

SOME EXTERNAL AND INTERNAL FACTORS
RELATED TO THE GROWTH CYCLE OF COFFEE

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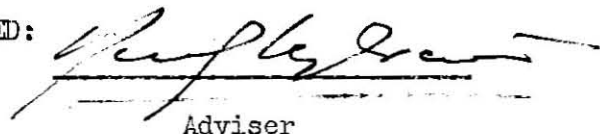
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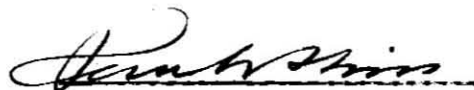
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I

INTRODUCTION

The economically important beverage called coffee, is mostly the production of the tree Coffea arabica L. This tree is grown in the tropical and subtropical regions of the world. The importance of this crop, especially for the people of the Western Hemisphere is quite obvious. This commodity is not only used in vast quantities by all the peoples here, but figures greatly in the economic structures of many of our countries. From some of the latest data available (1948), it appears that coffee constituted approximately 44 per cent of the general exports of nine Latin American Countries (67).

Although the economics of this crop and its very production is bound closely to the livelihood of millions of people, comparatively little investigation has been made to understand the basic physiology of the plant that produces it. This fact has led to a number of studies giving conflicting results, with an equal number of unjustified hypotheses or conclusions.

Better knowledge of the physiology of the plant would provide a firmer basis for the development and interpretation of future investigative works.

This paper is the second of a series dealing with the relationship between the growth cycle of coffee and external and internal factors. Specifically it attempts to evaluate climatic factors as temperature, rainfall, and light; edaphic factors as soil nitrogen and moisture; and internal factors as represented by the reproductive cycle and foliar analyses for nitrogen and ash.

The initial work on this subject was done by McFarlane (50), who traced the vegetative cycle of this plant from July 1948 to July 1949. He found that the growth cycle of the mature coffee tree in the Turrialba region shows a definite period of vegetative activity and dormancy.

McFarlane advanced the hypothesis that two possible factors may control this cycle, namely: 1. leaching of soil nitrates by excessive rainfall; 2. development of the fruit.

REVIEW OF PERTINENT LITERATURE

Growth Cycles of Plants

The literature shows that the general growth cycle of plants, when it is plotted by graphic methods, is in the form of a normal curve. Curtis and Clark (18), Meyer and Anderson (55), and Miller (56), give a thorough review of this same conclusion.

The rate of growth of a plant, or plant part, is relatively slow at first, increases rapidly to a maximum and finally decreases until it ceases (56). This is generally true in the case of both annuals and perennials.

In the case of annuals the grand cycle starts with germination from seed and terminates in senescence and death.

Termination of the growth cycle in perennials, however, does not end in death but periods of dormancy that are in turn followed by more active growth.

This recurring cycle is most definite in the temperate regions where it coincides with the march of the seasons. The spring flush usually produces the most rapid growth, followed by slower growth through the early summer. The growth rate usually becomes nil before cold weather appears. This is true for both deciduous and evergreen plants.

Careful observations of this phenomenon have been made by numerous workers, for example, Kramer (44) who worked with various species of tree seedlings, Murneek (63) who worked with the apple tree, and Wittwer and Murneek (95) who worked with the cherry tree.

It should be noted that literature dealing with growth cycles of tropical and subtropical plants is scarce and generally incomplete, thus comparatively little is known of their fluctuations.

Chandler (14) found that avocado trees growing in the subtropical climate of California, exhibited three flushes after the dormant season. A long flush started in the spring soon after the peak of blooming. There was then a summer flush and an autumn flush. Also in California, Chapman and Parker (15) stated that the orange trees began their growth cycle usually in February with maximum growth and flowering in late March and early April. Roy and Gardner (73) in Florida, worked with the orange tree and reported initiation of spring growth in January after the so-called winter dormancy.

Marloth (51) also reported on the citrus growth cycle in Eastern Transvaal. With seasons opposite to those of the Northern Hemisphere, he reported that citrus ended its dormancy at the coming of spring in August. The first flush lasted until October. The next flush was at its height in midsummer, and lasted from mid-November to January. A lesser flush occurred from February to March.

Chandler (14) stated that the growth of the tea plant tended to be continuous if environmental conditions were favorable. Bond (8), working specifically with this plant, observed that the growth was rhythmic and went through alternations of four active growth and dormancy periods that were to a large extent independent of seasonal change in climate.

Greenwood and Posnette (31) made observations on the growth of cacao. Their results indicated that the flushing of mature cacao was suppressed when the weekly mean of the daily maximum temperature was below 83° F., and that no other environmental factors measured had an influence on flushing.

Weevers (92), in a review of literature, cited Shimper and Valkens who viewed the occurrence of rest periods as being an immutable property of plants. He also said that Klebs took up an entirely different point of view. Klebs was of the opinion that the mutual ratio of mineral and organic nutrients played an important part in bud growth. Whereas an excess of the latter

heralds a period of dormancy through inhibition of enzymatic activity, an excess of the former causes a renewal of activity.

Weevers (92, p.217), in summarizing his views, stated,

...it may be said that as a result of internal autonomic causes there are several periods of bud growth in one year, though this periodic bud growth, and thus plant growth as a whole, is strictly determined by cosmic circumstances.

Growth Cycles of Coffee

Wakefield (91) followed the growth cycle of coffee in Tanganyika, and established the existence of definite periods of activity and dormancy in that region. He found that shoot growth commenced in the beginning of September, with a peak in October and November. It then decreased in December. Another growth flush began in March, reached a peak in April, and decreased again in June. He listed the months of flowering as October through December and February through March, with harvesting from July through October. This worker mentioned the fact that a heavy crop may delay the subsequent period of shoot growth.

Rayner (70) working in Kenya, divided the growth cycle of coffee into six periods: 1. during the short rains in November and December when the growth was rather low; 2. in January when growth increased with sunshine but fell later as the soil dried; 3. the greatest amount of growth was then recorded in February after two rainstorms but fell again as the soil dried; 4. from March to mid April was the period of the long rains, and variations in hours of sunlight seemed correlated with variations in growth; 5. growth declined until it reached a very low level in July, probably produced by a reduction of hours of sunshine and by the crop on the trees; 6. growth increased somewhat as the hours of sunshine increased. He stated that the trees flowered

about nine times, but the flowering at the end of February far exceeded the others.

Thomas (81) reported only one spurt in the growth cycle of bearing coffee of the Robusta species in Uganda. He stated that the vegetative growth commenced in January and began to die down in March and April. He reported that his measurements showed the importance of the time of ripening of the fruit on the vegetative growth of the trees.

A typical branch was studied and measured over a period of two years including the recording of leaves, flowers, and fruit. The branch continued to grow until April 1934, when a large crop of berries began to develop. When the berries were picked from November 1934 to January 1935, vegetative growth restarted, only to die down in March 1935 when another crop was set.

He said that from these observations he made the unexpected discovery that fruiting coffee trees produced most of their growth in the dry season, for that was the time when they were carrying little fruit crop. The amount of fruit was the controlling factor on vegetative growth and not the conditions of soil or variations in the climate. This was shown by the facts that, first, young bushes which had not started to fruit, grew most rapidly in the rainy season. In the second place pollinated branches on which few or no fruit were set, continued to grow, while adjacent branches on which a heavy crop was set by open pollination would make no new leaves.

Mayne (53) in South India divided the coffee growth cycle into four parts according to climate. The first part covered the harvest and post harvest rest period of the plant. This was a dry cool season from the end of November to the middle of March with growth at a minimum. Towards the end of this period, with temperature rise, vegetative growth commenced even though no rain had fallen. The trees blossomed late in March or April.

The second period he classed as the hot weather period from mid-March to the end of May or early June. In this period with the first rains, a rapid vegetative development took place. This growth fell off by the end of May, and ceased earlier in years of heavy crops.

The rainy southeast monsoon occurs from early June to the end of August and comprised the third period. Vegetative growth was almost at a standstill in June and July.

The fourth period covered the northeast monsoon from September until about the end of November. At this time, growth commenced again in August and continued through September and October.

Mayne drew attention in this paper to the apparent antagonistic effect of crop development on vegetative growth and pointed out that during the periods of maximum fruit growth, vegetative growth was minimal.

Rayner (71), comparing the growth and bearing habits of Coffea arabica in Kenya and Southern India, stated that leaching, drought, low temperature, and fruit set were probable factors in controlling the growth cycle.

In Java, Meulen (54) noted that Robusta coffee growth began in December after the wet season had started. According to his information, dormancy set in during the dry season of April to October.

Ultée (87), in a report on coffee of the Arabica, Robusta, and Liberica varieties and their crosses in Java and Sumatra, agrees with Meulen on the seasonal aspect of growth. He noted that the peak of growth was after the fruit was picked, and coincided with the regular rainy season. As the fruits ripened, the trees went into dormancy. The fruit was off by the end of the rainy season.

Dean (20) found in Hawaii that maximum growth of laterals occurred simultaneously with and following flowering during the spring. Dean's data

indicated that the amount of rainfall, between the months of February and June, was correlated with vegetative growth at that time.

Herndlhofer (36), in Campinas Brazil, observed that the vegetative growth began in July and August with the main blossoming in September and October, and harvest in May. High temperature and rain occurs from November to March while low temperature and dry periods occur between May and September.

Alvim (1), however, said that in the state of Minas Gerais, Brazil, the growth started in August and September concurrently with the bloom, with its peak in September. Growth was reduced in March. The dormant period for coffee there lasted from May through July and part of August which was the dry cool season.

The growth cycle on the continent of South America has been followed in Colombia by Suárez de Castro (80). His records of periodic growth showed that vegetative activity began about the first part of January and continued to May. The growth dropped rapidly to a low in June and July, then increased to a second but minor peak in August. Activity was at its lowest for the remainder of the year. January showed the lowest minimum temperatures with an average of 15°C ., and one low of 11.8°C .

In Guatemala at the Instituto Agropecuario Nacional, the growth cycle was followed during the year 1947 (25). Data showed that growth started at the end of December. The rate increased markedly to February, was reduced somewhat in March and then increased again to the years highest value by April. The curve then dropped very quickly to June. It rose again in July to one third of the highest peak, then declined slowly to November and December. The coldest months are November through February with the rainy season extending from May through October (66).

In El Salvador (89,90), the growth curve for a 2-1/2 year period showed that vegetative activity began about the first part of February and increased to a peak in March and April. Another peak in June was noted. Also, a minor one occurred during the months of August to October. After this the growth rate dropped till the latter part of January.

Rainfall did not begin until April, about three months after the growth started.

The earlier of the two reports noted that the growth rate began to decline when the rainfall mounted in intensity in the months of June and July. The coolest months of the year in this region are November to January, and the warmest are March to May. (66).

McFarlane (50), at the Inter-American Institute of Agricultural Sciences in Costa Rica, traced the vegetative cycle of this plant from July 1948, to July 1949. His observations showed that initiation of growth began in the first week of January and increased rapidly after the 15th of January. The growth rate reached a peak the first week of March, then declined until April 25th. Growth was still very active at this time. A sharp upward movement of growth rate then took place and reached the highest peak of the measurement period at the end of May. Immediately after this peak, the growth rate fell sharply until the first week in September and remained at a very low value for the rest of the year.

He advanced the opinion that leaching of soil nitrates by heavy rains in May and/or setting and maturation of fruit may have been responsible for the decline in growth. He also offers an opinion that the drop in growth rate in April may have been caused by too little soil moisture in March.

Factors Affecting Growth Cycles

No attempt will be made here to review the very extensive literature on the subject of all the factors affecting growth cycles in plants. Reference will be made, however, to the articles more pertinent to this work.

External factors

Due to the periodicity of rainfall, varying levels of soil moisture may be available for plant growth at different times of the year. Veihmeyer and Hendrickson (88), reviewed this subject thoroughly. Conflicting evidence was given concerning the hypothesis that varying amounts of soil moisture influence plant growth. The prevailing opinion is, however, that plants can extract soil moisture with equal facility from field capacity to permanent wilting point (55).

Data presented by some workers (20,50,54,70,71) advanced the idea that varying soil moisture at certain periods of the year may control or influence the growth cycle of coffee.

Temperature, in many cases, is regarded as a limiting factor in vegetative development. This was specifically noted in citrus (34,51) and cacao (31,39).

Most of the literature pertaining to coffee indicates that the dormant period of this plant occurs during the time of lower temperatures of the region. (1,6,20,25,50,53,70,71,89,90).

The stimulatory effects of low temperature must also be considered (17,29,38).

Curtis and Clark (19,p.584) commenting upon this subject, stated, Low temperatures instead of inducing rest are more commonly

effective in breaking it. In fact, with many plants the buds enter the rest condition during the hot weather of middle or late summer.

Very little emphasis has been given this concept concerning tropical and subtropical plants. This is probably due to the fact that only relatively small temperature fluctuations occur in the tropics, as compared to the temperate regions where most of the investigations of this nature have been conducted.

It appears that the only direct reference to low temperature stimulation of plants in the tropics, occurs in Weever's Fifty Years Of Plant Physiology (92). He reported that Ch. Coster found the opening of Dendrobium crumenatum flowers is dependent upon a sudden drop in temperature, as will occur in the tropics after heavy rainfall.

The investigation of the cyclical vegetative growth habit of temperate trees has been approached from yet another angle, that is, photoperiodism.

Kramer (44) noted that Klebs was one of the first to investigate the effects of length of day on woody species. He reported that some temperate tree species grew all winter when placed under continuous light. Moshkov (58,59,60) reported that certain southern tree species when grown at Leningrad, Russia, where the maximum length of day is 20 hours, continued to grow until killed by frost instead of becoming dormant at the end of summer. If the photoperiod was artificially shortened, such species ceased growth earlier in the season. Garner and Allard (30) subjected several woody species to different day lengths. They found that increased day length would forestall dormancy and in some cases prevent it. This work brought forth the hypothesis that length of day might be an important factor in determining the time of beginning and of ending the dormant period.

Kramer (44) tested this hypothesis very carefully. He found that by

subjecting different species of temperate zone trees to varying day lengths, the duration of the growth period was controlled to a considerable extent. Long day length delayed dormancy or kept the trees growing continuously. Resumption of growth by dormant trees was hastened by additional light and retarded by shortening the photoperiod below the normal length of day. Gustafson (33) found that either an increase in day length or low temperature would break the dormancy of Pinus resinosa.

Photoperiodism in the tropics is an established fact (10). Sircar (77), in his discussion of Vernalization and Photoperiodism in the Tropics, reviewed the growth and bearing requirements of certain tropical crops in India. He asserted that relatively small changes in natural day length influence the growth cycle.

The literature reveals one mention of this phenomena in relation to coffee. Franco (26) subjected young coffee plants to 4 hours less light and concluded that the resultant decrease in the production of vegetative parts placed this plant in the short day group.

Nitrate, generally being the most abundant available nitrogen source in the soil, is extremely important to plant growth at certain periods of the vegetative cycle. In the temperate regions it is generally considered as having a close relationship with the season of the year. Batham and Nigam (4) concluded that the greatest accumulation of nitrate took place in the summer and the least in the winter. Limbach (47) noted a very definite periodicity of nitrification with high quantities in spring and fall, and low quantities in midsummer and winter.

With regard to soil conditions, temperature extremes and leaching by rain are regarded as two of the most important controlling factors in the quantitative status of soil nitrate. The fluctuations of this ion in the

tropical and subtropical regions are attributed to fluctuations in the soil moisture. Annett et al (2), working in India, stated that the nitrate content of the soil was increased by the first light rains following a prolonged period of dry weather, and decreased with subsequent heavy rains. Hardy (35) in Trinidad, found that with an increase in soil moisture there was a decrease in nitrate, and vice versa. Griffith and Manning (32), however, found the opposite to be true in Uganda.

The fluctuations of nitrates in coffee soils of different regions have been followed. Beckley and McNaughtan (7), working in Kenya, stated that as the soil surface dried with drought, the nitrate content decreased in some cases to as little as 5 parts per million. Dean and Beaumont (21) followed the available nitrogen cycle in Hawaii and reported that it responded to season and rainfall. They said that there appeared to be a tendency for the nitrates and ammonium content of the soil to decrease during the dry winter and increase during the wet spring.

In Tanganyika, Saunders and Wakefield (75) asserted that long heavy rains caused denitrification of the soil and subsequent nitrogen starvation in the plant.

Trench and Beckley (85) in Kenya, also attributed the loss of nitrate, with its resultant effects upon the coffee growth, to excessive leaching. Rayner (71) compared the growth cycles of coffee in Kenya and Southern India and concluded that low nitrate content at certain times of the year became the controlling factor in growth. McFarlane (50), in Costa Rica also listed the possibility of leaching of nitrates as causing a decrease in growth.

Internal factors

The idea that the reproductive processes have a great influence upon

the vegetative growth cycle of plants is shared by many.

Murneek and Wittwer (65, p.201) wrote,

Most perennials and many annuals with a continuous type of growth... have recurrent periods of flowering and fruiting. Their life does not end with, but is altered markedly by reproduction. The reproductive organs and associated tissues exert a conspicuous physiological control on their metabolism and subsequent development. Reproduction having proceeded at a maximum, the plants may become periodically or permanently restricted in vegetation....

The interesting feature in this sequence of events is that these changes are to a large extent independent of the external environment, but directly related to flower and fruit production. It is conspicuously 'internal'.

Wittwer (94) stated that the two phases in reproduction i.e. fertilization and fruit development, are stimulative and repressive respectively, to vegetative growth.

Murneek (61), working with tomato, noted that in every instance the presence of a relatively large crop of fruit was found to be the cause of retarded development. He claimed that nitrogen was the limiting factor for growth when taken by the fruit. In a later paper (62), the worker found that gametic union in the tomato plant caused a stimulation in metabolic activity, with resultant increased vegetative growth. Dearborn (22), working specifically with cucumber plants, corroborated Murneek's work.

It has been said (95) that perennials, as represented by the cherry tree, may also be similarly affected in certain phases of the vegetative cycle by the reproductive processes.

Murneek (61) was of the opinion that in respect to woody perennials, the analysis of the effect of reproduction upon vegetative growth is made more complex by the presence of proportionally large amounts of storage products of diverse types.

No attention has been given to the possible effects of sexual fertili-

zation upon the vegetative growth of coffee; however, some investigators have tried to explain the drop in growth rate to the repressive influence of fruit development. This was thought to be the result of monopolization of the synthesized products (50,53,70,71,81,91).

Thomas (84, p.353) said,

...leaf analysis is based on the functioning assimilating leaves as the control laboratories of nutrition....The emphasis on the modern work is placed upon the internal concentration of nutrients in the leaf, especially upon the changes in levels during different stages of the growth cycle....

The nitrogen cycle of the leaf has been followed by a number of workers in the temperate regions. Thomas (82) traced it in Pyrus malus for one growing season, and found that from the first sampling of leaves in spring, there was a steady decrease of total nitrogen to the middle of August, an increase to the middle of September, then another decrease until leaf fall. He claimed that the increase in nitrogen in September was attributed to a cessation of vegetative growth. The second drop from September to leaf fall was caused by a translocation from the leaf into the one and two year old wood. He concluded that the total nitrogen and certain partition fractions varied with growth, decreasing when growth was very rapid.

Murneek (63) worked with apple trees and came to the same general conclusions. He stated that the greatest drop occurred during the early development of the leaves when there is a heavy demand for nitrogen by all the succulent organs, and again in late fall. This worker postulated that a nitrogen equilibrium seemed to exist in leaves in midsummer.

Other investigators working with the same and other temperate zone trees have come to similar conclusions (9,11,42,48,64). Judkins (41), however, found no correlation between leaf nitrogen and shoot growth in the peach tree.

Cameron and Appieiman (12) and Cameron and Compton (13) traced the nitrogen cycle in the orange tree and reported that the tree contained more nitrogen just before the initiation of growth activity in the spring than at any other time of the year. During the period of active growth, blossoming, and fruit setting in the spring and early summer, a decrease occurred in the nitrogen content of all parts of the tree. During the summer and autumn, there was a gradual increase to the midwinter maximum. The drop in nitrogen at the time of new growth and blossoming was confirmed by Hilgeman et al. (37) and Jones et al. (40).

Herndlhofer (36) in Brazil studied the nitrogen cycle of coffee. He analysed composite samples of young and old leaves every month. His results showed that leaf nitrogen was highest from August through January with a high peak in September and another in December. Lowest values were in the months of April and July. He stated that the development of the fruit causes a drop in nitrogen of the leaves.

Roelofsen and Coolhaas (72) and Schweizer (76) in the Dutch East Indies, presented data on the nitrogen cycle of the coffee trees. The data of Roelofsen and Coolhaas indicated an almost continuous drop in leaf nitrogen of bearing and non-bearing trees from leaf maturation to leaf fall. They could not ascertain with certainty that the development of the berry caused a shortage of nitrogen. Schweizer noted that leaves lasted only one year because of the very dry season. He found that a great blossoming withdrew nitrogen from the leaf and that a heavy crop would cause early leaf drop long before the fruit ripened. He went on to say, however, that a normal crop did not withdraw nitrogen from the leaf but did from the bark and wood of the branches.

MATERIALS AND METHODS

Growth Measurements of Mature and Immature Coffee Trees

The method of growth measurements in this investigation was the same as that used the previous year by McFarlane (50). He based his work on the conclusions of Beaumont (6), in Hawaii, who found that terminal growth and lateral growth are closely and positively correlated.

Lateral growth measurements were made at the Institute in Turrialba to estimate the vegetative growth rate of coffee. The growth of an individual branch was determined by measuring separately, the linear increases of the last two internodes. Also, the advent of new internodes was recorded. These measurements were made every 14 days. Whenever the time of measurements fell short of, or were over this period, they were interpolated to a 14 day unit.

A separate record was kept for each tree. The growth of each measured branch was tabulated on this record individually. The growth increase for each tree was found by averaging the growth increases of the respective measured branches.

The method of analyses for significant differences between 14-day intervals was taken from Snedecor's Statistical Methods Chapter 4 (78). The formula $t = \frac{\bar{X}}{\sqrt{\frac{n(n-1)}{sx^2}}}$ for groups of equal size was used, where t = test for significance at the 5 per cent level. \bar{X} designates the difference between the two group means. n = number of trees per group measured and sx^2 = total sum of squares of both groups. The formula $t = \frac{\sqrt{\frac{n_1 n_2 (n_1 - n_2 - 2)}{(n_1 - n_2) sx^2}}}{\bar{X}}$ was used for groups of unequal size. The growth measurements of this work were separated into three different experiments.

Mature trees of a commercially operated field

This part of the study traced the growth of 47 randomized mature bearing coffee trees in a commercially operated field for the second year. These trees were in two plots of ground, A and B, separated by a small stream.*

Plot A was flat. Plot B was higher than plot A and sloped towards it. From September, 1949 to December, 1949, growth of trees in both plots was measured at the same time every 14 days. However, due to a flood in December 1949 that inundated plot A and disrupted the soil surface, it was deemed advisable to discontinue measurements of that plot. Twenty-five new trees were then selected and marked in plot B at random among the measured trees of this plot. The experiment then continued to December 1950.

Four to six branches on each tree were selected to determine the vegetative growth rate. These branches were healthy laterals and were distributed as evenly as possible over the entire tree.

Fertilized and defruited mature trees

This experiment was situated in the Institute experimental plots, and ran from June 1949 to July 1950. It was divided into 4 treatments.

1. Fertilized 2 applications. These trees were fertilized once heavily with sodium nitrate (479 gm. per tree) on May 20, 1949, and once on May 2, 1950.

2. Fertilized 5 applications. These trees were fertilized lightly with sodium nitrate (160 gm. per tree) on May 20, July 20, and October 1, 1949, then on May 20, and July 20, 1950. The fertilizer for both treatments was applied in a circle (6 inch inner diameter and 15 inch outer diameter) around the base of each tree.

* For more specific description of field see page 21

3. Defruited. These trees were defruited 1 time in the 1949 season and 4 times in the 1950 season.

4. Untreated or Control. These trees were untouched and used solely for comparison with the preceeding treatments.

The experiment was of a randomized block design with 3 replications containing 5 trees each. Six laterals per tree were selected at random for the growth measurements.

Immature trees

The trees of this experiment were approximately 1-1/2 years old when first measured and were situated in the Institute nursery. They were measured from November 1949 to December 1950. Artificial shade of approximately 40 per cent was provided by overhead spacing of cane poles to approximate the natural shade over the mature trees. These young trees were 26 in number and in 1 block. Each one was considered as a replication.

Two lateral branches were selected from each tree for measurement. One branch was at the lower portion and the other branch was at the upper portion of the tree.

Flower and Fruit Counts

The data on the flower counts were gathered by Roger Jean Baptiste, a graduate assistant, at the Institute. The location of the trees was about 1/2 mile from those that were measured for vegetative growth. Counts were made approximately every 7 days from 50 trees with 2 branches used per tree, (Fig.3).

Source of data for fruit count was the 47 trees in the commercially operated field. The fruit was counted 3 times; April 9, May 5, and June 20, (Fig.3).

Both groups of data were summarized and calculated as to percentage of flowering and fruit set at certain periods during the season.

Foliar Analyses

Leaves used for nitrogen and ash determinations came from the 47 mature trees. The trees were divided into 3 replications in relation to position and proximity. Each month 4 leaves were taken at random positions from each tree and placed in a marked paper bag, together with those of the other trees in that replication. These leaves were selected midway on the leafy portions of the laterals (24), and were unblemished, apparently healthy specimens. Wellman (93) has noted that mature coffee leaves may remain on the tree as long as 3 years.

The samples were taken at approximately 9 o'clock in the morning (18, 52, 84), then immediately carried to the laboratory. They were brushed clean of all clinging matter and dried in a forced draft oven at 70° C. (23, 84).

When thoroughly dried, the petioles were separated from the blades and discarded. (46, 86). Only the blades were used in these analyses. The leaves were then ground in a Wiley mill to pass a 0.5 mm. screen, redried to constant weight at 70 C. and stored in sealed bottles until analyzed.

Total nitrogen was determined by the modified Cünning Kjeldahl method (3, 49).

Alcohol insoluble nitrogen was determined by the Kjeldahl method (3) on the sample after 12 hours washing with 80 per cent alcohol in soxhlet extractors (49).

Alcohol soluble nitrogen was determined by subtracting the percentage of alcohol insoluble nitrogen from the percentage of total nitrogen.

Total ash was determined by subjecting the sample to a temperature of 525° C. in an electric muffle furnace until constant weight was attained (3).

Percentages were determined on the dry weight basis (96), and the mathematical interpretation of the data was by analysis of variance with both 1 per cent and 5 per cent levels of significance computed.

Soil Determinations

The field location for this experiment was the same as that of the 47 mature trees. The field covers about one hectare. As a whole it gently slopes toward a stream on one side. More specifically, it consists of a flat high portion, a moderately sloping portion and a low portion just above the stream bed.

The soil is a red sandy clay of volcanic origin. The composition of the surface soil varies from a high clay content in the upper and sloping portions of the field to a high sand content in the lower parts. The subsurface at the 16 inch level is rocky in some parts but with a greater clay content than the surface. There has been no definite classification of soils in this region.

Six permanent locations were selected in relation to the investigated trees, and marked with numbered posts. Positions were selected as follows: 2 on the high flat portion; 2 on the sloping portion; and 2 on the low portion of the field.

Two levels of soil were analysed at each position; one level was the surface to 3 inches, the other level was at the 16 inch depth.

Each position was divided into 4 quadrants with 12 sampling points, roughly 1 foot equidistant, in each quadrant. One point in a quadrant was sampled each month. The four resulting samples were then placed together and considered as a composit sample for that individual position. The surface sample and sub-

surface samples were collected at the same point.

The point for sampling was first cleaned of debris, then the surface soil was dug with a small hand trowel and placed in a marked paper bag together with soil from the other 3 quadrants. After the 4 points were sampled for surface soil, they were enlarged carefully and cleaned of loose earth to prevent contamination of the subsurface level. An open soil auger was then screwed into the soil to approximately 16 inches for the subsurface sample.

The samples were taken immediately to the laboratory, picked clean of all rocks and objects unincorporated with the soil, and weighed and dried in a forced draft oven at 55° C. to constant weight (5,27,68,69,74). The soil samples were then weighed again, crushed lightly in a porcelain mortar and passed through a 0.59 mm. screen. The samples were placed in large mouth bottles and redried at 55° C., then corked and stored until chemically analysed.

Total nitrogen was analysed by the modified Gunning Kjeldahl method (3). All samples were in duplicate.

Nitrate nitrogen was analysed by the phenol-disulfonic acid method (69) with a Klett-Summerson colorimeter (43).

Soil moisture at time of sampling was computed on the dry weight basis.

The method of analysis of data was by analysis of variance, with each month considered as a treatment and each position considered as a replication. Separate analysis of variance were run on both levels for total nitrogen, nitrate, and soil moisture. Both the 1 per cent and 5 per cent levels of significance were computed.

Climatological Data

All climatological data were taken from the Institute weather station.

Average 4 week maximum and minimum temperatures are presented in graph form. (Fig. 6). Also, average 4 week weighted mean temperatures are presented in graph form (Fig. 6). The weighted mean temperature was obtained by measuring the area under the curve with a planometer.

Rainfall data are presented in graph form for 4 week periods (Fig.6).

Light intensity data was measured in hours of sunlight. Average 4 week light intensity figures are presented in graph form (Fig.6).

EXPERIMENTAL RESULTS

Growth Cycle of Coffee

An examination of the data presented in this section will demonstrate that the vegetative growth cycle of coffee in the Turrialba region is pronounced and definite. (Fig.1).

Mature trees

The first measurements were started on July 11, 1949 when the growth rate was decreasing (Table 1). In the next 14 day period there was a minor but significant increase in growth. From August 8, there was an almost continuous drop to November 15. At this time the trees were considered dormant and continued in this state until December 18*. From this date there was a gradual but significant increase in the rate of growth to January 20, 1950.

A great increase in the rate of growth occurred after this date and continued to increase until March 6. It then dropped to a low on April 16. The trees at this time were by no means dormant but actively growing. Another increase occurred on May 14 and lasted until May 30. This was followed by a decline to another low on August 1.

A third and minor rise of the year subsequently occurred and increased to October 3. The decline into dormancy then began and continued downward to December 1, 1950, at which date the experiment was terminated.

Immature trees

The growth curve of the young trees also shows a periodic cycle. This curve

*Though the plant is considered dormant at this time, an occasional branch did show vegetative activity.

Table 1

SUMMARY OF DATA SHOWING TWO WEEK AVERAGE GROWTH PER LATERAL
BRANCH OF FORTY-SEVEN MATURE COFFEE TREES
(Centimeters)

Date	Growth	Date	Growth
July 11, 1949	0.55	Mar. 17, 1950	1.46
July 25	0.78*	Mar. 31	1.29*
Aug. 8	0.79	Apr. 16	0.57*
Aug. 22	0.47*	Apr. 30	0.60
Sept. 6	0.23*	May 14	0.96*
Sept. 20	0.27	May 30	1.01
Oct. 4	0.34	June 15	0.96
Oct. 18	0.21*	June 30	0.76*
Nov. 1	0.07*	July 14	0.32*
Nov. 15	0.02	Aug. 1	0.23
Nov. 29	0.05	Aug. 17	0.28
Dec. 18	0.05	Sept. 3	0.54*
Jan. 6, 1950	0.19*	Sept. 18	0.54
Jan. 20,	0.24	Oct. 3	0.61
Feb. 3	0.77*	Oct. 18	0.50*
Feb. 22	1.44*	Nov. 1	0.36*
Mar. 6	1.66*	Nov. 17	0.14*
		Dec. 1	0.07

* Sig. diff. from preceding date @ 5%

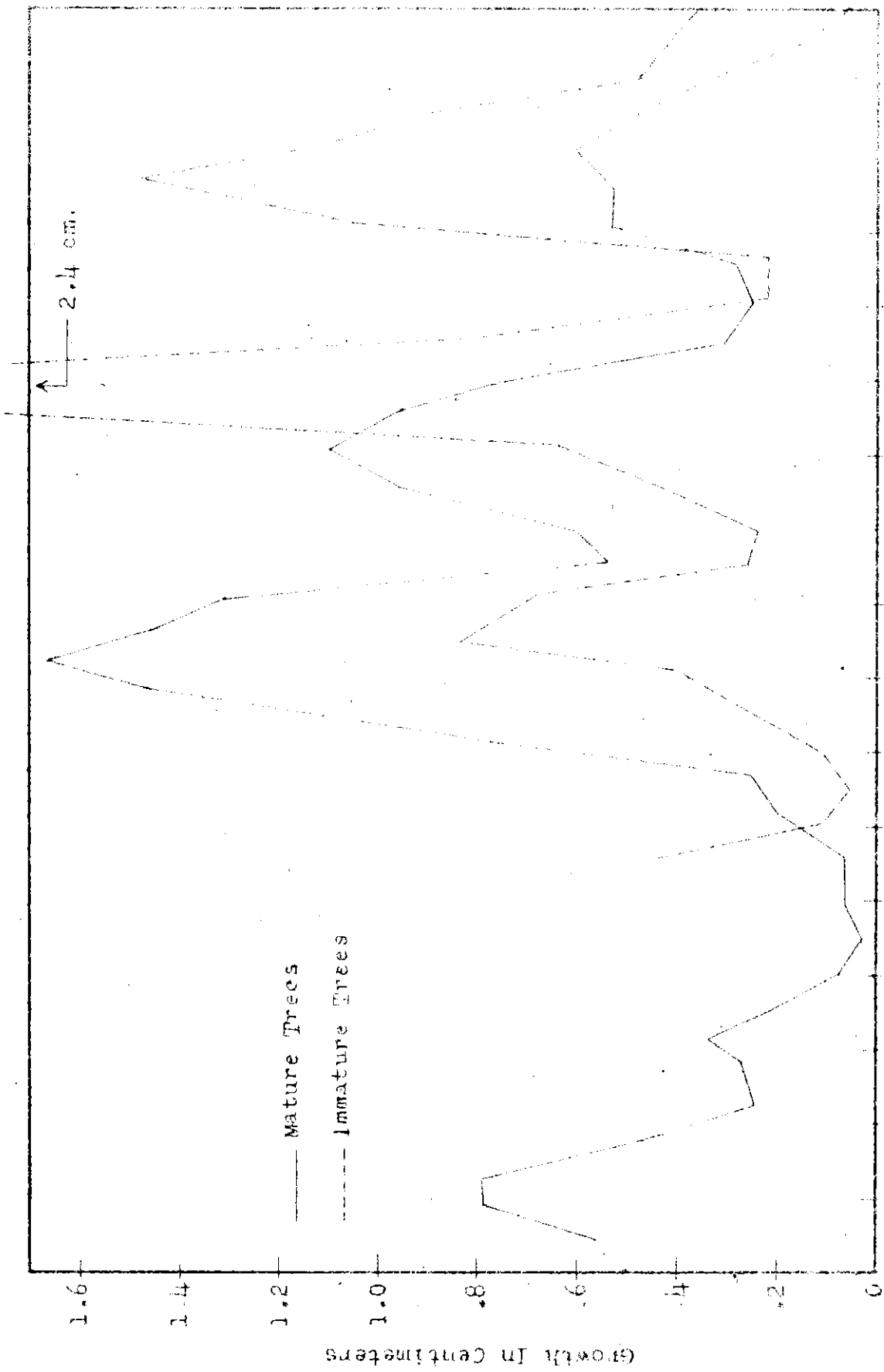


FIG. 1. AVERAGE TWO WEEK GROWTH RATE OF MATURE AND IMMATURE COFFEE TREES (1949-1950)

bears a striking similarity to the one of the mature trees; however, the fluctuations are much greater (Fig.1).

A significant drop in growth rate occurred from December 16, 1949, to January 16, 1950 (Table 2). This was the lowest point in the growth rate curve. A steady increase occurred from this date to March 15. There was then a significant drop to April 29. Just afterwards, the second and greatest growth surge began and lasted until July 1. From this great peak in growth it dropped precipitously to August 3. The growth rate then started up again and lasted until September 16, whence it dropped to December 1, 1950.

Fertilized and defruited trees

The general growth curve of these trees (Fig. 2) closely followed that of the 47 mature trees. The growth of these trees was first measured on June 14, 1949, on an upward growth swing. The growth increased to July 12, then dropped to dormancy that lasted from mid November to mid December. After this apparently inactive period there was an increase to March 15, 1950, then a drop to May 29. An increase in growth again developed and lasted until July 30. A steep drop subsequently occurred to August 2. The next measurement period showed a slight increase in growth but after this, the trend again took a downward direction.

Only the defruited trees showed a significant difference in growth over that of the controls (Table 3). These differences manifested themselves on the upswing and top of the growth curve. As the growth rate declined, the significant differences between the two treatments became smaller and then vanished.

Although the intensity of the growth curve of the defruited trees was greater than that of the controls, the cycle remained the same.

Table 2

SUMMARY OF DATA SHOWING TWO WEEK AVERAGE GROWTH PER LATERAL
BRANCH OF TWENTY-SIX IMMATURE COFFEE TREES
(Centimeters)

Date	Growth	Date	Growth
Dec. 16, 1949	0.43	June 15, 1950	2.23*
Jan. 2, 1950	0.12*	July 1	2.44
Jan. 16	0.04	July 14	0.82*
Jan. 30	0.12	Aug. 3	0.22*
Feb. 15	0.27*	Aug. 17	0.22
Mar. 5	0.41	Sept. 2	1.06*
Mar. 15	0.84*	Sept. 16	1.47
Mar. 29	0.70	Oct. 3	1.14
Apr. 15	0.26*	Oct. 18	0.90
Apr. 29	0.23	Nov. 2	0.49*
May 13	0.42	Nov. 18	0.40
May 30	0.63	Dec. 1	0.37

* Sig. diff. from preceding date @ 5%

The other two treatments with the two levels of sodium nitrate showed no significant differences over the controls at the 5 per cent level.

Flower and Fruit Counts

On February 17, 1950, the first flowers were observed and counted. According to the data at this date it was estimated that the trees produced a 7 per cent bloom. Including this date to March 22, a total of 25 per cent of the bloom had then occurred. From March 29 to April 19, 72 per cent of the bloom was produced. The remaining 13 per cent was produced through June 7, 1950 (Fig.3).

By April 9, 1950, 76 per cent of the fruit had set on the 47 mature trees. On May 5, a second count was made showing that another 7 per cent had set. The third and last count on June 20, 1950, showed that 17 per cent more fruit had accumulated.

No more fruit counts were made after this time, since blooming had ceased (Fig. 3).

Foliar Analyses

Total nitrogen

The annual total nitrogen cycle of mature coffee leaves presents a bi-model curve (Fig. 4).

A look at Table 4 will show that the curve during the months of November and December 1949 evidenced a decrease in the per cent of total nitrogen. An increase then began and continued until April 27. The total nitrogen dropped after this to a new low on July 31. It then increased again to October 31 only to decrease the succeeding month. The lowest per cent of total nitrogen occurred December 27, 1949, with the highest per cent on April 27, 1950 (Table 4).

Table 3

SUMMARY OF DATA SHOWING TWO WEEK AVERAGE GROWTH PER LATERAL BRANCH OF
DEFRUITED, NITRATE FERTILIZED, AND UNTREATED COFFEE TREES
(Centimeters)

Date	Defruited	Fertilized 2 times	Fertilized 5 times	Untreated
June 14, 1949	0.98	0.71	0.45	0.49
June 28	1.66*	1.01	0.99	0.64
July 12	2.04	1.23	1.19	0.74
July 26	1.72	0.77	0.78	0.59
Aug. 9	1.04	0.40	0.39	0.34
Aug. 24	0.76	0.30	0.34	0.35
Sept. 7	0.48	0.30	0.32	0.22
Sept. 21	0.70*	0.39	0.24	0.17
Oct. 5	0.74	0.26	0.16	0.16
Oct. 19	0.42	0.14	0.10	0.19
Nov. 1	0.19	0.10	0.05	0.05
Nov. 16	0.15	0.08	0.02	0.03
Dec. 14	0.02	0.17	0.00	0.07
Jan. 1, 1950	0.20	0.22	0.17	0.16
Jan. 15	0.37	0.40	0.38	0.55
Jan. 30	0.92	0.71	0.72	0.75
Feb. 15	0.95	0.72	0.63	0.63
Mar. 5	0.95	0.89	0.75	0.61
Mar. 15	1.26	1.23	0.71	0.84
Mar. 29	0.77	1.01	0.85	0.80
Apr. 18	0.40	0.54	0.48	0.49
Apr. 29	0.39	0.51	0.37	0.40
May 14	0.51	0.65	0.63	0.41
May 30	0.71	0.80	0.79	0.73
June 14	1.75*	1.45	1.45	1.33
June 30	2.03	1.59	1.59	1.28
July 14	0.88	0.84	0.75	0.68
Aug. 2	0.49	0.52	0.35	0.42
Aug. 17	0.86	0.64	0.47	0.61
Sept. 2	0.74	0.60	0.51	0.53

* Sig. diff. from untreated trees @ 5% at same date

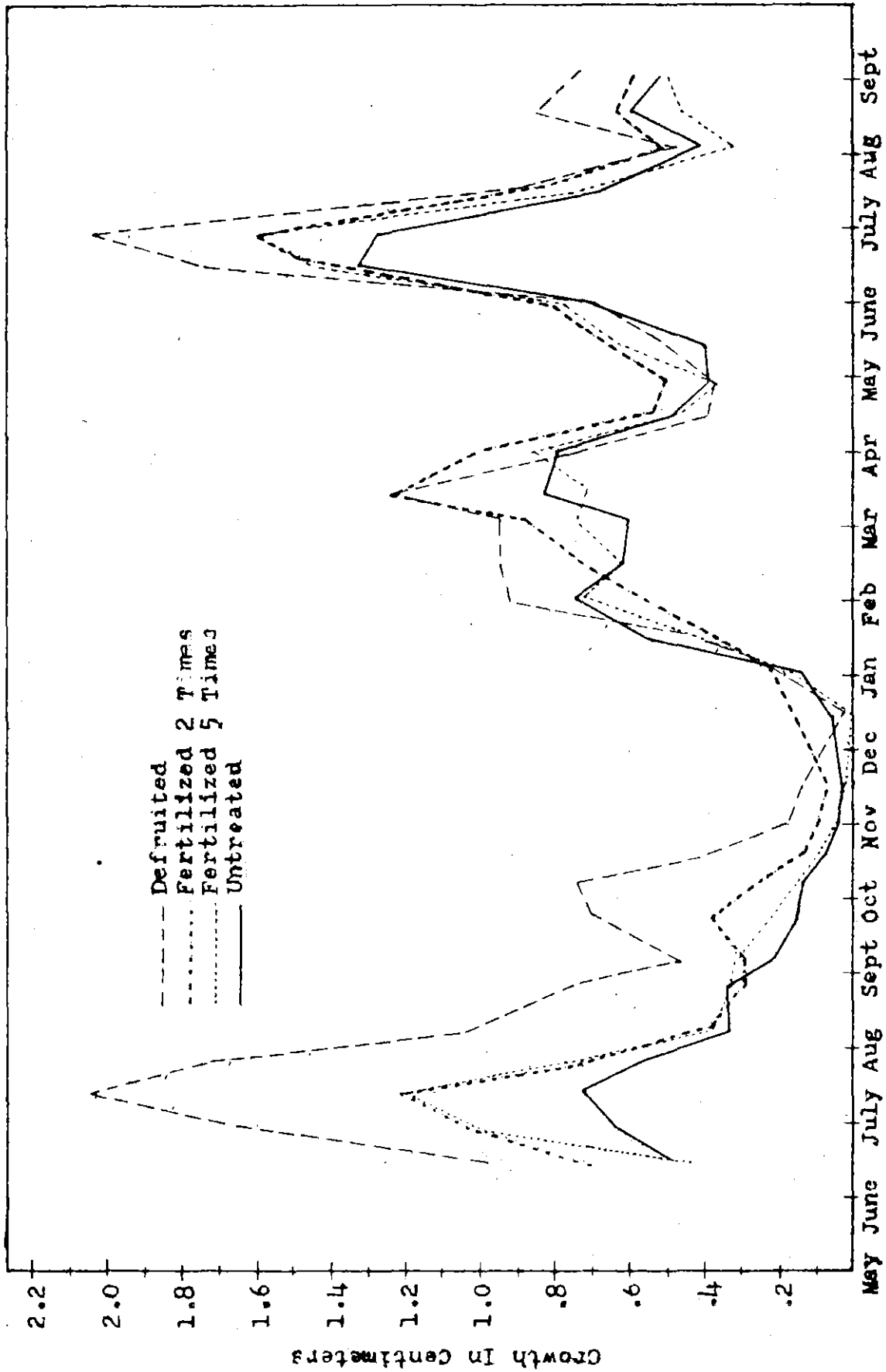


FIG. 2. AVERAGE TWO WEEK GROWTH OF DEFRUITED, NITRATE FERTILIZED, AND UNTREATED, MATURE COFFEE TREES (1949-1950)

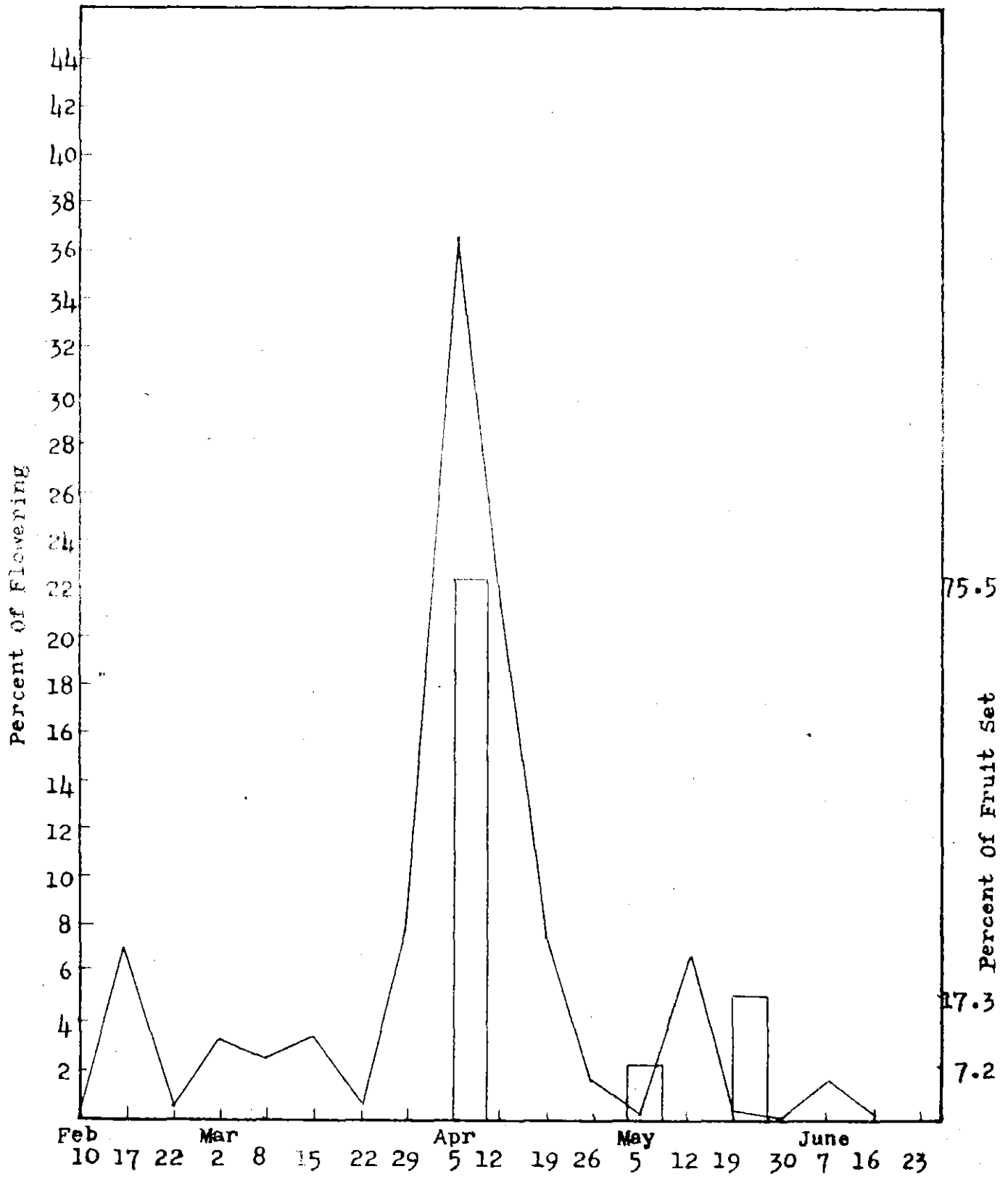


FIG. 3. WEEKLY FLOWERING OF 50 COFFEE TREES WITH BAR GRAPH OF FRUIT SET (1950)

Alcohol insoluble nitrogen

The annual insoluble nitrogen cycle closely follows that of the total nitrogen (Fig. 4). A significant increase occurred from December 27, 1949, to April 27, 1950, then fell steadily to July 31 (Table 4). The next month showed no change. There was then a rise to the second peak on October 31, 1950, followed by a drop the next month.

Alcohol soluble nitrogen

The soluble nitrogen in coffee leaves fluctuates considerably more than the other two nitrogen portions; nevertheless, it still evinces the bi-modal tendency (Fig. 4).

The analysis for the first date, November 10, 1949, showed the highest in soluble nitrogen during the 12 month period (Table 4). It then dropped the next month. On March 3, 1950, it was at the 12 month low. A significant increase occurred for the next 2 months, and remained high for a third like period, forming one of the peaks. The soluble nitrogen then dropped to another low the following date, July 1. It again increased significantly for 2 months and remained high for a third. This formed the second peak. A drop then occurred October 31, and remained unchanged to December 1, 1950.

Total nitrogen of bearing and defruited trees

Analyses from leaf samples taken November 3, 1950, from the defruited and untreated trees, showed no significant difference in total nitrogen (Table 5).

Table 4

SUMMARY OF DATA SHOWING MONTHLY TRENDS OF LEAF NITROGEN AND TOTAL ASH
(Nitrogen-parts per thousands: Ash-per cent)

Date	Alcohol insoluble nitrogen	Alcohol soluble nitrogen	Total nitrogen	Total ash
Nov. 10, 1949	18.4	7.1	25.5	---
Dec. 27	17.7	4.9	22.6	8.59
Jan. 29, 1950	18.4	5.3	23.7	6.90
Mar. 3	20.2	4.5	24.7	6.90
Mar. 29	21.2	5.9	27.1	7.42
Apr. 27	21.4	6.5	27.9	7.37
May 30	20.2	6.7	26.1	7.60
July 1	19.1	5.1	24.2	7.98
July 30	17.7	5.7	23.4	7.64
Aug. 31	17.6	6.9	24.4	7.92
Oct. 2	20.1	6.9	27.0	8.32
Oct. 31	22.1	5.2	27.4	9.01
Dec. 1	21.0	5.3	26.3	9.12

Min. sig. diff.

@ 1% =	1.5	0.69	1.7	0.51
@ 5% =	1.1	0.50	1.3	0.37

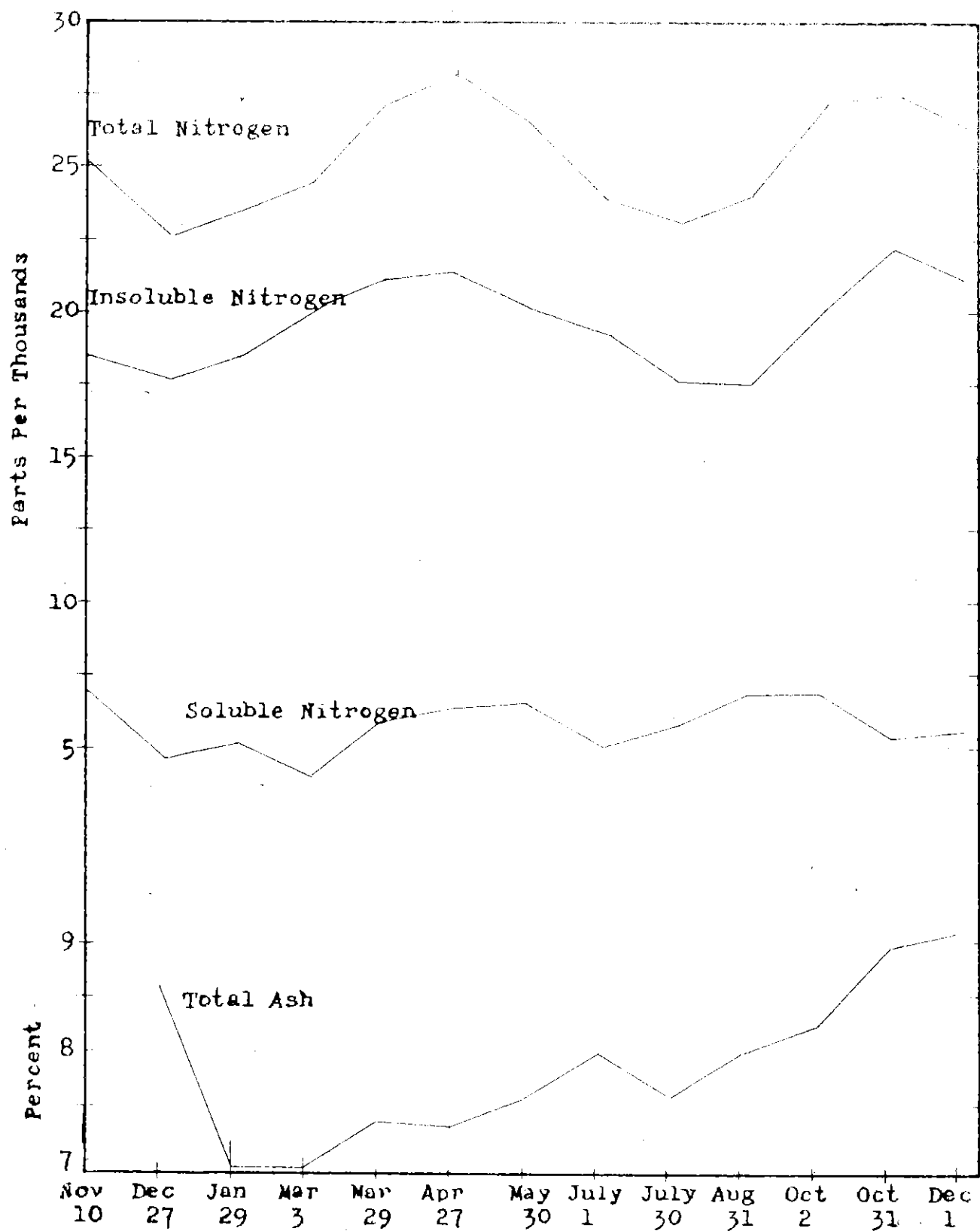


FIG 4. MONTHLY TRENDS IN TOTAL NITROGEN, ALCOHOL INSOLUBLE NITROGEN, ALCOHOL SOLUBLE NITROGEN, AND TOTAL ASH OF MATURE COFFEE LEAVES (1949-1950)

Table 5

TOTAL NITROGEN OF LEAF SAMPLES OF BEARING AND DEFRUITED
COFFEE TREES, SAMPLED NOVEMBER 3, 1950
(Parts per thousand)

Treatment	Replications			Ave.
	#1	#2	#3	
Defruited	30.538	29.326	29.032	29.632
Bearing	29.506	29.483	27.912	28.967

Min. sig. diff. @ 5% = 1.771

Total ash

The total ash content of the leaf, when presented in graph form, shows an asymmetrical curve skewed to the left. (Fig. 4). From a high on December 27, 1949, there occurred a sharp drop to the 12 month low on January 30, 1950. The next month showed no change, but a significant increase appeared the following period on March 29. After the succeeding month of April an almost steady increase was then evident until December 1, 1950, where it equaled the previous December high (Table 4).

Soil Determinations

Total nitrogen

The fluctuations in total nitrogen content of the soil, as evidenced by the 6 fixed positions, were very small over the 12 month period. This applies to both the surface and 16 inch levels (Fig. 5). In the surface level only the month of April showed a significant difference with 4 parts per thousand; the other 11 months averaged about 3.8 parts per thousand (Table 6).

The soils taken from the 16 inch level showed total nitrogen averaged about 2.1 parts per thousand for 9 months. The month of March showed a significant increase, however, to 2.8 parts per thousand. The next 2 significant deviations from the average occurred as decreases on August 3, and August 30. These values were 1.98 parts per thousand and 1.95 parts per thousand respectively.

Nitrate nitrogen

The nitrate content of the soil, as would be expected, showed marked variations in both the levels sampled. Fluctuation was greater, however, in

Table 6

SUMMARY OF DATA SHOWING MONTHLY FLUCTUATIONS IN TOTAL SOIL NITROGEN
(Parts per thousand)

Date	Average of six positions(1"-3")*	Average of six positions(16")**
Nov. 9, 1949	3.69	2.00
Dec. 27	3.86	2.04
Jan. 27, 1950	3.82	2.24
Feb. 28	3.88	2.33
Mar. 27	3.86	2.81
Apr. 27	4.19	2.18
May 31	3.82	2.19
July 1	3.84	2.26
Aug. 3	3.74	1.98
Aug. 30	3.76	1.95
Oct. 2	3.90	2.20
Oct. 31	3.90	2.15

*1"-3" min. sig. diff. @ 1% = 0.49: @ 5% = 0.37

**16" min. sig. diff. @ 1% = 0.31: @ 5% = 0.23

Table 7

SUMMARY OF DATA SHOWING MONTHLY FLUCTUATIONS IN SOIL NITRATE
(Parts per million)

Date	Average of six positions(1"-3")*	Average of six positions(16")**
Nov. 9, 1949	38.1	5.8
Dec. 27	22.8	8.9
Jan. 27, 1950	41.0	15.6
Feb. 28	31.8	17.3
Mar. 27	25.0	13.9
Apr. 27	63.0	29.0
May 31	28.8	17.3
July 1	25.5.	18.8
Aug. 3	28.7	10.1
Aug. 30	26.8	16.4
Oct. 2	26.2	20.4
Oct. 31	23.0	15.2

*1"-3" min. sig. diff. @ 1% = 13.01: @ 5% = 9.76

**16" min. sig. diff. @ 1% = 7.79: @ 5% = 5.84

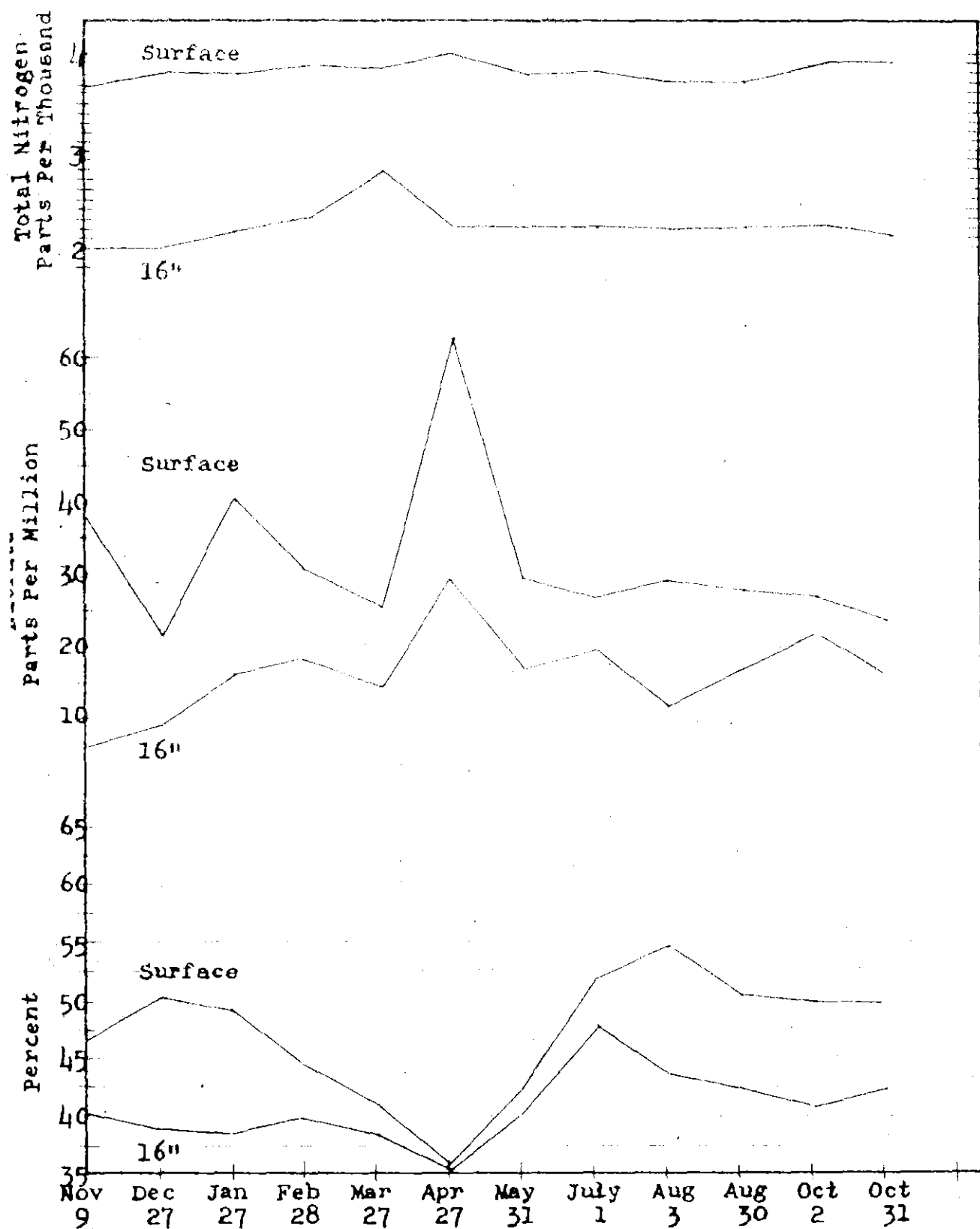


FIG. 5 MONTHLY VALUES OF TOTAL NITROGEN, NITRATE, AND MOISTURE AT TWO DIFFERENT LEVELS IN THE SOIL (1949-1950)

surface layer (Fig. 5).

Average nitrate content of the surface was 32 parts per million with a range of 23 parts per million in October to 63 parts per million in April (Table 7). Three peaks in the nitrate curve occurred; November 9, January 27, and April 27.

The first sampling on November 9, 1949, showed a high nitrate content of 38 parts per million. The second measurement period, December 27, showed a decrease to 23 parts per million. An increase occurred the next month to a second major peak of 41 parts per million. It then dropped to a low of 25 parts per million on March 27, 1950, but again increased the next month to the highest value, 63 parts per million. After this it dropped to a low and continued without any significant change for the next 5 months with an average of about 26 parts per million.

The more uniform 16 inch level showed only one high peak in nitrate content. This occurred on April 27, 1950, with 29 parts per million. The first significant difference in nitrate content of the 16 inch layer, occurred with an increase to 16 parts per million on January 27, from 9 parts per million the month before. No change occurred until the April high. The nitrate content then dropped the next month to 17 parts per million, remained the same for another like period, and decreased again, to 10 parts per million by August 3. It then increased to 16 parts per million by August 30, and remained about the same until the end of the experiment.

Moisture

The soil moisture in both levels showed a definite periodic fluctuation during the 12 month period of observations. (Fig 5).

Table 8

SUMMARY OF DATA SHOWING MONTHLY FLUCTUATIONS OF SOIL MOISTURE
(Per cent)

Date	Average of six positions(1"-3")*	Average of six positions(16")**
Nov. 9, 1949	47.2	40.3
Dec. 27	51.7	38.8
Jan. 27, 1950	48.2	38.5
Feb. 28	44.0	39.8
Mar. 27	41.3	38.3
Apr. 27	36.8	36.0
May 31	43.7	40.3
July 1	52.0	47.3
Aug. 3	54.2	43.0
Aug. 30	50.0	42.3
Oct. 2	49.7	41.2
Oct. 31	49.7	42.3

*1"-3" min. sig. diff. @ 1% = 9.35: @ 5% = 7.02

**16" min. sig. diff. @ 1% = 4.93: @ 5% = 3.70

The surface level had at all times a greater moisture content. It ranged from 37 per cent on April 27, to 54 per cent on August 3 (Table 8).

The first significant change in the surface moisture occurred as a drop from a high of 51 per cent on December 27, 1949, to 44 per cent on February 28, 1950. The moisture content then continued decreasing to April 27, for the 12 month low. It then began a steady increase for 3 months to the 12 month high on August 3. The next 3 months thereafter, ending with October 31, showed no significant change.

Soil moisture in the 16 inch layer remained without significant change for the first 5 months of observation from November 9, 1949, to March 27, 1950. with an average of 38 per cent. The 5th month, however, started a downward trend that ended on April 27, with the 12 month low of 36 per cent.

A steady increase occurred the next 2 months to the 12 month high of 47 per cent on July 1. A significant drop appeared the next month to 43 per cent and continued on without change to October 31, 1950.

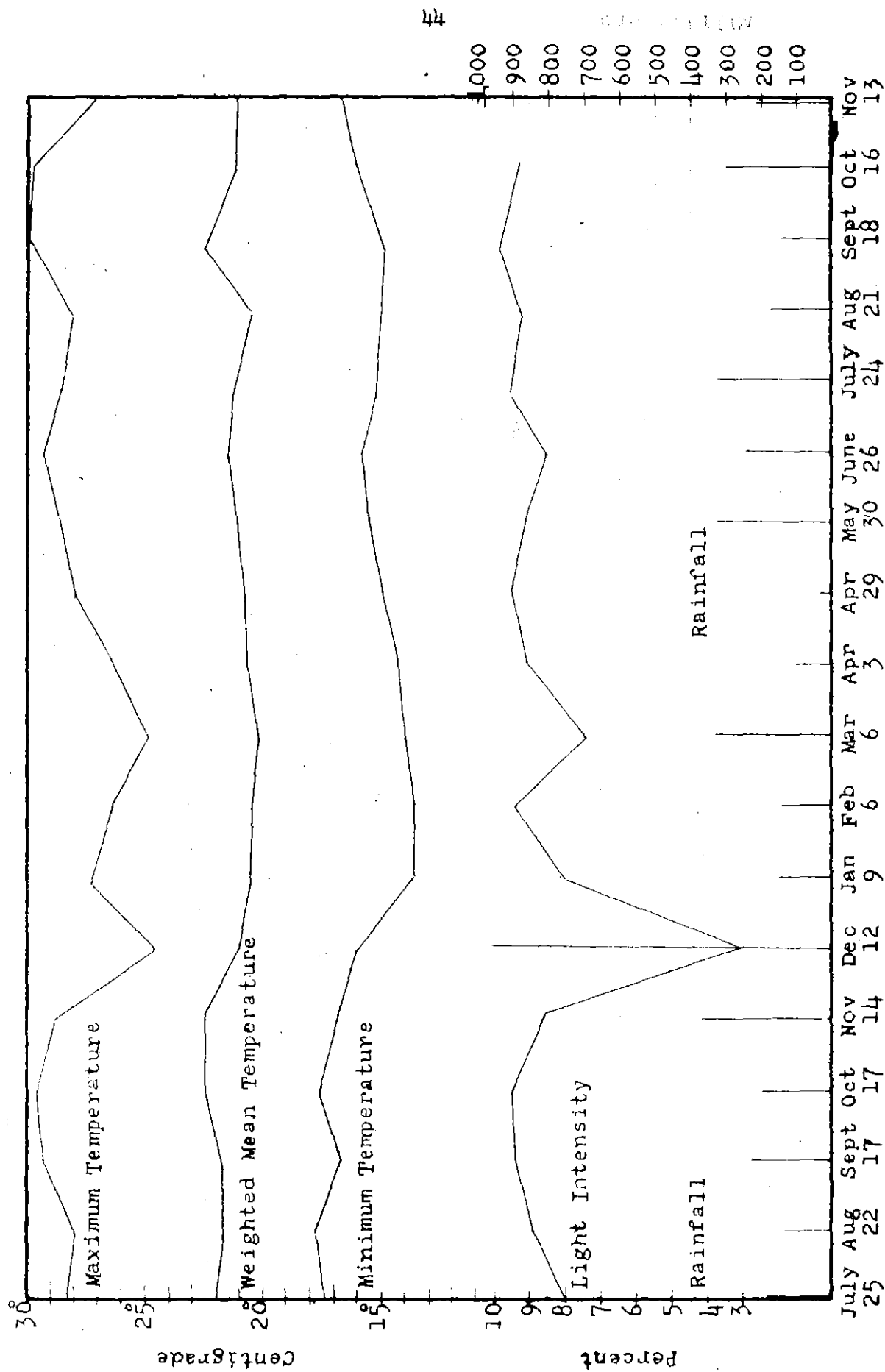


FIG. 6. CLIMATOLOGICAL DATA BY FOUR WEEK PERIODS (1949-1950)

DISCUSSION

Observations from July 1948 to December 1950 show two main periods in the growth cycle. One is the minimum growth period that covers 5 months from the middle of August to the middle of January. The other is the maximum growth period that occurs during the remaining 7 months.

In order to attempt explanation of this cycle, as many factors as deemed feasible were taken into account. These were of both external and internal types. External factors included those of climatic and edaphic phenomena. Internal factors included those as represented by observations of the reproductive cycle and foliar analyses for nitrogen fractions and total ash.

It is significant to note that during the 1949-1950 growth cycle; maximum amount of rainfall, high surface soil moisture, least light intensity, and lowest temperatures were coincident with minimum vegetative growth in the Turrialba region (Figs. 5 & 6). At this time the lowest amount of nitrate was found for 1 month in the surface soil and for 2 months in the 16 inch level. The onset of vegetative growth was coincident with a decrease in rainfall and surface soil moisture, an increase in light intensity, a slight increase in maximum temperatures, and an increase in the nitrate content of both levels of the soil.

McFarlane's data (50), however, showed that in the preceeding year, 1948, during the dormant season, the rainfall was quite different. Only 310 mm. fell during the months of November and December, as compared to 1,363 mm. during the months of November and December 1949. Also, during the period when vegetative growth was greatest, the rainfall was quite different between the 2 years. During the months of February and March 1949, 104 mm. of rain fell as compared to 455 mm. of rain the same months a year later. Another striking difference between the 2 years is that the maximum rainfall occurred in May.

1948, and in November and December 1949.

Light intensity for both years was almost opposite. Weather records showed the least amount of light during the months of November and December 1949, while in the preceeding year McFarlane's records showed that the most light occurred these 2 months and the following 4 months.

Though rainfall and light conditions were different for both years, temperatures were quite the same. The months from December through March showed the lowest temperatures for both years.

Considering these 2 sets of observations, the conflicting data of rainfall and light intensity for the 2 years seems to negate any supposed effect of these respective factors in controlling the vegetative growth cycle. It may also be stated here that observations for a 12 month period showed soil moisture was never a limiting factor, as represented by a minimum amount of 36 per cent.

The nitrate content of the soil, although fluctuating markedly, does not seem to present itself as a limiting factor at any time during the 12 month observation period. It was negatively correlated with the rainfall and is shown to be considerably leached by heavy rains in November and December. Nevertheless, at this lowest point in content the 16 inch layer showed from 5.8 to 8.9 parts per million, and the surface layer, where most of the feeder roots are concentrated, showed from 22.8 to 38.1 parts per million. This statement that nitrate does not appear to be a limiting factor is seemingly corroborated by the information of Russell (74). Also, the characteristic leaf yellowing of nitrogen starved plants have never been seen in the mature plantings (75,85).

The absence of significantly increased vegetative growth and unchanged growth cycle of the nitrate fertilized trees further substantiates the belief that fluctuations of nitrate content in the soil of this region does not control the growth cycle.

Experimental results showed that the total nitrogen of the soil may be disregarded in this respect. A significant increase in total nitrogen occurred at the end of April in the surface level, and at the end of March in the 16 inch level. Also a significant decrease occurred during the month of August in the 16 inch level. These deviations were only temporary as shown by the next month's observations, and exhibited no apparent bearing either upon the nitrate content or growth rate.

Temperature at first appears to be an important or at least a significant factor when compared with the growth cycle. Both dormant periods occurred during the months containing low temperatures. However, by looking at Figures 1 and 6, it will be seen that actually, the growth rate began to decrease at least 3 months before the advent of lower temperatures in 1949, and at least 5 months before the advent of lower temperatures in 1950. McFarlane (50) observed that even though the month of January 1949 had the lowest temperature, vegetative growth rate had already begun its upward swing at that time. This then, lends strength to the idea that the small temperature fluctuations as such, in the Turrialba region do not act as a controlling factor by suppressing growth (50).

The relation of temperature fluctuations and growth may be viewed from another aspect. Many plants require different periods of low temperatures during dormancy. This is quite well known in the case of temperate zone perennials (17,19,29,38).

Humphries (39) made studies in the tropics of the periodicity and intensity of Cacao flushing in Trinidad. He compared these data with different environmental conditions and concluded that flushing was positively correlated with maximum air temperatures. However, a critical examination of the data showed that the most intense flushing generally came after a period of low temperatures.

Where ever the growth of coffee has been reported upon, there is a general agreement that a definite active and dormant vegetative period exists. The dormant period occurs during the cooler part of the year. Towards, or at the end of this cool period, vegetative growth is initiated (1,20,25,36,53,89,90)

Initiation of growth may be delayed until the beginning of the rainy season, with apparently soil moisture acting as a limiting factor (54,70).

It seems, therefore, that this low temperature period should not be discounted as having a possible stimulatory effect upon the vegetative activity of coffee.

A study of all the available data (1,16,20,25,28,36,50,53,71,89,90) shows that flowering and vegetative growth generally fall within that part of the year containing an increasing day length. This is true both above and below the equator. Coffee growing very near the equator seems to exhibit periodic growth and bloom that varies in time from region to region (28,54,72,76,79,91).

The analysis of this phenomenon is complicated by the fact that the increase in day length in many regions is usually preceeded by minimum temperatures and accompanied by rains. It follows, therefore, that only until these other environmental factors are separated out by studies under controlled conditions, will it be possible to correctly determine the influence of day length change.

Some workers (50,71,81,91) have advanced the idea that fruit development may explain the decrease in vegetative growth of the coffee tree. Their opinion is that the developing fruit monopolizes the synthesized products to the detriment of the vegetative parts.

The present investigation has not given data which conforms with that view. Defruiting of trees during the 1950 season did not prevent the dormant period nor did it delay the approach of dormancy. The only significant

difference that occurred was a more rapid growth rate during the approach to and peak of vegetative activity.

Most fruit trees, as in the case of coffee, increase vegetative activity immediately before, during or immediately after blossoming and fruit setting. Dearborn (22), Murneek (62), Murneek and Wittwer (65), Wittwer (94), and others have found that there is an increase in activity in the vegetative portions of the plant at the time of sexual fertilization.

Growth measurements of young coffee trees that were too young to bear show that although these young plants did not function reproductively, they nevertheless underwent almost simultaneously the same vegetative cycle as the mature plants. The only difference that existed between the two growth rate curves was the more intense growth of the young trees. This might be explained by juvenility. It appears, therefore, that in the case of coffee the reproductive process has little or no apparent effect upon the vegetative cycle as a whole.

A great percentage of the nitrogen of a tree is located in the leaves (11,12,13), and as such, the periodic fluctuations of the element in these organs are deemed metabolically important. The fluctuation of total nitrogen in the coffee leaf closely follows that of the vegetative growth. Both rise and fall in general unison with the exception of the April slump in growth rate. The dates of increase and decrease of the two cycles were so close, that it is no possible in this study to determine exactly which manifested itself first, growth or total nitrogen. The alcohol insoluble or proteinaceous fraction (14) represents roughly 2/3 of the total amount and shows practically the same fluctuations.

The alcohol soluble or labile form also shows rhythmic fluctuations in relation to the growth curve. Comparisons between the two, however, are not as easily defined. Decrease in the labile nitrogen continues almost to the first

peak in growth rate, then increases while the growth rate takes its first drop. The nitrogen fraction then remains unchanged while the growth rate again increases. After this, both values drop together. The last and minor rise in the growth rate is preceded by a rise in soluble nitrogen. The two values then drop again together.

This information seems to indicate that the percentage of foliar nitrogen, especially the proteinaceous part, is closely and positively related with the growth cycle as a whole, and is not a negative result of the growth as inferred by Cameron and Appleman (12) in the case of the orange tree.

The insignificant difference between the nitrogen content of leaves of defruited and bearing trees at the time of harvest, tends to corroborate the opinion of Roelofson and Coolhaas (72) who could not find any definite effect of coffee fruit development on the leaf content of this element. This is in contrast with Herndlhofer (36), who claims that fruit development in coffee causes a decrease in leaf nitrogen.

The total ash, as represented by per cent of the dry weight, shows a trend entirely unlike any of the other factors studied. It seems connected with the overall periodic cycle of the plant. During dormancy of the plant, the content of ash is at its height. With the initiation of growth in the early part of January there occurs a sharp drop in this constituent to the lowest point of the year. An almost steady increase then occurs, culminating at the end of the next dormant period.

These data seem to indicate a rapid translocation of the minerals from the leaf to other portions of the plant, probably the meristematic regions. As the growth rate progresses in its downward and uneven course to dormancy, the mineral content of the leaf is gradually built up again.

CONCLUSIONS

The growth cycle of the coffee tree in the Turrialba region shows a definite period of vegetative activity and dormancy. The months of February, March and June show the most activity while the months of November and December show the least.

Environmental factors such as light intensity, rainfall, soil moisture, soil nitrate and total soil nitrogen do not seem to control the growth cycle by acting as limiting factors.

The only observed environmental factors that were correlated with growth are temperature and day-length. Both the dormant period and low temperatures occur together. The lower temperatures, however, are not considered as causing dormancy but as possibly breaking the rest period.

Photoperiodism cannot be overlooked. In different regions above the equator where observations have been made, the growth cycle shows that increased vegetative activity and blossoming occur on an increasing day length. Below the equator, where similar observations have been made, growth and blossoming also occur on an increasing day length.

Whether the growth cycle is controlled by either of these two environmental factors, an interplay of both, or some other common factor, cannot be immediately ascertained and must await more detailed study.

Dormancy is not caused by fruit development as formerly supposed in the case of coffee, nor does blossoming necessarily stimulate growth. The growth cycle of defruited and immature trees substantiate this fact.

The positive correlation between the amount of leaf nitrogen and growth rate seems to indicate that a very close relationship exists between the two, with the possibility of internal nitrogen acting as a controlling factor.

Total ash constituents of the leaf show an annual cyclical trend. The data indicates a negative relationship with growth.

SUMMARY

The possible effects of some external factors as light, temperatures, rainfall, soil moisture, and soil nitrogen, and some internal factors as effects of reproduction, foliar nitrogen and foliar ash, have been studied in an attempt to explain the periodic growth of coffee.

Only two environmental factors seem to be associated with the cycle; temperature and day length.

Low temperature does not seem to act as a limiting factor but is believed to act possibly as a stimulant to growth by breaking the rest period.

All data available indicate that coffee initiates growth and blossoming on an increasing day length, both above and below the equator.

The growth cycle is not noticeably affected by either phase of the reproductive cycle.

A positive correlation exists between the growth rate and internal nitrogen as represented by foliar analyses. Credence is given to an hypothesis that internal nitrogen may act as a controlling factor to growth.

SUMARIO

Con el objeto de tratar de explicar el crecimiento periódico del café se han efectuado estudios de los posibles efectos de algunos factores externos, como luz, temperatura, humedad y nitrógeno del suelo; y algunos factores internos, como efectos de reproducción, contenido de nitrógeno y ceniza en las hojas. Este ciclo parece estar asociado con dos factores ambientales solamente: temperatura y longitud del día.

Una temperatura baja no parece ser un factor limitante, pero se cree que posiblemente actúe como estimulante en el crecimiento por romper el período de descanso.

Las informaciones disponibles indican que el café inicia sus períodos de crecimiento y de florescencia en una longitud del día creciente, ambos sobre y bajo el ecuador. El ciclo de crecimiento no es afectado perceptiblemente por una u otra de las fases del ciclo reproductivo.

Existe una positiva correlación entre el grado de crecimiento y el nitrógeno interno, que se ha podido comprobar por análisis foliares. Se da crédito a una hipótesis de que el nitrógeno interno puede actuar como un factor determinante del crecimiento.

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