50
6	50-100	50-100
7	50-100	100-150
8	100-150	0-50

For the final sample only, the depth of each block of soil was further broken down into 25 cm divisions.

During each sampling, excavation was continued into a block only when roots were observed in the previous block. All roots from each block were bagged and labeled and subsequently carefully washed, weighed, and oven dried at 80°C until constant weight was obtained. Total fresh and dry weights were calculated by adding respectively the weights of the different layers.

At planting, fresh and dry weights of stems, leaves, and roots of three plants were taken. These were considered as zero readings.

To assess root growth, the following two parameters were also measured:

Maximum root depth: This was measured as the maximum vertical distance from the soil surface to the point where the last root was observed.

Maximum root spread-diameter: This was the greatest horizontal distance between any two points, as measured through the trunk, at which root spread was observed.

Climatic Conditions:

The climate of Central Trinidad, where the experiments were carried out, is typical of the wet climate of tropical windward coast with fairly heavy but moderately well distributed rainfall for between seven and eight months in a year. The dry season varies from weak to intense, with four to five dry months. An important feature of rainfall is the great variability from year to year and from month to month. The temperature varies from a mean monthly maximum in January of 30°C and in May of 32.2°C to a mean monthly minimum of 20°C in February and 22.2°C in September (Brown and Bally, 1970).

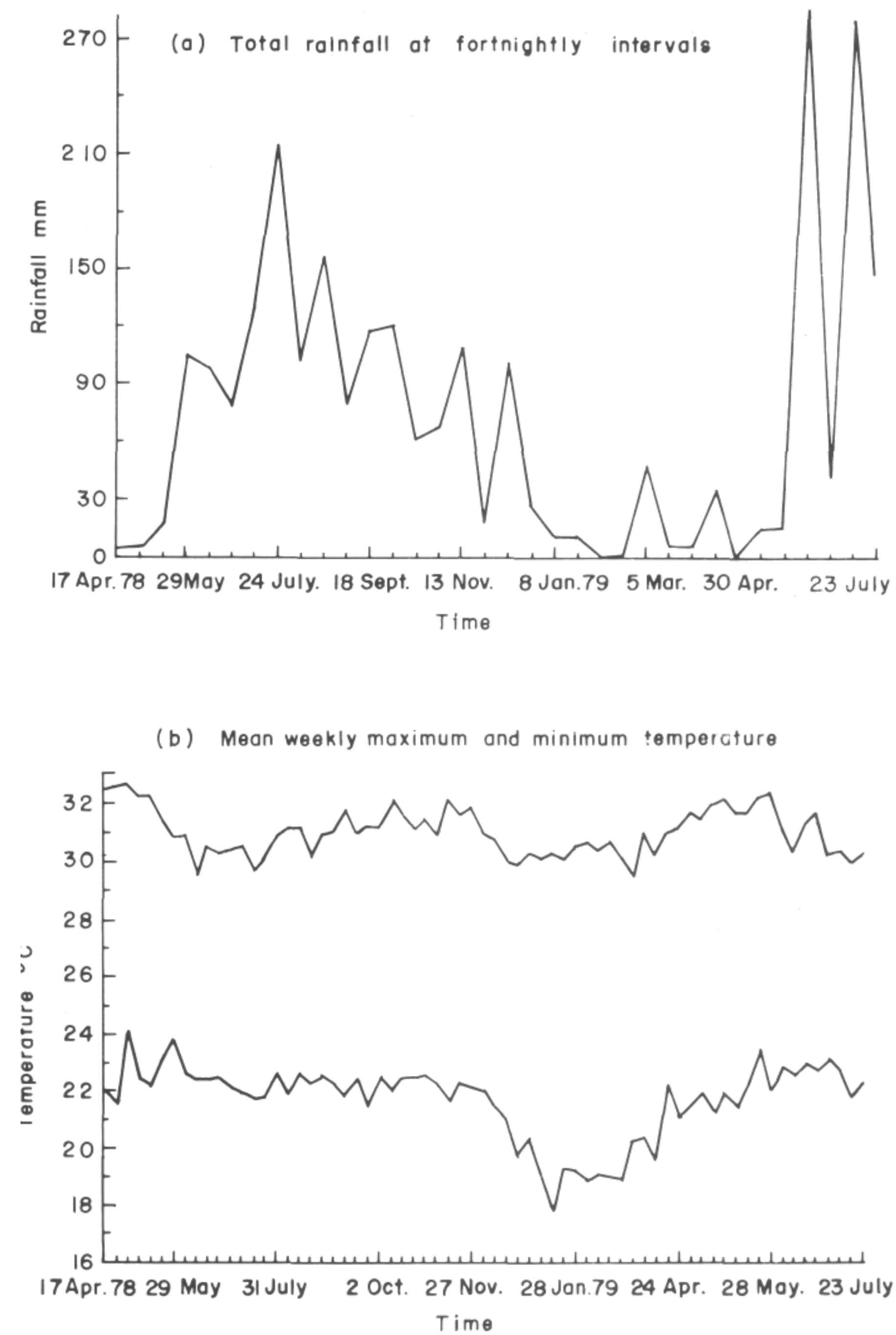

FIGURE 1. Rainfall and maximum and minimum air temperature at the University Field Station.

For experimental purposes, the wet season was taken as the period from the end of May 1978 until the middle of December 1978 and the dry season as the period from the middle of December 1978 until the end of May 1979. Total rainfall was 1,488 mm for the wet and 165 mm for the dry season. Maximum temperature recorded was 32.4°C, in May, and minimum 18.0°C, in January [*Figure 1*].

Results and Discussion

General characteristics of shoot growth

Shoot growth of avocado plants was monopodial, and resulted mostly from opening and expansion of terminal buds on the main axes and branches and from some axillary buds near the apices. Shoot growth occurred in several recurrent waves (cycles or flushes) within the same growing season or year. A shoot growth flush was defined as the bursting of a bud into leaves and internodes and their subsequent growth until they attained their full length. The number of flushes of individual shoots over the year was variable. Only some of the buds on a plant became active during a given flush. The position of a bud on the plant was very important: shoots on the distal portions of the plant grew upright and produced more flushes than those on the inner portion of the plant.

Based upon observations (Experiment 1) it was concluded that avocado plants developed five distinct types of shoots:

(a) Long shoots: These were shoots which developed from terminal buds located at the distal portions of the plant. They grew upright and growth often continued throughout the major part of the growing season producing five to six flushes a year. They had an average length of 50 to 80 cm [*Figures 2e and 2f*].

(b) Short shoots: These were shoots which developed from terminal buds or axillary buds near the terminals. They were located at the inner portion of the plant and produced only one or two flushes at the beginning of the growing season. They had an average length of less than 20 cm [*Figures 2a and 2b*].

(c) Intermediate shoots: These were shoots which developed mainly from terminal buds and some axillary buds near the terminal. They were located at either the distal or the inner portion of the plant and produced three to four flushes. Intermediate shoots had an average length of 23 cm to 34 cm [*Figures 2c and 2d*].

(d) Lateral shoots: As described (a, b, c) buds developed into long, short, or intermediate shoots. Often as the leaves of these shoots (mainly long and intermediate) developed, within their axils further shoots developed simultaneously — these being termed as lateral shoots. Thus, axillary buds as such did not persist in the axils of the leaves. Normally, this happened at the beginning of each flush, which corresponded to the period of maximum activity. Most of these shoots developed into short or intermediate shoots, but some abscised within the first year. Their basalmost internode was inordinately elongated.

(e) Aborted shoots: Toward the end of each flush, axillary buds began to form lateral shoots; but their initial activity quickly declined, resulting in very short shoots up to 3 cm in length. These shoots subsequently abscised after two to three months.

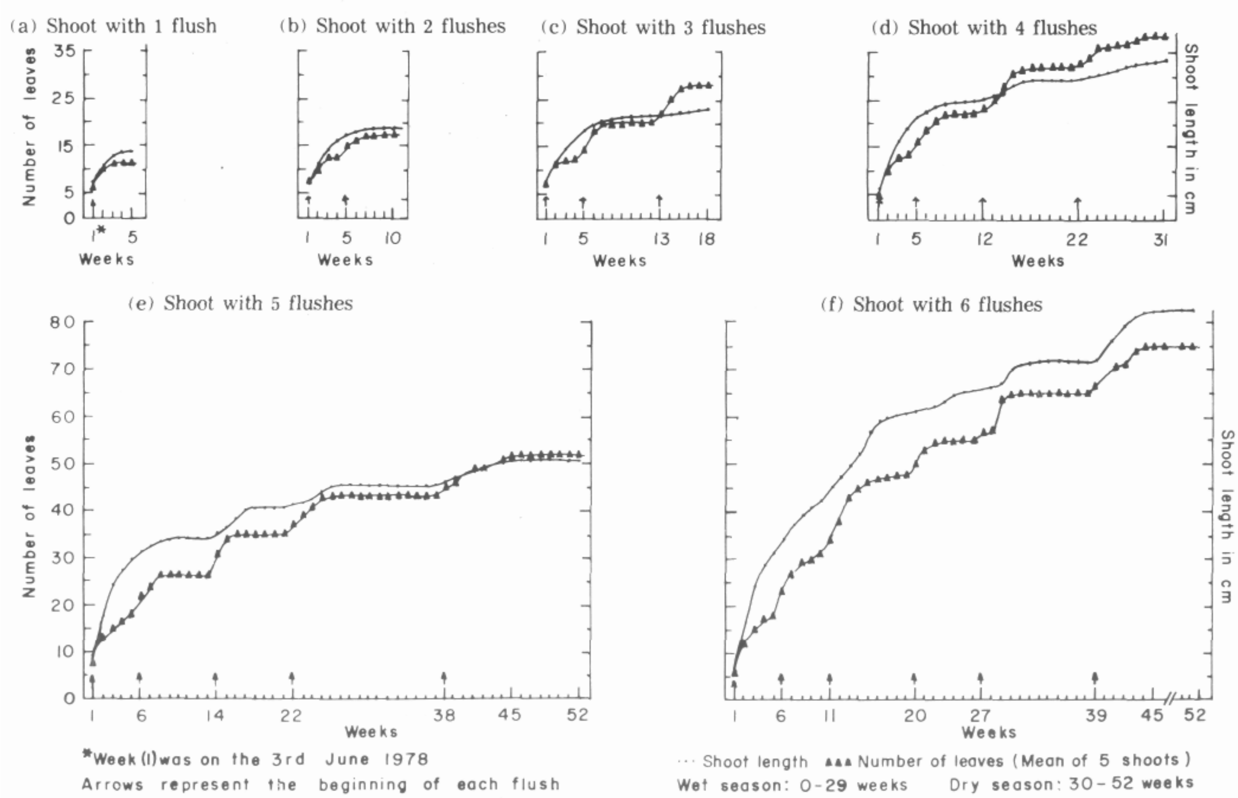

FIGURE 2. Growth patterns of various types of avocado shoots in the course of a year (Exp. 1)

Number of flushes and intervals between flushes

In five year old avocado plants, Simmonds variety, as many as six flushes occurred in the course of the year commencing on the 3rd of June, 1978, and ending on the 9th of June, 1979, [*Figure 2f*]. The number of leaves was used as the main criterion to determine shoot growth flushes, as in some cases the new terminal of the following flush opened and expanded before the shoot of the previous flush had completed elongation; i. e., two flushes overlapped.

Shoot growth started at the beginning of June and continued until the end of December (main growing season) during which time five flushes were produced. The sixth and last flush occurred during the dry season between the end of February and the beginning of April.

In all cases [*Figure 2*], the first flush was the strongest; and during this flush, increase in shoot length, leaf number, and mean internode length were always greatest. In all shoots with more than one flush, there was no interval between the end of the first and the start of the second flush [*Figure 2*]. The new terminal bud of the second flush burst before or as soon as the shoot of the first flush had completed growth. Each of the following two flushes developed about 4 to 5 weeks after the previous flush had finished [*Figure 2c, 2d, and 2e*]. Shoots with 5 flushes developed their last flush after 12 weeks of inactivity [*Figure 2e*] Shoots with 6 flushes [*Figure 2f*] grew almost continuously throughout the first five flushes. The last flush developed after 8 weeks of inactivity.

At the beginning and at the end of each flush, the leaves were shortened and more bract-like than leaf-like. During the rest of the flushing period, full-length leaves were formed. Also during flushing periods, the new leaves had a rose colour; but when they matured, their colour turned into the normal dark green.

Climate seems to be one of the most important factors influencing the number of shoot growth flushes. Venning and Lincoln (1958-59) reported that in Florida and Cuba the avocado plant made four distinct growth flushes during the year, whereas Rodrigues and Ryan (1960) reported that in California (subtropical climate), the Guatemalan avocado variety Hass produced only two growth flushes.

Assuming that the reasonably uniform ambient temperatures in this experiment did not influence shoot growth, the rainfall [*Figure 1a*] seems to have been the most important climatic factor. Shoot growth started at the beginning of June [*Figure 2*], just after the start of the rains, and continued up to the end of December, when the rains stopped. During the dry season, shoot growth was almost absent except for one flush during March-April [*Figure 2e and 2f*]. This flush coincided with a period of rain [*Figure 1a*]. The plants were observed to flush again on the 16th of June, 1979, the beginning of the next wet season.

Cambial Growth

The cambial growth of five-year-old avocado plants, Simmonds variety, was continuous; and no distinct cycles were observed, except that from the middle of April until the end of May, the rate of cambial growth slowed down [*Figure 3*]. Separate straight lines were fitted to the parts of the growth curves for the wet season (27th of May, 1978, to 16th of December, 1978) and dry season (16th of December, 1978, to 26th of May, 1979). The mean rate of increase hi girth during the wet season was 0.35 cm per week and was significantly greater ($P<0.01$) than that of the dry season, which was 0.27 cm per week [*Figure 3*].

The higher rate of cambial growth during the wet season was probably due to the greater number of shoot growth flushes [*Figure 2*]. Morey (1973) and Kczlowski (1971) reported that internode extension, leaf development, and duration of leaf retention greatly influenced cambial growth. The lower rate of cambial growth during the dry season could have been partially related to the reduction in the number of growth flushes (one flush) and the physiological shedding of leaves during this season. Plants were observed to shed more leaves during the end of the dry season, and this was associated with the reduction of the cambial growth during the period from the middle of April until the end of May.

Shoot dry weight and its distribution between leaf and stem.

During the first four months after planting, the rate of increase in shoot dry weight of young avocado plants, Pollock variety, was very low [*Figure 4a*]*;* and there was an increase in dry weight of only 10% of the ultimate total increase in shoot dry weight of the year. Between the fourth and tenth month, dry weight accumulation increased rapidly; and 81% of the total dry weight increase was produced. During the last two months, shoot dry weight accumulation again slowed down; and only 9% was produced.

It would appear that a period of four months was necessary for an avocado plant to become well established hi the field. After this, the rate of dry weight accumulation of the shoot started to increase rapidly. Although shoot growth flushes were more during the wet than during the dry season, the rate of increase in the dry weight of shoot was more rapid during the latter season. The main reason for this was the secondary thickening of the stems. Also the maturity of the leaves was a contributory factor. This explanation can be supported by the ratio of fresh to dry weight of stem and leaf. Two months after planting, this ratio was 4.1 for stems and 3.6 for leaves; whereas eight months after planting, the ratio was 3.0 for stems and 2.8 for leaves.

During the early stage of plant life the rates of dry weight accumulation of stem and leaf were very similar, with the leaf dry weight being slightly greater than that of the stem [*Figure 4b*]*.* As the plant grew (four months after planting), the dry weight of stem increased rapidly; and after the sixth month, the rate of dry weight accumulation in the stems surpassed that of the leaves. The main reason was that the stems started to attain secondary growth. During the last two months, dry weight accumulation slowed down due to the abscission of small branches, the reduced rate of cambial growth, and a reduction in leaf dry weight which was mainly due to leaf shedding. During this period (end of dry season), a peak in leaf shedding was observed.

As the data of stem and leaf dry weight accumulation followed the exponential growth curve, they were converted into logarithms; and the regression equations for the two straight lines up to the tenth month were found [*Figure 4c*]*.* Straight lines were fitted up to the tenth month, because after this point there was a decrease in leaf dry weight. [*Figure 4b*] Comparing the logarithmic rates of dry weight accumulation of stem and leaf, no significant difference was found. Thus it can be seen [*Figure 4b*] that, although there were differences hi the accumulation of dry weight in stems and leaves at different stages of growth, the overall rate of dry weight accumulation in these organs was similar [*Figure 4c*]

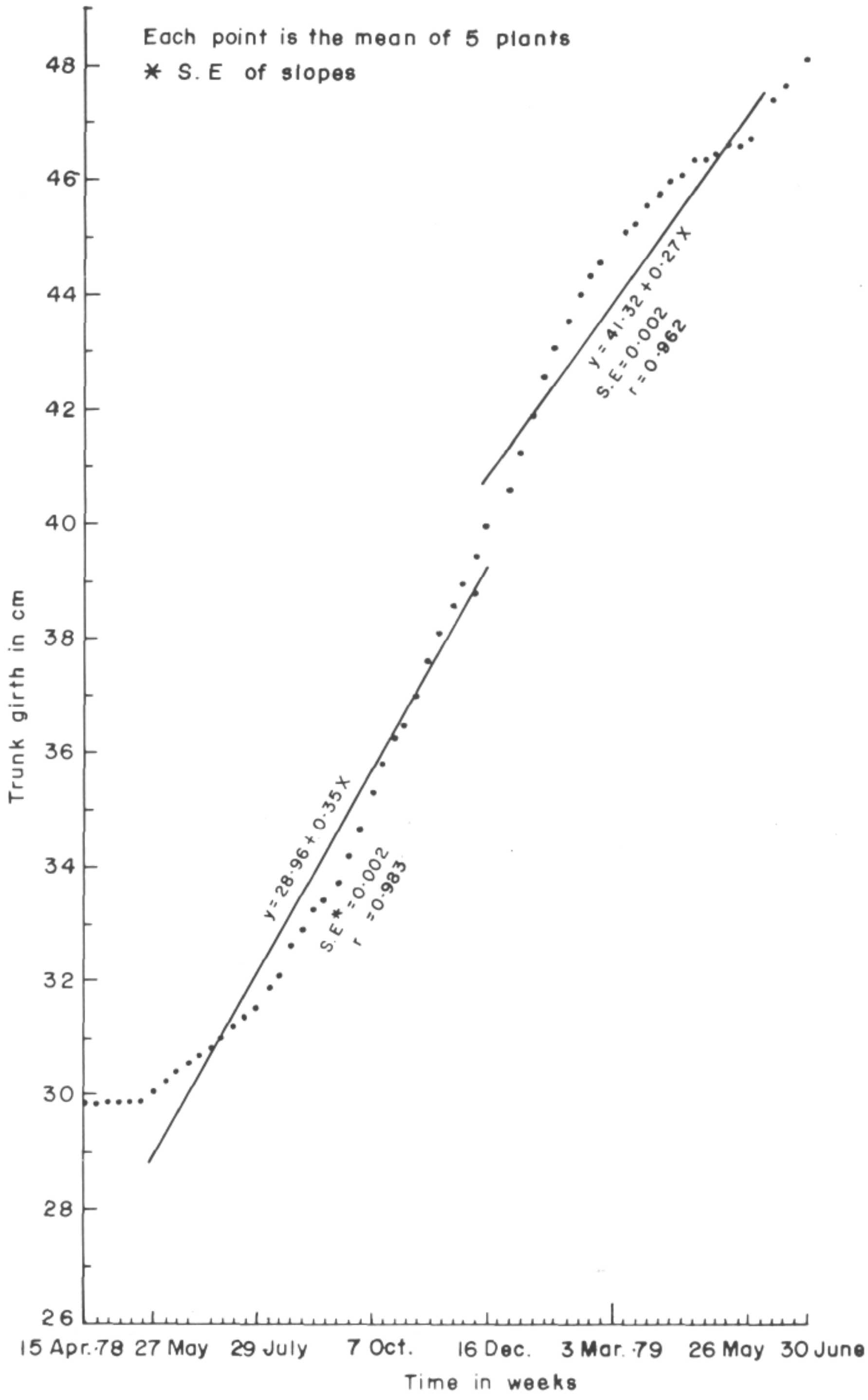

FIGURE 3. Trunk girth of five year old avocado plants, Simmonds variety (Exp. 1)

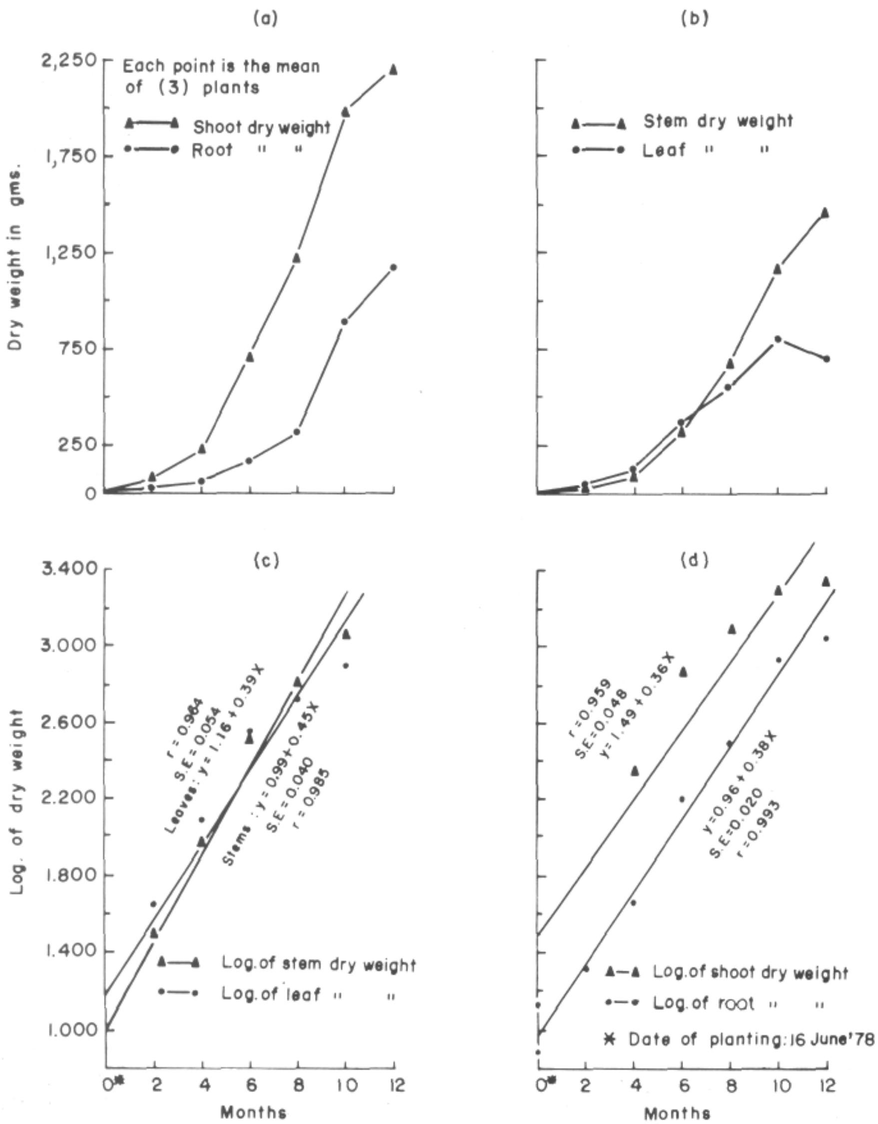

FIGURE 4. Distribution of dry weight of young avocado plants, Pollock variety, growing in River Estate loam soil during their first year of field life (Exp. 2)

General characteristics of root growth

The avocado root system consisted of an imperfect tap root which at a short distance from the soil surface, generally from 15 cm to 30 cm, divided into branches which bent to assume lateral positions.

The primary lateral roots divided, mainly by forked branching into secondary lateral roots, and these again divided into a fourth order of roots at a wider angle than that of the secondary roots. This much branched system developed an abundance of rootlets, each one having a white tip about 2 mm long. Coit (1940) and Donnelly (1941) gave similar descriptions of the avocado root system.

The colour of the active new root growth was white. No root hairs were observed on avocado roots after periodic observations on root samples in situ with a microscope. Burgis and Wolfe (1946) and Ginsburg and Avezohar-Hershenson (1965) also reported that avocado plants have no root hairs.

Root dry weight accumulation

During the first four months after planting, the rate of root dry Weight accumulation of young avocado plants, Pollock variety, was very low [*Figure 4a*], and there was an increase in dry weight of only 3% of the ultimate total increase of root dry weight for the year. In the next four months, there was an increase of 24%; and between the eighth and tenth month, almost half of the total dry weight increase was produced. During the last two months, dry weight accumulation dropped to 24%.

The results indicated that a period of 4 months was necessary for a plant to become well established in the soil; and so, during this period, the rate of dry weight accumulation of roots was low. After this period, the rate of dry weight accumulation increased rapidly. This was mainly because some of the roots started to thicken and became woody perennial roots. This is supported by the ratio of fresh to dry weight of roots, which was 5.0 two months after planting and 2.9 ten months after planting. Also, another contributory factor was the new roots which added to the total mass of thickening roots.

A comparison between the logarithmic rates of increase of shoot and root dry weights, over the year, did not show any significant difference [*Figure 4d*]. It can be therefore concluded that although there were differences in the accumulation of dry weights in the shoot and root at different stages of growth [*Figure 4a*], the overall rate of dry weight accumulation in these organs was similar.

Root Distribution

At two months after planting, 100% of the root system was found within a radius of 50 cm from the trunk and within a depth of 50 cm of the soil surface [*Figure 5*]. By 4 months after planting, almost 100% of the roots were found in the same layer (a total of 0.6 g. dry weight was found outside of this layer). Six months after planting, slightly more roots were found more widely spread; 2% of the root dry weight was located within a distance of 50 cm to 100 cm from the trunk and 1.0 g. of root dry weight was found beyond the depth of 50 cm from the soil surface.

With the beginning of the dry season (8 months after planting), more roots started to grow, both in depth and spread. By 10 months after planting, a large increase in dry weight was observed. Also, some roots (8.0g.) were found within a radius of 50 cm from the trunk and at a depth of 100-150 cm. One year after planting, roots were spread within a radius of 150 cm from the trunk and to a depth of 150 cm below the soil surface.

It appears that during the dry season [*Figure 5*], the roots grew in depth to search for soil moisture. With the beginning of the next wet season, roots started to spread (month 12, *Figure 5*). However the bulk of the root system (83% of the root dry weight) was still located within a radius of 50 cm from the trunk and within a depth 50 cm from the soil surface.

Donnelly (1941) reported that avocado roots are spotty hi distribution — large sections of ground around trees that made vigorous growth showed no roots. To investigate this, during the fifth sampling (10 months after planting), roots were collected separately in four quadrants — north, south, east, and west. Their fresh weights were as follows: North-264.0 g, south-417.4 g, east-278.1 g, and west-306.6g (means of three plants). However, visual observations during the excavations indicated that small sections of ground had no roots.

Height of plant, width of canopy, and root depth and spread [*Figure 6*]

The rate of increase in height was high up to the middle of February (eighth month) and low during the last two months. The reason was that no shoot growth was observed during the latter period, except from the beginning of June 1979 when shoot growth started again.

The curve of canopy spread had approximately the same pattern as that of the height, except that the rate of increase in canopy spread during the last two months was higher than that of the height.

Root growth in depth was continuous with approximately the same rate, except for the period between the middle of October and the middle of December (4th-6th month) when increase in depth was negligible. This could not be explained.

Root growth in spread was continuous throughout the year with a high rate of increase. Between the middle of December and the middle of April (6th-10th month), the rate of increase in root spread slightly slowed down. This was probably due to the reduced soil moisture content in the soil surface layer, as this period coincided with the dry season. With the beginning of the rains (June 1979), roots started to spread rapidly again.

A year after planting, out of the three plants, maximum root spread diameter observed was 275cm and maximum root depth 150 cm. During the excavations of the last sampling, the water table was observed to rise up to 150 cm from the soil surface. This could be a factor which limited the root depth.

The results showed that the height of avocado plants was always greater than root depth and canopy spread. This was due to the dominance of the apical meristems, as shoot growth in avocado plants was mainly via the terminal buds. Terminal buds located at the distal portion of the plant grew upright, and their growth was almost continuous throughout the growing season.

Root spread was always greater than the canopy spread or root depth. This indicates that avocado root system grows more horizontally than vertically and root growth extends beyond the canopy of the plant.

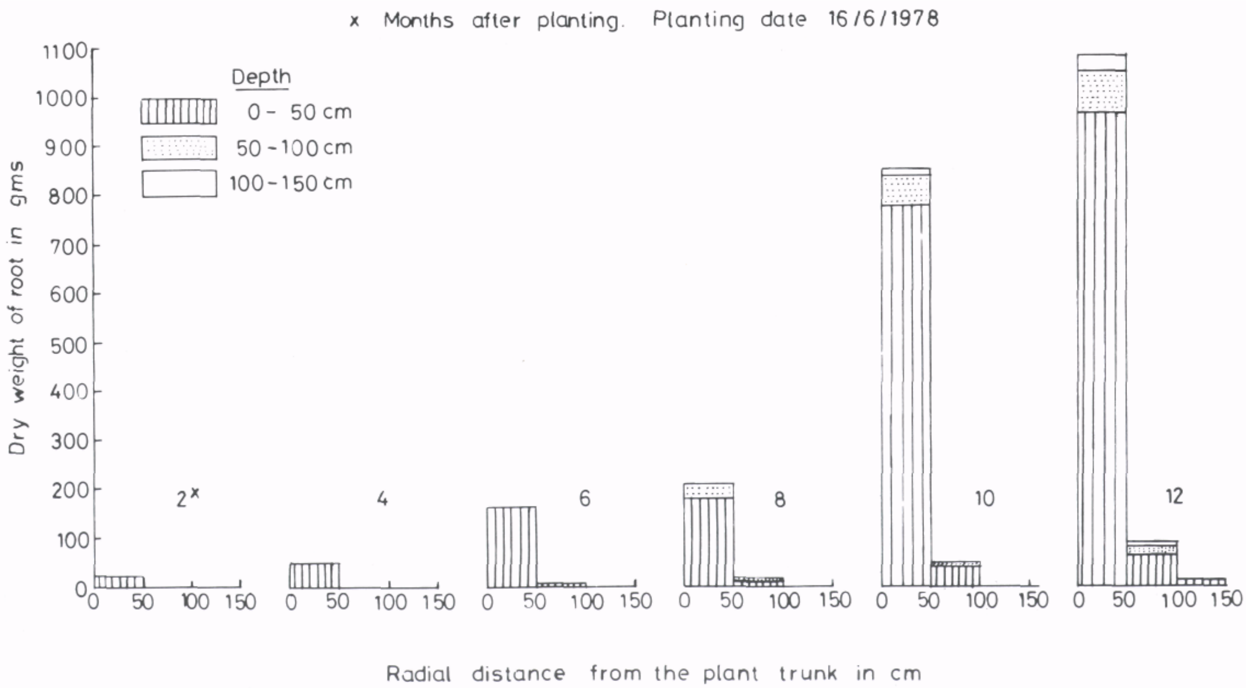

FIGURE 5. Root distribution of young avocado plants, Pollock variety, growing in River Estate loam soil (Exp. 2)

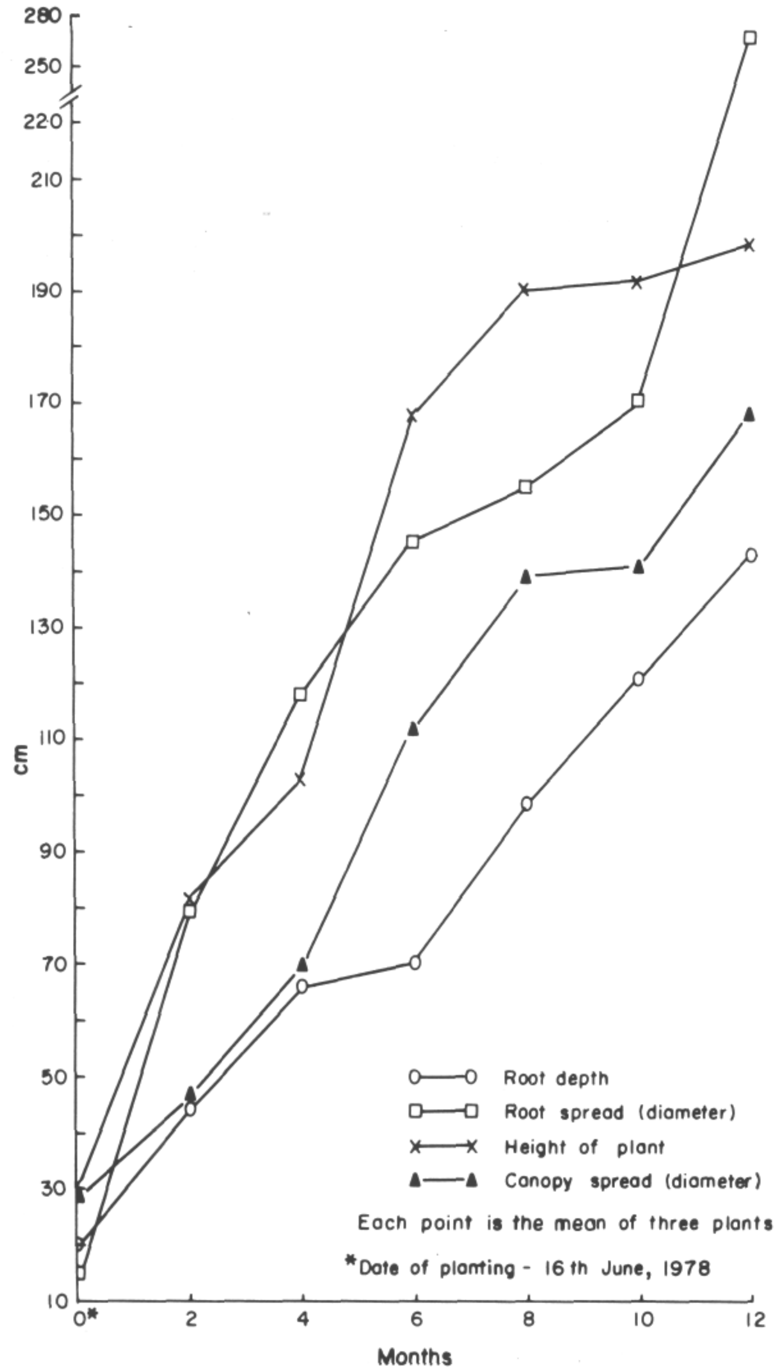

FIGURE 6. Mean height, width of canopy, and mean maximum root depth and spread of young avocado plants, Pollock variety, growing in River Estate loam soil (Exp. 2)

SUMMARY

In avocado, shoot growth was monopodial and occurred in cycles or flushes. Shoot growth resulted mostly from terminal buds and some axillary buds which were located near the terminal bud. The position of the bud on the plant was very important. Buds

located in the distal portion of the plant grew upright and produced more flushes than those located in the inner portion of the plant.

In five-year-old avocado plants, Simmonds variety, as many as six shoot growth flushes occurred during the course of a year. The main shoot growth period was the wet season, and a strong association was observed between shoot growth and rainfall.

Cambial growth in avocado plants was continuous throughout the year, but the rate of cambial growth was significantly greater in the wet than in the dry season.

A period of four months was necessary for avocado plants to become well established in the field. During this period, the rate of increase in shoot and root dry weight was very slow.

After the fourth month, the rate of dry weight accumulation increased rapidly. The main reason for this was the secondary thickening of the stems and roots. Although there were differences between shoot and root and between stem and leaf dry weights at different stages of growth, no significant difference was found between their overall logarithmic rates of dry weight accumulation.

Avocado was a surface rooting plant and developed a much-branched root system. No root hairs were observed on avocado roots. One year after planting, the entire avocado root system was found within a radius of 150 cm from the trunk and within 150 cm from the soil surface. However, the bulk of the root system (83% of the root dry weight) was still located within a radius of 50 cm from the trunk and within a depth 50 cm from the soil surface. During this period, height of the plant was greater than root depth and root spread was greater than canopy spread.

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