PINEAPPLE GROWTH AND NUTRITION OVER A PLANT CROP CYCLE IN SOUTH-EASTERN QUEENSLAND

1. ROOT DEVELOPMENT AND GENERAL GROWTH FEATURES

By R. F. BLACK, B.Sc., Ph.D.*

SUMMARY

The morphological and growth features of a monthly sampling study on a standard commercial planting are described. A spring planting of the Cayenne variety was used and the sampling terminated at the green fruit stage.

The numbers of major roots, their length measurements and the dry weights of the whole root systems are recorded. The general development of the root systems is described.

Root growth was continuous over the cold winter months while soil moisture was adequate. The weight of the recovered roots decreased considerably during the dry spring months and nematode damage was also apparent. Recovery occurred after the first rains in October.

It is suggested that the use of raised beds may limit the longevity of the root system.

Leaves and stems also continued growth through the winter months up until the onset of dry conditions. Recovery after the October rains was associated with the development of fruit and reproductive parts.

The wide degree of variability in both growth and physiological age of the sampled plants commencing about July was interpreted as indicating very strong interplant competition.

Tissue moisture contents in terms of the water:dry-matter ratio were followed for all plant parts except the roots. Stem W/D ratios produced a well-defined peak of 7.3 in February and this foreshadowed a long period of accumulation of food reserves for the remainder of the sampled growth cycle.

I. INTRODUCTION

Many field problems in pineapple culture concerned with poor growth and fruit development appear to be caused by deficiencies in root growth or health. This probably applies particularly to ratoon fruiting cycles.

*Chief Plant Physiologist, Pineapple Research Laboratory, Nambour. (Queensland Department of Agriculture and Stock)

Before effective physiological experiments could be carried out on these problems it was considered necessary to obtain base data on some of the characteristics of root development and growth in the field. It was decided to make the first study over a plant crop cycle commencing with a spring planting.

Root growth would need to be studied with respect to growth in the leaves and stems. It was further decided to utilize the plant samples obtained for a seasonal study on nutrient uptake and concentrations for the major elements, nitrogen, phosphorus and potassium. These nutritional data will be considered in a later paper.

II. MATERIALS AND METHODS

(a) Sampling Site

A planting of slips (Cayenne variety) on a south-facing slope (Block G3) in the Pineapple Industry Demonstration Farm, Beerwah, south-eastern Queensland, was chosen for the work. The soil, a Glasshouse Sandy Loam (Vallance 1938), was well suited to root recovery operations. The double-row raised beds (tops about 9 in. above drains) had been fumigated against nematodes one month before planting with 1½ pt DD per running chain (20 gal per ac) injected from two jets. Two summer cover crops of velvet beans and two winter cover crops of ryecorn had been grown in the two years prior to planting.

The slips were planted on August 5, 1959, at 12-in. intervals with approximately 20 in. between sub-rows. The double-rows were spaced at 6 ft. 3 in. between centres and ran approximately east-west across the slope with a 2½ per cent. fall.

Fertilizing throughout the plant crop cycle was by side-dressings of a 10:6:10 mixture except for a side-dressing of a 12:2:15 mixture applied on March 31, 1960. The fertilizer treatment times are indicated on Figure 7. The first side-dressing contained copper and zinc, and was hoed in between the sub-rows three weeks after planting. Weeds were controlled by ground sprays of PCP and manual chipping. Flowering for the summer plant crop was natural though backward plants were forced for an early winter crop on October 14,1960, using alpha-naphthylacetic acid (ANA).

(b) Sampling Methods

The sampling unit consisted of six adjacent plants in the double-row. The datum plant was the central plant of the three in the northern sub-row.

Five sampling blocks were marked out running across the slope. Each block consisted of three adjacent double-rows, each row containing 50 sampling units. Six or more guard plants were left at each end of each double-row.

On the monthly sampling days, one sampling unit was selected at random from the 150 sampling units of each block. The datum plant for each block was then carefully removed from the soil, using forks, careful hand techniques and washing. As plant growth progressed, usually all six of the plants in the sampling unit were dug up to ensure the highest possible recovery of roots from the datum plant.

Immediately after removal of the plant from the soil, the roots and leaves were syringed thoroughly, wrapped in plastic and then removed to the laboratory.

In the laboratory, counts were made of the number of major roots per plant and their lengths measured. These major roots develop initially from within the stem but may also arise as secondary roots. They are usually morphologically distinct from the much finer minor or feeder roots which develop in profusion from the major roots. The minor roots were not counted or measured in length.

In the counting, the major roots were separated with respect to whether they possessed an active root cap, had a dead tip, or had been broken off near the tip in the sampling.

After a further very thorough washing, the whole root system was dried at 65°C and its oven-dry weight obtained. It was then ground and a sample retained for chemical analysis.

The longest leaf on the plant was removed and its length measured. Up to flowering, this leaf is the youngest fully expanded leaf and thus fully developed with respect to cell division and enlargement. After flowering, the successive leaves and bracts become progressively smaller with maturity and so the longest leaves become older with each sampling beyond this point.

After removal of all leaves, the stem length was measured. The fresh weights of the leaves and stem were also obtained. The fresh material was then cut into sections and dried in a forced-draught oven at 65°C.

Inflorescence heads, which first appeared at the 12th sampling on August 1, 1960, were severed from the stem at the stem "shoulder", their lengths measured, and their separate fresh and dry weights obtained.

With the differentiation of fruit, the tops were removed and the fruit severed from the stalk. The lengths and diameters of the fruit were measured and their fresh and dry weights obtained. The fresh and dry weights of the tops were also measured. The stalks were treated in the same way as for the inflorescence heads.

All suckers and enlarged resting buds of each flowering plant were removed, bulked, and their fresh and dry weight obtained. Where the flowering plant also possessed slips, these and any enlarged resting buds present were removed and treated in the same way as for the suckers.

At each sampling except the first a small soil sample was collected from the 3–6-in. level directly under the datum plant. The pH of each sample was measured, using a glass electrode.

(c) Meteorological Data

The climatic data used were taken from the records of the Forest Research Station, Beerwah, which is situated two miles to the north-east of the Pineapple Industry Demonstration Farm. Daily maximum and minimum temperatures and rainfall readings were used.

Weekly averages for the maximum and minimum temperatures and the weekly totals for rainfall were calculated (Figure 7). Weekly grouping of the data was considered to be the most suitable and convenient method for a plant growth study in the field.

III. RESULTS

(a) Root Growth

(i) *Soil Reaction.*—The first measurements, done for the sampling on October 8, 1959 (approximately two months after planting), ranged from pH 4·7 to 5·1 and the second set, for the sampling on November 5, from 4·7 to 5·2.

The readings dropped over the next two months to a range of 4·0 to 4·6 for the sampling of January 7, 1960. For the next year all readings remained generally within this range.

(ii) *Preplant Roots.*—All pineapple planting material has some short roots which protrude from the stem prior to planting. The growth data presented here are concerned only with development subsequent to planting.

In the 2nd and 3rd samplings, measurements were taken of the total lengths of the preplant roots. The mean preplant root length external to the stem for the 10 slips measured was 87·5 cm per plant.

(iii) *Root Counts*.—The mean total root count per plant increased fairly steadily except for the 13th, 14th and 15th sampling times in the early summer of 1960 (Figure 1).

A sampling variation probably accounted largely for the very low count of the 14th sampling on October 4. However, the soil was very dry at this time (see Figure 7 for meteorological data) and root recovery correspondingly more difficult. Also there was considerable evidence of root-knot nematode activity commencing at this time. A number of terminal swellings on major roots were noticeable from this sampling to the end of the series. This was reflected in the higher number of roots with dead tips (Figure 1).

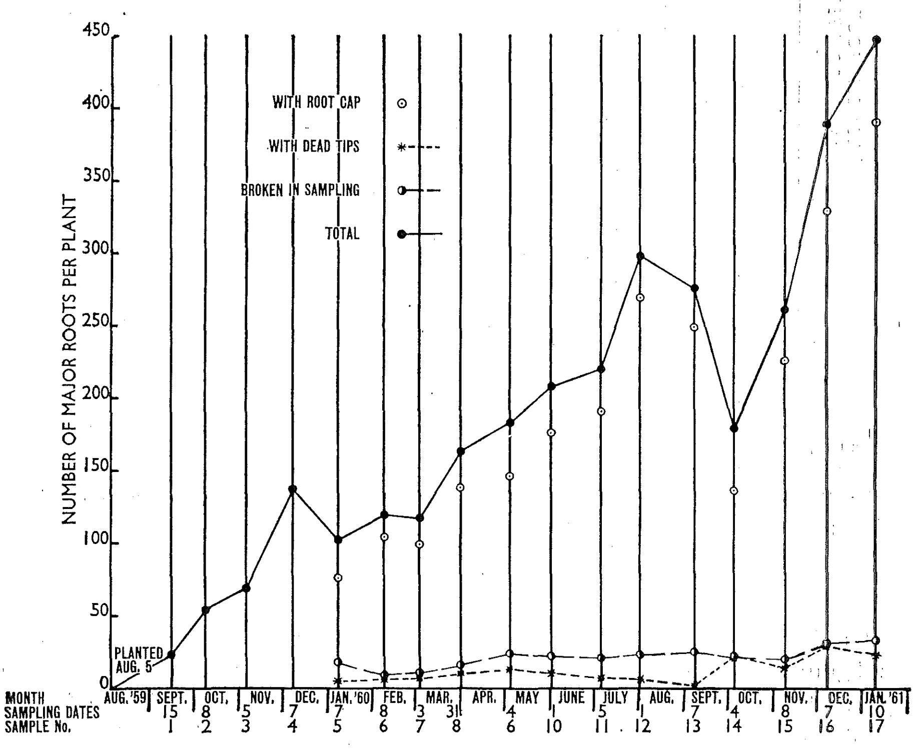

Fig. 1.—Counts of major roots per plant expressed as a mean of the five plants sampled. Counts do not include minor or feeder roots. Major roots were separated according to whether the tips were active, dead or were broken in sampling.

(iv) *Root Measurements*.—Vigorous root development commenced early in November 1959 and continued right through the winter months up until the beginning of August 1960. After a lapse during the dry period of August and

September (Figure 7), vigorous root development continued from the month of November to January 10, 1961 (Figure 2).

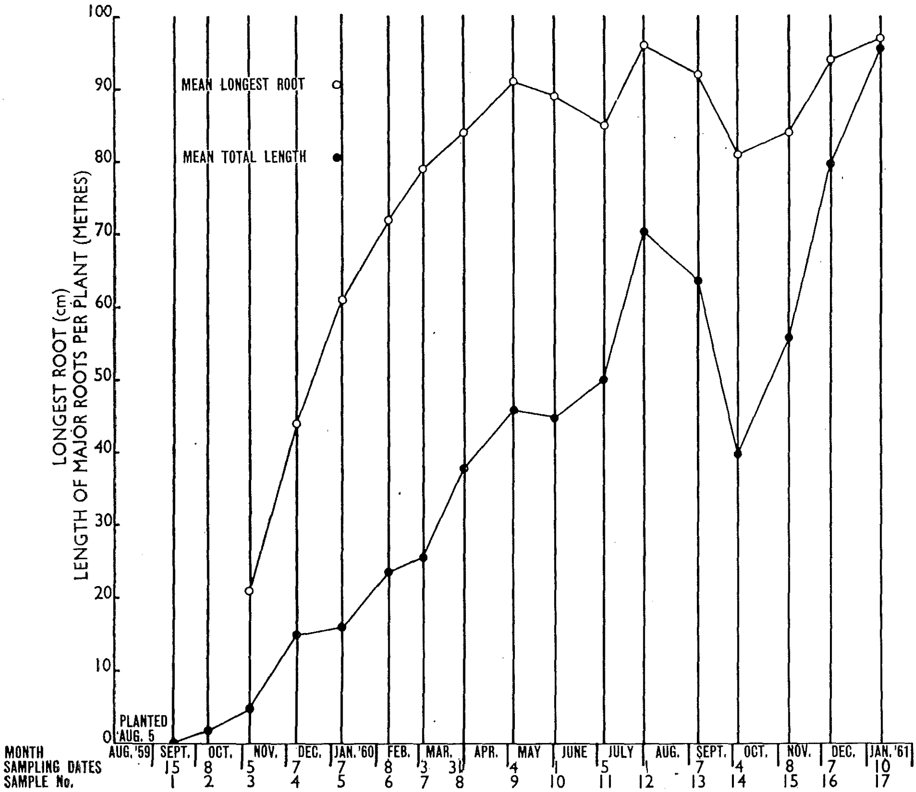

Fig. 2.—Total lengths of the major roots per plant, expressed as a mean of the five plants sampled, are shown on the lower curve. Upper curve shows the mean longest root for each sampling.

On August 1, 1960, the average major root length per plant stood at 70·4 m. This figure does not include the masses of minor feeder roots. The average major root increases based on the whole growing season from planting to August 1 amounted to 19·5 cm (7·7 in.) per plant per day. The rate of growth subsequent to the October sampling was apparently greater than this.

The estimates of the mean longest root for each sampling followed an asymptotic growth curve (Figure 2). However, during the later stages the curve showed trends which reflected similar trends shown by the curve for the mean total length of the root systems. Probable factors here would have been sampling variations, soil dryness and nematode attacks.

Except for the first two samplings, the longest roots were "surface" roots spreading laterally from the plant. At the 4th sampling, in December 1959, there were many roots going to a depth of 30 cm (12 in.) and there were some going deeper. The longest root at this time was a "surface" root 58 cm (23 in.) long. At the 7th sampling early in March 1960 the vertical penetration of the soil extended to about 46 cm (18 in.). The limit of vertical penetration throughout the plant crop cycle was about 60 cm. The longest single "surface" root, measured in December 1960, was 131 cm.

Many secondary feeder roots had developed to a maximum length of 1 cm at the 2nd sampling on October 8, 1959. Tertiary feeder roots had developed by the 3rd sampling in early November. By the 4th sampling in early December there were some secondary roots which were classed as major roots. Sometimes this classification was difficult, but usually these roots were distinctly longer and

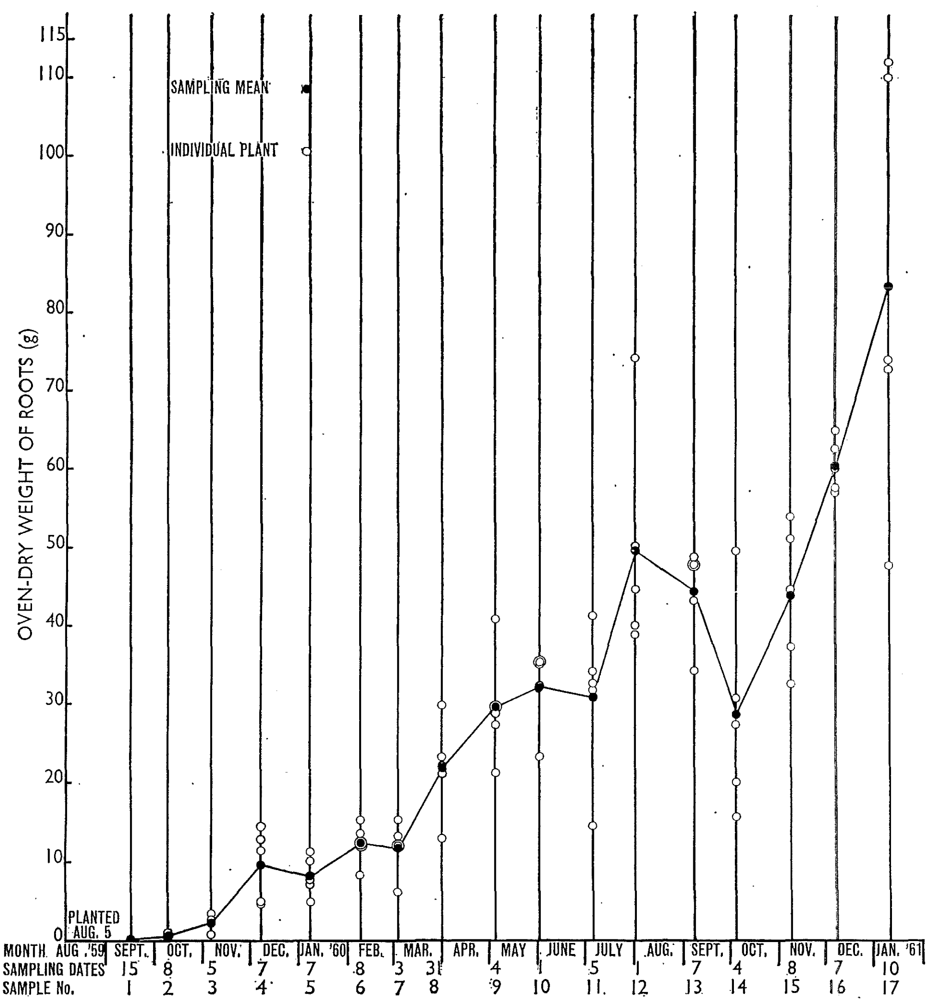

Fig. 3.—Oven-dry weights of the total roots plotted for the individual plants and as means for the five plants of each sampling.

thicker than the feeder or minor roots. Notwithstanding this, most of the new major roots formed developed from higher nodes of the stem base (Figure 4).

(v) *Root Oven-dry Weights*.—The mean root system dry weights showed similar developmental trends to those for root numbers and lengths (Figure 3). However, the variability among plants, as shown by the individual plots for oven-dry weight, was often very large.

(b) Leaves and Stems

(i) *Length Measurements*.—Over the 4-month period from early November 1959 to early March 1960 the length of the longest leaves rose rapidly to that characteristic of the mature plants (Figure 4). Over the next five months, up to floral differentiation in late July, successive longest leaves developed to an approximately constant length of 96 cm. Up to this time, the youngest of the longest leaves at each sampling would be at a constant physiological age.

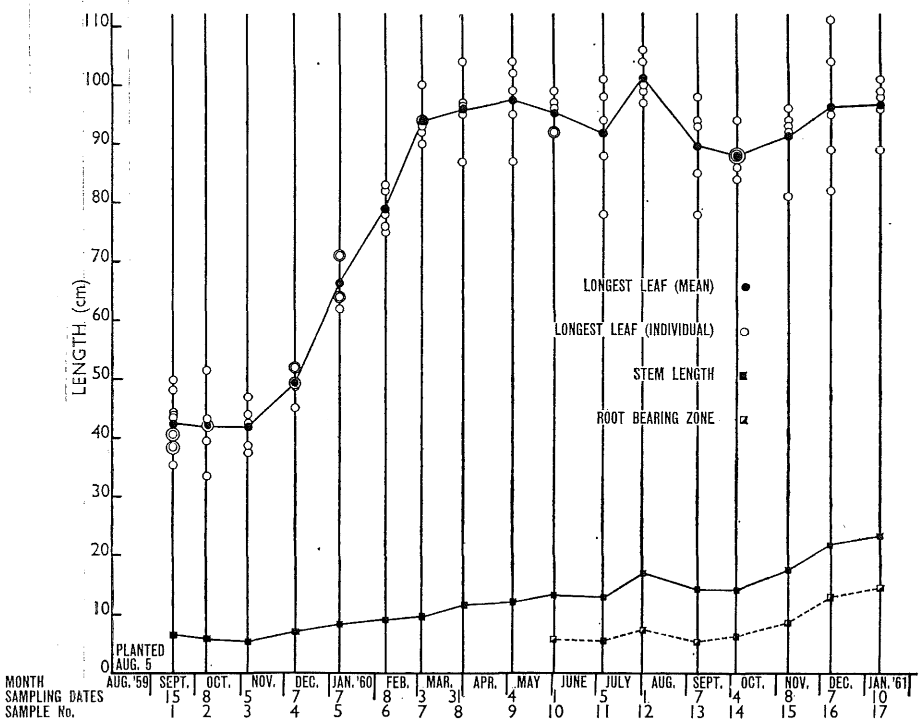

Fig. 4.—Mean length measurements for the longest leaves, stems and suberized root-bearing zone of the stems. The length of the longest leaf for each plant sampled is also plotted.

After floral differentiation, the longest leaves became progressively older with respect to physiological age and time. This was shown by the increasing length of dead tissue at the leaf tip, the difficulty of removing the leaf and the increasing number of nodes between the point of attachment and the stem apex.

Leaves arising from the higher nodes after floral differentiation became progressively shorter at maturity. On the fruit stalk, these graded into bracts, often less than 5 cm in length, which subtended the developing fruit.

With the exception of the first three samplings, stem length increased progressively throughout the sampling period (Figure 4). The initial decrease, if significant, probably indicated a decreasing cell size during establishment. On the other hand, the increasing stem length after floral differentiation in late July would possibly be produced more by cell expansion than by cell division.

The length of the root-bearing zone of the stem appeared to follow a constant arithmetical relationship to the top of the stem (Figure 4), the upper portion remaining fairly constant in length at about 8·5 cm. The root-bearing zone was more or less defined for measuring purposes by brown layers of suberized cells. Some very short roots just protruding from the stem could be found above this zone.

(ii) *Oven-dry Weights*.—The dry-weight data for the leaves (Figure 5) indicated a loss of dry weight for the first two months subsequent to planting. A net gain of dry weight from the first sampling did not occur until January 1960. Thereafter growth proceeded through the late summer and winter months up to the 12th sampling on August 1.

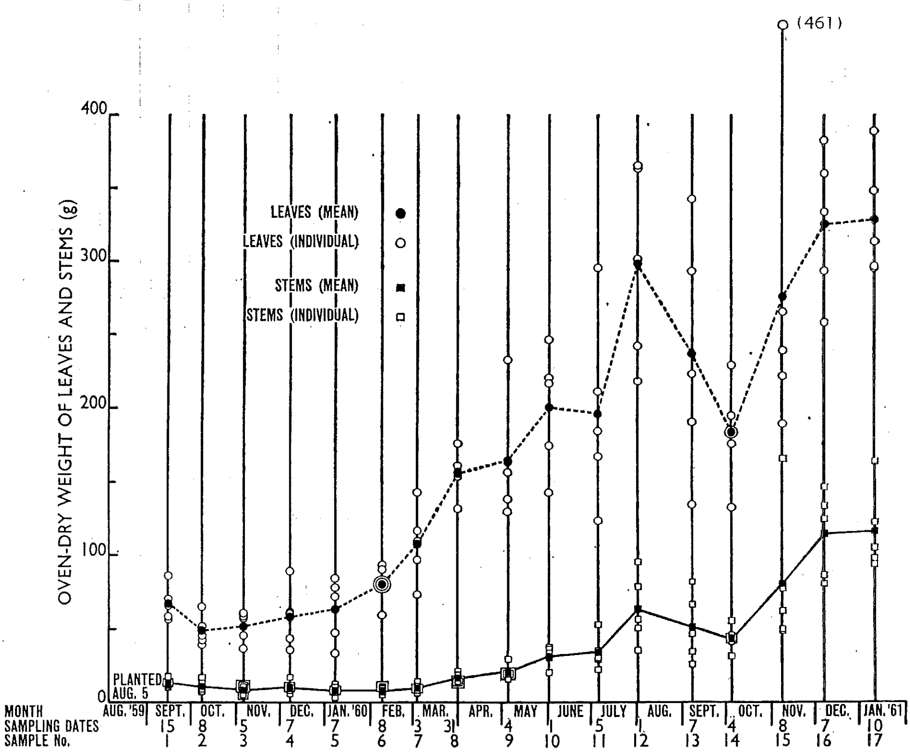

Fig. 5.—Sampling mean and individual plant oven-dry weights plotted for leaves and stems.

The two following samplings indicated a dramatic loss in leaf dry-weight brought about by adverse climatic factors. The 15th and 16th samplings showed a quick recovery but growth over the final months slowed down probably because of the development of reproductive parts (Figures 6 and 7).

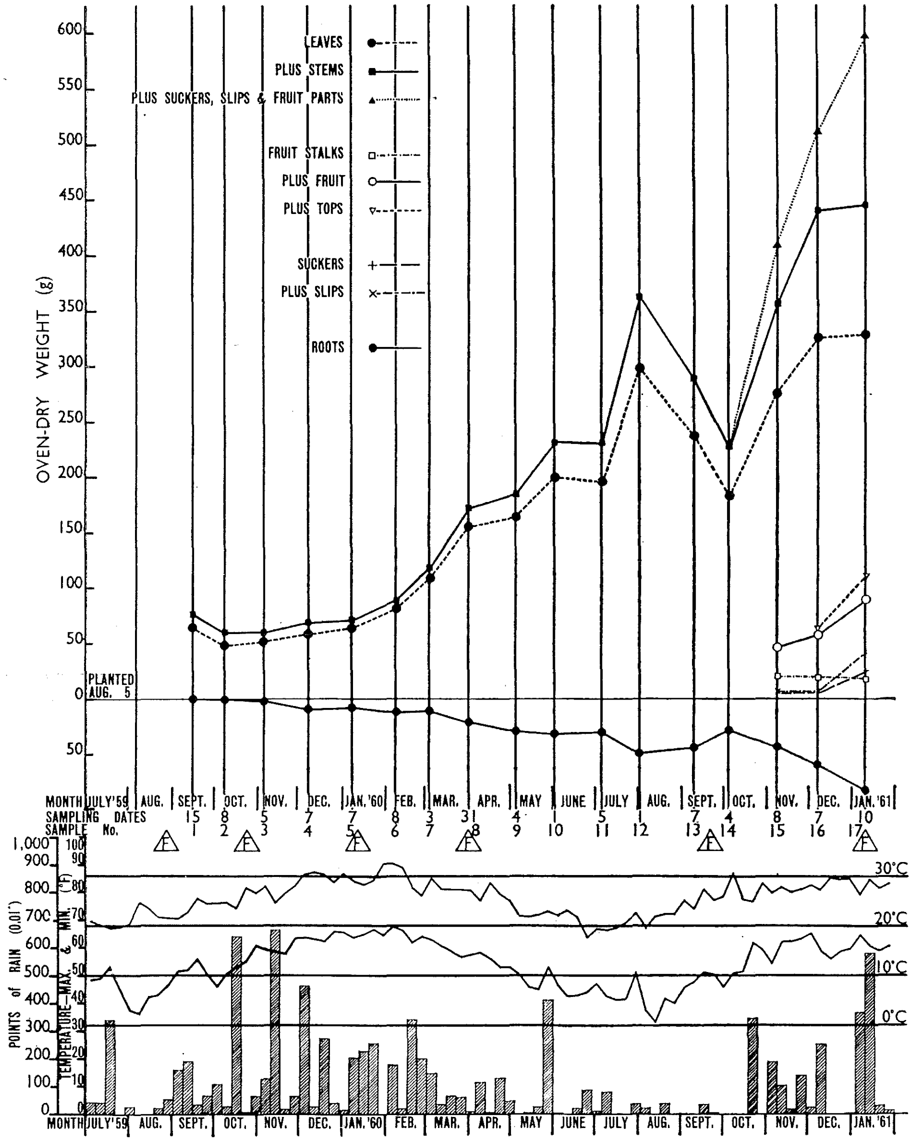

Fig. 6.—Oven-dry weight growth summation for leaves, stems, suckers, slips, fruit parts and roots. For the last three samplings, separate summations are plotted for (*a*) fruit stalks, fruits and tops, and (*b*) suckers and slips. Values for the leaves, stems and roots are means for the five plants sampled. Values for fruit and reproductive parts are means on a per-plant basis calculated for the number of sampled plants actually bearing these structures. Fertilizing times are shown by the triangles marked F. Maximum and minimum temperatures are plotted as weekly means, while rainfall is shown as weekly totals.

The dry-weight data for the stems generally followed that for the leaves, though a net gain from the first sampling was delayed until March 1960, that is, two months later than the leaves and seven months after planting (Figure 5).

A feature of these results was the large degree of interplant variability commencing from about the 11th sampling in July (Figure 5). The number of plants sampled per sampling day was insufficient to measure these effects accurately but the results do suggest strong interplant competition for light, soil space and soil moisture.

(iii) *Fresh Weights*.—The mean fresh-weight data for the leaves and stems (Figure 7) showed generally similar trends to those for the dry-weight data. The most important difference was the shorter recovery times from the weights as at the first sampling.

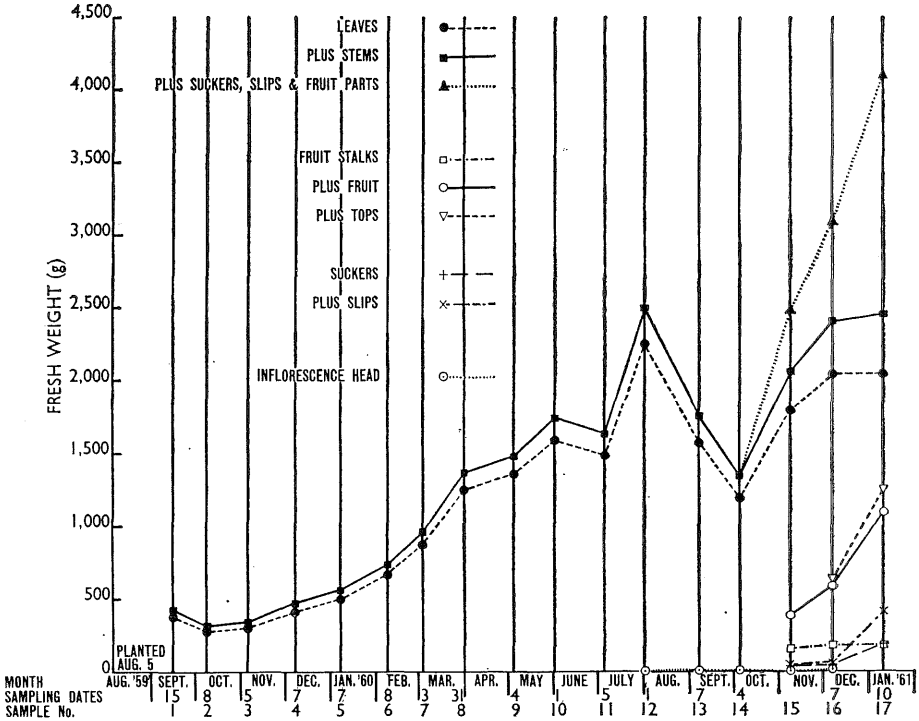

Fig. 7.—Fresh weight growth summation for leaves, stems, suckers, slips and fruit parts. For the last three samplings, separate summations are plotted for (*a*) fruit stalks, fruit and tops, and (*b*) suckers and slips. Undifferentiated inflorescence heads are also plotted where applicable. Values for the leaves and stems are means for the five plants sampled. Values for fruit and reproductive parts are means on a per-plant basis calculated for the number of sampled plants actually bearing these structures.

Here, the stems recovered their weight from the first sampling before the leaves and just shortly after the second sampling. The leaves had made a net gain from the first sampling by early December 1959 at the 4th sampling. These shorter recovery times indicated an early and rapid uptake of water into the tissues, the rate of uptake being greatest into the stem tissues (Figure 8).

(c) Fruit and Reproductive Parts

Though the purpose of the planting was a summer crop, only 58 per cent. of the plants actually produced summer fruit. A further 27 per cent. produced intermediate (autumn) fruit, most of these being the result of the forcing in October 1960. These intermediate fruit were commonly of low weight, long but of very small diameter. At the end of March 1961, 8 per cent. of the plants were bearing winter crop fruit while the remaining 7 per cent. had not yet flowered.

This low percentage of flowering for the summer crop made it impossible to obtain precise information on plant growth responses during the fruiting stage. This, together with the fact that facilities for processing large ripening fruit were not available, led to the termination of sampling in January 1961.

The 12th sampling on August 1, 1960, produced three datum plants out of the five with an inflorescence head at the heart of the plant. These also appeared in all subsequent samplings except the last. There was no clear external differentiation between fruit and stalk in these parts. Their lengths ranged from 1 cm to 7 cm. As the inflorescence head is a transient structure, its weight showed no important progression (Figure 7).

The 15th sampling on November 8, 1960, produced one datum plant with a small green fruit. Four fruit appeared in the 16th sampling and five in the 17th. The largest fruit sampled at the last sampling was 1173 g fresh weight and measured $11 \cdot 6$ cm in diameter and $14 \cdot 8$ cm in length. The stalk was $20 \cdot 1$ cm in length.

Over the period of the last three samplings the mean weight data for the fruit and tops increased rapidly, whereas the data for the stalks remained fairly constant (Figures 6 and 7).

The differentiation of a young fruit on the end of the stalk was invariably associated with the appearance of suckers. These usually occurred from the stem "shoulder" to some little distance down, though in one instance a small sucker 7 cm long arose from the top portion of the root zone. The number of developing suckers per plant varied from one to three, while the number of apparently resting sucker buds varied from three to five.

Seven out of the 10 plants sampled with young fruit also possessed developing slips from axillary buds arising from the stalk. Of these, three plants also had well-defined resting slip buds which have a distinctive blunt top. The number of developing slips per plant varied from one to five.

The weight data for the suckers and slips showed little change between the 15th and 16th samplings, but a considerable amount of growth between the 16th and 17th samplings (Figures 6 and 7).

(d) Water: Dry-matter Ratios

Water:dry-matter (W/D) ratios for all plant parts except roots were calculated by subtracting dry weights from fresh weights and dividing the resulting measure of plant water by the dry weight.

The studies of Krauss (1949 *a*, p. 357) have shown that in a turgid fully developed leaf from a field-grown plant a distinctive water-storage tissue may occupy approximately one-half of the leaf cross-section in the median portion of the central region; also that the relative amount of this tissue may vary with age, environment and other conditions. These features undoubtedly account for the wide variations over the plant crop cycle of the leaf W/D ratios (Figure 8).

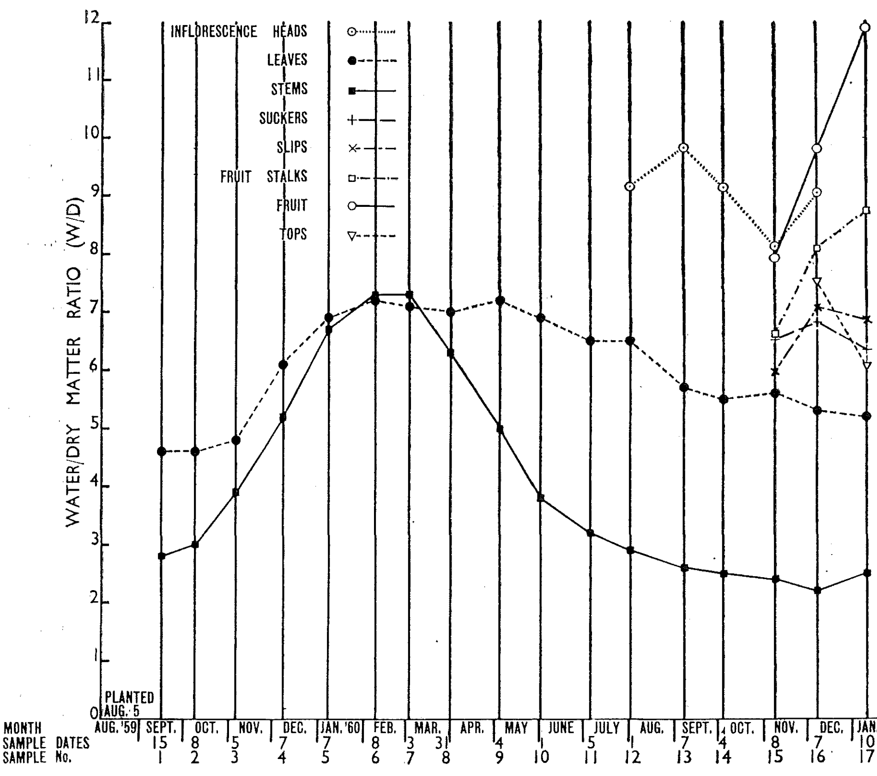

Fig. 8.—Water/dry-matter ratios for all plant parts except roots.

After reaching a maximum value of about 7 during the hot moist months, the ratio commenced to fall during the cold months of June and July. The ratio then fell more sharply during the cold and dry months of August and

September. An interesting point is that the W/D ratio did not recover when growth recovered from October on, but continued to fall gradually during the development of the reproductive parts, all of which showed higher W/D ratios (Figure 8).

The W/D trends for the stems over the growth cycle were most marked and of particular interest. The well-defined peak value of 7·3 in February 1960 occurred one month prior to the first net gains in dry weight made by the stems (Figure 5). Stem length increased linearly across these two regions of change (Figure 4). Thus stem development appears to have occurred in two well-defined phases. The first, extending from planting to the 6th sampling in February 1960, took place with no gains in dry weight but with a considerable increase in moisture content. The second phase, which extended over the remainder of the cycle, was a period of rapid accumulation of dry matter, probably mainly in the form of food reserves.

IV. DISCUSSION

Pineapples generally grow better in acid soils containing a low percentage of lime (Collins 1960, p. 137). Soil pH of samples from the root zones showed a drop in pH of about half a unit between the 3rd and 5th samplings. This increase in acidity was either plant-induced or fertilizer-induced; or perhaps both factors played a part. November and December 1959, the period over which the pH fell, was also the period of early vigorous root growth in the soil immediately below the stem base (Figures 1, 2 and 3).

A long-standing belief in the pineapple industry has been that plant growth, and particularly root growth, is very slow, if not stationary, over the winter months in south-eastern Queensland. The present work has shown, on the contrary, that for plants growing vigorously from the previous summer, the growth of both roots and tops will proceed through the winter months while soil moisture is adequate.

The dry spring period of August, September and the first half of October presented a very different growth response, with evidence of considerable damage to the existing root system. The period was essentially a dry one over which both maximum and minimum temperatures tended to rise. However, some very low minimum temperatures occurred in August. The soil was noticeably dry throughout the root zone at the 14th sampling in early October.

The other important feature of this dry period with respect to root health and development was the prevalence of nematode damage in a planting area fumigated only one month prior to planting. The results also indicate that, when conditions became more favourable for growth, the root systems were able to recover from these attacks.

Treatments which might help to reduce this dry spring damage to the root systems are:

(1) Light supplementary irrigations sufficient to maintain root health. Keeping the soil moist might also help to reduce some low-temperature effects.

(2) Improved fumigation techniques designed to reduce reinfestation of the root zones at the start of the second growing season.

Pineapple root primordia initiate within 1 cm vertical distance from the stem apex and their vascular tissue differentiates in close association and connection with the leaf traces of leaves forming a little higher up the stem (Krauss 1948, p. 173; 1949 *b*, p. 552). Thus the structure of the pineapple plant allows for the provision of roots more or less directly connected to each leaf.

These roots are initiated partly in the stelar and partly in the cortical tissue of the stem apical meristem. They then follow an oblique course downwards through the cortex of the stem at an angle of about 45° from the stem axis (Krauss 1949 *b*, p. 568). The roots emerge from the stem about 1 cm or so below their point of origin.

The root-bearing zone measured (Figure 4) was that part of the stem bearing the bulk of the longer roots and was distinguishable from the rest of the stem by the reddish-brown layers of suberized cells. Shorter unsuberized roots protruded from the stem above this zone.

To obtain good renewal of the root system over the second and third (ratoon) years of growth, it would seem desirable to raise the soil surface in order to keep up with the lengthening of the root-bearing zone. This might be expected to reduce the number of higher roots which remain tightly wound about the stem and confined to the axils of the leaves. These are the so-called "axillary" roots of Krauss (1948, p. 170), the bulk of which may never reach the soil.

Raising of the rooting medium is incompatible with the current practice of growing plants on raised beds. As the raised beds erode, the soil surface is actually lowered, particularly along the sloping sides. This brings the older roots to the surface and certainly does not allow any increase of soil space for the renewal of roots.

The raised beds tend to confine the spread of the "surface" roots to the bed, thus increasing interplant competition and preventing spread into the inter-row spaces. Generally the longer roots were traced along the beds, sometimes passing up to three other plants. The increased root competition would make the effects of soil drought more severe.

The use of raised beds is necessary in many soils and situations to provide adequate soil aeration so as to ensure root health and freedom from fungal attack, and good surface drainage for storm water. Nevertheless, this cultural practice does appear to set a definite limit to the longevity of the pineapple root system.

The marginal nature of the climate under which pineapples are grown at Beerwah (Figure 6) is well illustrated by the comparison with the climatic data recorded by Martin-Prével (1959) for a similar study on the Cayenne pineapple in tropical west Africa (Guinea). Here there were no marked cyclic trends of temperature with respect to seasons. The highest mean maximum for a 10-day period was 35°C, while the lowest mean minimum was 14°C. The length of the longest leaves was of the same order for both studies.

Earlier work by Py (1959) in Guinea showed very smooth fresh-weight growth curves proceeding up to means of 3881 g for the total leaves and 706 g for the stems for 14-month-old vegetative plants which had been forced two months earlier.

The comparable sampling for this work would be the 12th (August 1, 1960). Here the mean for the total leaves was 2251 g and the mean for the stems 245 g of fresh weight (Figure 6). Thus the Beerwah plants had a shorter growth cycle and were much smaller, particularly in the stems.

Further work is required on winter and spring seasonal effects on pineapple growth. The aim will be to separate, as much as possible, temperature effects from drought effects. However, some interactions between low temperature and dryness as factors influencing plant growth are probably inevitable.

Extension of the field of study is also required to include, on the one hand, the first winter of establishment of the longer cycle autumn plantings, and, on the other, from a summer crop harvesting to a ratoon cycle.

V. ACKNOWLEDGEMENTS

This work was made possible by a research grant from the Pineapple Sectional Group Committee of the Committee of Direction of Fruit Marketing.

The assistance of the Farm Committee of the Pineapple Industry Demonstration Farm in making available the planting area used is gratefully acknowledged, as is also the co-operation of the Manager (Mr. Max Crawford) in providing cultural information and assistance throughout the sampling period. Thanks are due to Mr. A. T. Schmitz, Miss Barbara L. Railton and other staff members of the Pineapple Research Laboratory, Nambour, for assistance with the sampling, processing and preparation of the text figures.

REFERENCES

COLLINS, J. L. (1960).—"The Pineapple—Botany, Cultivation, and Utilization." 1st Ed. (Interscience Publishers: New York).

KRAUSS, BEATRICE H. (1948).—Anatomy of the vegetative organs of the pineapple, *Ananus comosus* (L.) Merr. I. Introduction, organography, the stem, and the lateral branch or axillary buds. *Bot. Gaz.* 110: 159-217.

KRAUSS, BEATRICE H. (1949*a*).—Anatomy of the vegetative organs of the pineapple, *Ananus comosus* (L.) Merr. II. The leaf. *Bot. Gaz.* 110: 333-404.

KRAUSS, BEATRICE H. (1949*b*).—Anatomy of the vegetative organs of the pineapple, *Ananus comosus* (L.) Merr. III. The root and the cork. *Bot. Gaz.* 110: 550-87.

MARTIN-PRÉVEL, P. (1959).—Apercu sur les relations croissance-nutrition minérale chez l'ananas. *Fruits d'outre Mer* 14: 101-22.

PY, C. (1959).—Étude sur la croissance de l'ananas en Guinée. *Fruits d'outre Mer* 14: 3-24.

VALLANCE, L. G. (1938).—A soil survey of the Beerburrum, Glasshouse Mountains and Beerwah pineapple districts. *Qd Agric. J.* 49:554-79.

(Received for publication August 31, 1962)