SOME FACTORS AFFECTING GROWTH AND YIELD OF COFFEE

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W. Lee McFarlane

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INTRODUCTION

Coffee, its cultivation and trade, is one of the most important sources of income for the governments and inhabitants of tropical America. The economy of nations, such as Brazil, El Salvador, Guatemala, Costa Rica and Nicaragua, is closely geared to this one commodity. In each of these countries, 40% or more of the exports from 1935 to 1938 was coffee. In one year (1937) 91% of the total exports of El Salvador was coffee. (1) As early as the 17th century, coffee was a commodity of considerable international importance.

Although coffee is an old and a very important business, comparatively little basic scientific research has been made on this commodity in tropical America until recently. When a comparison is made between the research undertaken on a temperate zone crop such as apples, a younger agricultural industry and important on a much smaller scale, and the research undertaken on coffee, the latter will be found sadly lacking both on amount of research and results of research. Coffee today is being grown in much the same way it was 25 years ago, not because this is necessarily the best way, but because there has been insufficient basic research to enable people to understand what the crop needs. Experiments are designed for different shades, but no studies are made on what effects the shade has on the coffee plant itself. This is not to imply that shade experiments are without value, but to emphasize the fact that more time should be devoted to basic studies on which future research may be built.

This paper is presented as a partial step in the direction of basic work on coffee. It is a discussion of the relationship of certain climatic factors, chiefly rainfall, to vegetative growth,* flowering, and yield of coffee.

The one year of study which is summarized in this paper is insufficient to reach any definite conclusions on the problem under consideration. The project should be continued for at least two years more to complete the study. It should be extended to include different climatic situations under which coffee is grown. The basic knowledge thus gained could be utilized in determining the suitability of areas to coffee growing in so far as climatic factors are concerned. Knowledge of the growth cycle can be utilized in determining the best time for fertilizer applications, and possibly it will also serve as a basis for better pruning practices. The use of sunshine meters in connection with the project could give information which would be valuable in shade pruning practices.

REVIEW OF LITERATURE

Growth studies have been made on many tree crops in temperate zone climates. Gossard (2) studied the growth rate of the pecan in relation to blossoming in 1933. He found a very strong relationship between growth and number of blossoms per shoot. Much work has been done on apples in this field. For example Hofmann (3) found a significant relationship between terminal growth and yield in York Imperial apples. Overholser (4) in 1938, made some correlation tests of trunk circumference increase and length of terminal growth with yield of apples. In the citrus crop, Randhawa (5) found a correlation between growth and flowering.

In 1939, Dean (6) reported that the blossoming season of coffee in Hawaii was in the early spring, each tree having two or more distinct periods of flowering, depending supposedly, upon meteorological conditions.

* The term "growth" will be encountered many times in this paper. Unless otherwise specified, this will mean vegetative growth, as measured by elongation of lateral branches.

The maximum growth of laterals occurred for six weeks to two months simultaneously with and following the flowering. This is wood which will blossom and bear fruit the following year. Thus the coffee tree is preparing for the next years crop at the same time that it sets and develops the current years fruit. Dean also found that in Hawaii rainfall occurring during the year in which new fruiting wood is being produced is significantly related to the succeeding years yield of coffee. In other words the rainfall that is related to the seasonal fluctuations in coffee yield does not occur in the year of blossoming, maturing and harvesting of the cherries. When rainfall was divided into three periods (February to June, June to October and October to February) it was found that only rainfall occurring between February and June of the preceding season is significantly related to the annual yield.

Hacquart (7) working on coffee in Belgian Congo stated that the rhythm of flowering and fruiting is directly related to the rainfall peaks; flowering occurs at the end of each rainy period, and the crop ripens 10-11 months later.

Mayne (8) made a study on seasonal growth of coffee in South India. He divided the climate into 4 seasons, and gave the coffee activity in each season. His first season is the cool, dry season, which covered harvest and post harvest rest period, when growth was at a minimum. The second was a period of hot weather with some rain, during which the coffee flowers. With these first rains, a rapid vegetative development takes place and the greater part of the annual shoot growth is initiated. An initial rapid growth falls off with time, ceasing earlier in years of heavy crops. During rapid vegetative growth, development of fruit is slow. The third season is that of the southwest monsoon at the beginning of which the vegetative growth slackens, while fruit development accelerates and continues to the end of this period. Vegetative growth is almost at a standstill for two months during this period, but commences again towards the end. The fourth season is the northeast monsoon, with a continuation of vegetative growth during the first two months of the period. About one month after the start of this period, one finds the first indication of axillary bud differentiation becoming visible on the preceding hot weather shoot growth. Mayne summarized his work by stating that the amount of crop will be influenced by the kind and amount of vegetative growth made in the preceding season and the number of flower buds formed at each potentially productive node. Weather conditions of the crop year as they affect blossoming and fruit setting will play a part.

Rayner (9) states that in coffee in Kenya there is a hot, dry and sunny period during January and February when growth is at a minimum. It is believed that soil moisture is the limiting factor to growth, since watering trees at this time will give maximum growth, once recovery from the previous crop has occurred. The main period of rapid vegetative growth commences with the long rains and the greatest part of the annual growth is made at this time. The long rains are followed by a cold, cloudy, dry period, when growth is extremely slow. From watered trees it is suggested that leaching, especially of soil nitrates may have been responsible for this decrease in growth. Observations of watered trees bearing a fair crop in 1943 showed a gradually decreasing growth with time as the crop matured, when temperature and radiation effects were removed statistically.

It would seem likely, since at the time of the June-July minimum growth rainfall is very high, that leaching of soil nitrates may be the cause of this period of minimum growth in India as it may also be in Kenya following good, long rains.

In Guatemala, Cowgill (10) found that the time of greatest growth coincides with the time of formation and greater development of the fruit. This was a preliminary report of a project which is being continued.

About eight months after this project was initiated at Turrialba, it was discovered that Reeves and Vilanova (11) were doing similar work in El Salvador. They found that the growth period there commences in January, more than 3 months before the initiation of the rains. In both 1947 and 1948, the maximum velocity of growth occurred during the month of May and the first part of June and diminished rapidly coinciding with the time of the maximum fall of rain. This is in contrast to the situation in India and Kenya where growth was only appreciable during the rainy season, with the more rapid growth in the first part of the season. In El Salvador, there are periods in which the increase in rainfall coincides with a decrease in growth, and a decrease in rainfall coincides with an increase in growth. On the contrary, the gradual decrease of growth from August to December is evidently correlated with the decrease in the fall of rain, but the diminishing of the rainfall may not have been the cause of retarding the growth. Growth is rapid in the middle of February until the first strong rainfall in April or later, which is also the period of flowering of the coffee. They believe that relative humidity which reaches 100% at night may have an effect on growth of coffee in El Salvador.

In a supplementary observation of effects of cover, Reeves and Vilanova also found that a layer of destroyed leguminous vegetative matter had considerable effect on growth of coffee tree laterals. The trees which received such a cover had 46% greater growth in the period of less rain and 10% greater growth in the period of greater rains than the trees which did not receive such a cover. This could be a result of better supply of nitrogen, better soil moisture, or a combination of the two factors.

MATERIALS AND METHODS

This work is divided into three phases; 1. Observations which have been made on a selected number of trees during the past year; 2. Effects of rainfall on yield over a period of years; 3. A supplement to phase one, which was started in May 1949 to check on certain hypotheses which had been formulated. This phase involves defructification, and application of nitrate fertilizers.

(a) Phase One

The first phase of the problem relates chiefly to effects of rainfall on growth, during a period in which the coffee was kept under close observation. This phase has now been carried on for one year, with some good results, but it will be necessary to continue these observations over a longer period of time to obtain the maximum results.

In organizing this study, fifty trees were selected from a ½ hectare area of coffee. A drainage ditch ran through the field, dividing the selected trees into two plots of twenty-five trees each. Trees were selected on a basis of uniformity of size, age and general appearance. Beaumont (12) in Hawaii found that terminal growth is an accurate index of the potential crop of the following year when younger unpruned trees are used, but it does not apply to older trees which have undergone a certain amount of renewal pruning. He also found that terminal growth and lateral growth are closely correlated. Lateral growth measurements were used here to determine growth rates.

Six branches on each tree were selected to check weekly growth rate, blossoming, set of fruit and amount of fruit matured. Selected branches were distributed over the trees as follows; 1. two lateral branches from the lower portion of the tree, 2. two lateral branches from the higher uprights and 3. two lateral branches from the bent-over uprights. This gives a total of 150 branches measured in each plot, or 300 branches total.

Weekly measurements were made on each branch to determine the growth rate.* It was believed at the beginning of the study that measurement of the final internode would give the total measurable growth. This was found to be true except during periods of rapid growth, at which time there would be one-half to one centimeter of elongation in the next to last internode. Since there was no appreciable elongation elsewhere in the branch, only the last internode or when necessary the last two internodes were measured. Measurements were taken to the closest half centimeter.

* See sample work sheet for weekly measurements of tree No.6, plot A., page 36.

(b) Phase Two

Yield data were collected from 18 different fincas. The data included all available yield figures from 1928 to 1948, a 21 year period. It was intended to study the yearly variations in yield, to determine if there was a correlation between yields and rainfall. When all available rainfall records were collected, it was found that most records were of no value for this study for one or more of the following reasons; records covered an insufficient period of time, records lacked one or two months rainfall every second or third year, and where there were complete rainfall records, there were no yield data available, with the exception of the Turrialba area where yield data from 7 fincas were correlated with rainfall.

(c) Phase Three

After the main study had been underway for nine months, certain hypotheses were formulated and a supplementary study devised to test these hypotheses. Since this study was started only three months ago, there are no real results to date. However there are some interesting developments to be reported.

This project consists of four treatments of 15 trees, each treatment being divided into three plots. Treatments are as follows; A. check plots, B. defructification plots, C. and D. fertilization plots, C. receiving a single heavy application of nitrate fertiliser, and D. receiving the same amount of fertiliser, but in three applications at two month intervals. Branches were selected for measurement on these trees as in phase one.

NOTE: The coffee under observation in phase one, was in an estate under regular management. Cultural practices of coffee common to this area used. This included shoveling for control of weeds, pruning of both temporary and permanent shades, and pruning of the coffee trees.

Control of weeds was accomplished by shoveling in Mid-August, 1948, and in late April 1949. The banana shade was pruned in Mid-October, and again in late June, while the permanent shade trees received a single severe pruning the last of December and the first of January. The coffee trees were pruned at the same time as the permanent shade trees.

EXPERIMENTAL RESULTS

An examination of figure No.1*will demonstrate that there is a pronounced growth cycle in coffee. Measurements were started at the time that the growth rate was falling, about the middle of July, 1948. This coincides with the time of fruit maturation, and is also a time of heavier rains. The growth rate falls rapidly from July to the first of September. There were some fluctuations in growth noted from September to the middle of January, but during the entire period growth was slow. The period of slowest growth was reached about the first of November at which time growth was nearly nil. Of the 274 branches measured the week of November 1st, only 9 branches showed any growth, and the total elongation for the one week period was only six centimeters.

There was an upward tendency in the growth curve starting the first week in January which increased rapidly after the 15th of January. During the week ending January 31st, elongation was 10½ times the elongation of the week ending January 4th. The growth curve continued to increase, but at a slower rate until a peak was reached March 7th. The growth curve started decreasing after this date and continued dropping steadily until April 25th, when a low point was reached that was still above the average growth

* See also table No.1, page 37.

line. A sharp upward movement of growth curve was then incurred which reached the highest peak of the entire cycle on May 30th. Immediately after this peak, there was a very sharp drop in the curve, almost equalling the sharp rise in January. In July there seems to be a tendency for the growth rate to level off again, well below the average weekly growth of the entire year.

It may thus be seen that coffee trees measured had two distinct periods of growth; 1. a period of below average growth, which started the first of August in 1948, and the middle of June in 1949, and 2. a period of above average growth, starting the last of January in 1949 and lasting until the middle of June, 1949. The latter period is the more irregular of the two, having two high peaks, separated by a low point that is above the average growth line.

DISCUSSION

A full explanation of the growth phenomena in coffee cannot be made at this time because of inadequate information. It is believed that different factors are affecting the growth cycle at different times of the year. Some possible factors are; rainfall, soil moisture, leaching of nitrates, (both connected with rainfall), sunshine, temperature, blossoming, and setting and maturing of fruit.

The hypothesis is advanced that the latter mentioned factor, setting and maturing of fruit, is foremost in dividing growth into two distinct periods. In figure 1, bar grafts of estimated fruit set have been superimposed upon the chart of the growth cycle. It appears possible that the accumulation of fruit set might be the cause of the drop in the growth curve after the peak of May 30th. This peak coincides with the time of the second highest percentage of fruit set. (26% of total fruit set). The highest peak (30%) occurred four weeks earlier. Following this hypothesis, maturation of fruit continues to keep growth at a minimum until the end of the harvest period. The weeks in which growth was lowest, was also the time of maximum harvest. There is a slow tendency for increased growth after this time, but the steep rise in growth curve does not occur until two weeks after the last harvest date.

It thus appears that the factor of setting and maturation of fruit could be the major reason that the growth cycle in coffee has a period of rapid growth, lasting approximately six months, and another period of six months when growth is at a minimum. At the present time, proof of this hypothesis is not available; however the supplement which has been underway for three months now should tend to demonstrate the connection between development of fruit and vegetative growth.

The factor supposedly affecting growth that was given the most attention is rainfall. The one year during which this problem has been studied here is insufficient to reach a definite conclusion about the effect of rainfall on growth. The project should be continued so comparisons can be made between changes in rainfall of two or three years and the way these changes seem to affect growth in the different years. However simple correlations have been run between rainfall of the past year with the growth during the same period, with these preliminary results.

1. Four weeks rain was correlated with growth of the following four weeks, "r" is - .218 with 10 d.f.* Not significant.

* For 10 d.f. the 5% level of significance is .576 and the 1% level of significance is .708.

See note on statistical methods, page 35.

These figures indicate that there was no significant correlations between rainfall and growth for data considered in this fashion. Examination of figures 1 and 2 would seem to indicate that there is some correlation. The time during which growth was below average is the period when rainfall was usually above average, and the period during which growth is above average is a dry period. The final drop in growth curve starting June 1st, 1949 comes after three weeks of heavy rain. This indicates that there probably is a negative correlation, which is borne out by the fact that the above correlation is negative, though not significant.

Leaching of soil nitrates has been reported as a possible cause of the period of low growth in Kenya and also in India. Reeves (9) and Vilanova (11) suggest that a study of the nitrogen cycle might aid in reaching an answer to this question. The work completed here in Turrialba seems to confirm the opinion that leaching of nitrates is an important factor. It is during the period of high rainfall, when leaching would be most serious, that growth is at a minimum. It is after three weeks of heavy rain in May, presenting ideal conditions for leaching of soil nitrates, that the growth cycle drops sharply.

In regard to temperature, Mayne (8) in South India states that towards the end of the cool, dry season, around March 1st, with a temperature rise, vegetative growth commences even though no rain has fallen. An examination of figure 3 and 4 will indicate that this is not true of the Turrialba area in Costa Rica. Temperature variation is not great, mean monthly maximum temperature ranging from 78.6° to 84.9°, and mean minimum monthly temperature from 58.1° to 64.5°. January 1949 was the month in which both mean monthly maximum and minimum temperatures were lowest. If temperature does have an effect on growth in this area, then it has the opposite effect from that reported by Mayne. With such a small variation, it does not appear likely that there is much of a temperature effect on growth in coffee.

Attention so far has been directed at the chief two periods of growth, one above and the other below average. No attempt has been made to explain the dip in the growth curve that occurs in the middle of the period of rapid growth. Two factors, soil moisture and solar radiation intensity may play an important part at this period in the growth curve. There are no exact data on either of these factors, but estimates of number of cloudy days and of cloudy days plus half-cloudy days are given in figure 5. The estimate indicates that from November to April, days are brighter than in the other months. Examination of figure 2 shows a good rain the week of January 3rd. This combination of bright days and sufficient soil moisture results in an increased growth rate. There is very little rain for the next three months. Within seven weeks, the soil moisture becomes low and in spite of continued bright days, growth rate decreases. In the week of April 11th there is a fair rainfall, and two weeks later growth becomes more rapid again. The increase continues upward until the first of June when there is an abrupt dropping of the growth rate. This drop is preceded by three weeks of very heavy rain.

Meyer and Anderson (13) state that prolonged periods of internal "drought" in plants are most frequently brought about by an inadequate soil water supply. The growth of plants therefore usually shows a close correlation with the soil water supply. An inadequate soil water supply may check the growth of a plant more at certain stages in its development than others. In many species vegetative growth is more likely to be retarded by soil water deficiency than the development of reproductive organs.

In phase two, correlations between yield and rainfall, no correlations were attempted between yield and rainfall unless complete rainfall records were taken within three miles of the finca reporting yields. Therefore most of the yield data collected had to be discarded. However the data from three of these fincas in the Meseta Central of Costa Rica are presented in figure 6 to show that yearly yield variations are similar in the Meseta Central and in the Turrialba area.

Seven years yield data of 6 fincas in the Turrialba area are given in figure 7,* and 21 years yield data are given for the seventh finca in this area in figure 8.* Correlations were made between these yield figures and the rainfall shown in figure 9, the rainfall records having been taken at a central point of these 7 fincas.

Simple correlation problems were run between rainfall and the yield of the following year, also between rainfall and the yield of the same year for all 7 fincas. In addition with the finca reporting yields over a 21 year period, correlations were run between yield and the rainfall from January to June of each year, and from July to December of each year, both sets of correlations being run between rainfall and yield of the following year, and rainfall with yield of the same year. The following correlations were obtained;

* See also tables 2 and 3, pages 38 and 39.

Finca Number	"r" of rain with yield of following year	"r" of rain with yield of same year	d.f.	Value at 5%	Value at 1%
1	-.575	-.089	5	.754	.874
2	-.096	-.107	5		
3	-.423	+.183	5		
4	-.733	+.039	5		
5	-.472	+.220	5		
6	-.826	+.386	5		
total value	-.494	+.142	40	.304	.393
7	-.210	+.052	19	.433	.549
7 (with rain from Jan. to June)	-.214	+.143	19		
7 (with rain from July to December)	-.312	-.145	19		

It will be noted that all correlations between rainfall and yield of the following year are negative, though the correlation is significant for only one finca. Although the correlations were seldom significant, the consistent negative correlations between rainfall and yield of the following year would seem to indicate that there is a definite relationship existing here. Correlations of rainfall with yield of the same year range from -.107 to +.386, none of which approach the 5% level of significance. The varied nature of these correlations would tend to indicate that no relationship exists between rainfall and yield of the same year.

In setting up the supplementary study, reference is made to Murneek (14) in his study of the correlation between vegetative development and fruiting in the tomato plant. When tomato plants were deflorated or the fruits were removed as rapidly as they set, the plants continued to grow vegetatively. If, however, the fruits were allowed to remain on the plant and enlarge, vegetative development and the production of flowers gradually slowed down as more and more fruits began to develop.

The checking effect of the enlargement of fruits upon continued vegetative development and the development of flowers resulted, according to Murneek, from the virtually complete monopolization of the nitrogen in the plants by the fruits. In general, the more nitrogenous compounds available, the more fruits that set and started to develop before inhibition of flowering and vegetative growth began. Removal of the fruits at any time before the vegetative parts died resulted in a renewal of vegetative growth, and ultimately, in another cycle of reproductive development. Pearsall (15) stated that development of flowers often has a checking effect on vegetative growth, while at a later stage in the life history of the same plant, fruiting may inhibit both further flowering and vegetative growth.

The data of the supplementary study of defrustification and nitrogen fertilization are still too incomplete to analyze. However, examination of figure 10* will indicate that some results are being obtained. In the five measurements taken over a ten week period, the check plots have shown a minor rise and fall, in growth rate. The plots receiving a single heavy application of nitrogen had a steadily increasing growth rate for 6 weeks, reaching a point nearly double that of the check plots. In the next four weeks the growth rate fell until it was nearly the same as the check plots. The growth rate of plots receiving lighter applications of fertilizer increased slower than that of plots receiving heavier applications, but in a four-week period, the growth rate was the same. The defructification plots showed a very rapid rise in growth rate, in 6 weeks time it was triple that of the check plots. However, the growth rate started dropping and in four weeks it dropped almost as much as it rose. At the time of the last measurement, it was slightly more than double the check plots.

This data could be interpreted thus; at the beginning of the study, nitrogen was a limiting factor to growth; therefore when nitrogen was applied, growth increased.

* See also table No.4, page 40.

The larger application of nitrogen took effect faster than the smaller application. After a short period, nitrogen leached out and growth rates settled back to the same level as in the check plots. The defructification plots indicate that maturation of fruit is indeed a chief reason that the coffee tree goes into a partially dormant vegetative state during time of maturation of fruit. However, there is a big question -- the growth curves of these three plots are simply exaggerations of the growth curve of the check plots. All curves are rising the first six weeks, and falling the next four weeks.

Meyer and Anderson (13) have stated that although environmental factors may influence the length of time required for completion of the grand period of growth, or in extreme cases may cause complete cessation of growth thus causing interruptions in the cycle, usually the general trend of the grand curve of growth is immutable, indicating that it is primarily controlled by internal factors. This does not mean that the magnitude of the growth in a given plant may not vary greatly in accordance with prevailing environmental conditions, but simply that the relative rate of growth at any time during the growth period normally bears a definite relation to the relative growth increment which has already occurred and which may be expected to occur subsequently. There may be a clue in this statement explaining the above growth phenomenon.

It should be remembered that all explanations advanced in this paper are hypotheses, there being insufficient data for proving or disproving any of these explanations at the present time.

SUMMARY

This study has covered the growth cycle of coffee over a one year period. It was found that sometime during the beginning of the rainy season (mid-July in 1948, first of June in 1949), the growth curve drops rapidly. The two outstanding possible causes of this are; 1. rainfall leaching nitrogen from the soil and 2. maturation of fruit requiring more food material than is available for both vegetative growth and fruit development. Both of these possibilities are tied up with plant nutrition, and it appears possible that these two factors combined are the reason coffee goes into a more-or-less vegetative dormant stage for approximately six months.

In January, with clear days, all the fruit harvested, and possibly with the influence of good rainfall the last week in December and the first week in January, the growth curve starts up slowly at first, and increases rapidly for two weeks. For the next 1½ months, there is a steady increase of growth rate. Rainfall was very light during this period. Then around the first part of March a decline of the curve starts, which continues until late April. Two weeks before the decline ceases and another upward trend begins, there was a week

in which the rainfall was up to the yearly average level, and the week after the decline ceased, there was another week of fairly heavy rain. This decline could be interpreted as being caused by the fact that soil moisture became too low in March for optimum growth. The rain in mid-April and early May again presented soil moisture conditions ideal for growth. Therefore the growth curve increased until the last of May, then setting and maturation of fruit and/or leaching of soil nitrates by the three weeks of heavy rainfall in the latter part of May, causes a rapid fall of the growth curve, completing the yearly cycle.

Yield data were collected from different fincas for a period of 21 years, and where applicable were correlated with rainfall. It was found that there existed a constant negative correlation between rainfall and the yield of the following year, which was significant in some cases and close to significance in others. The correlations were always negative. When correlations were made between rainfall and yield of the same year, results varied from negative to positive correlations, none of which approached the 5% level of significance. This indicates that there is a negative correlation between rainfall and the yield of the following year, and no correlation between rainfall and yield of the same year. It is believed that the correlation in the former is a result of effect of rainfall on growth.

A supplementary study of the effects of nitrogen fertilizers and defructification has been under way only a short time now. So far it has neither proven or disproven any of the explanations which have been advanced to explain the growth phenomena characteristic of coffee. It has shown that maturation of fruit and/or leaching of nitrates is probably the cause of the drop of the growth curve at the beginning of the rainy season. However, there are portions of this supplement which cannot be explained too readily by either of these two factors. More data will be needed before this study can be analyzed properly.

It should be emphasized that all explanations of growth curves advanced in this paper are hypotheses, based on observations over a one year period, and that more data taken in the next two years will be required to affirm or reject these hypotheses.

R E S U M E N

Este estudio ha cubierto el ciclo de crecimiento del café en un período de un año. Se encontró que al iniciarse el período de lluvias (segunda quincena de Julio 1948 a primera quincena de Junio de 1949) la curva de crecimiento disminuye rápidamente. Las dos posibles causas sobresalientes de esto son: 1) lixiviación del nitrógeno de la tierra causada por la lluvia y 2) maduración del fruto que requiere más material alimenticio del disponible para crecimiento vegetativo y para el desarrollo del fruto. Ambas posibilidades están ligadas con la nutrición de la planta y parece posible que estos dos factores combinados sean la razón de que el café llegue a un estado vegetativo más o menos latente por un período de seis meses aproximadamente.

En Enero, cuando hay días claros y terminada la cosecha totalmente y posiblemente bajo la influencia de una buena lluvia en la última semana de diciembre y la primera semana de enero, la curva de crecimiento comienza a subir lentamente al principio, y aumenta rápidamente en dos semanas. En el mes y medio siguiente, hay un aumento firme en crecimiento. Durante este período las lluvias fueron muy leves. Alrededor de la primera quincena de marzo comenzó a declinar

la curva, que continua en la misma tendencia hasta fines de abril. Dos semanas antes de cesar el descenso y que la tendencia a subir se inicie hubo una semana en la cual la lluvia alcanzó el promedio anual, y la semana después de que el descenso terminó hubo otra semana de lluvias bastante fuerte. Este descenso podría ser interpretado como debido al hecho de que la humedad del suelo llegó a ser demasiado baja en marzo para un crecimiento óptimo. La lluvia a mediados de abril y principios de mayo otra vez ofreció condiciones de humedad del suelo ideales para el crecimiento, por lo tanto, la curva de crecimiento sube hasta fines de mayo, cuando la formación y la maduración del fruto y/o la lixiviación de los nitratos del suelo durante las tres semanas de lluvias fuertes de fines de mayo, o ambos factores a la vez, causan una rápida caída en la curva de crecimiento, completando el ciclo anual.

Se colectó información en rendimientos de diferentes fincas por un período de 21 años, y cuando fué posible se correlacionaron con la precipitación. Se encontró que existía una correlación negativa constante entre las lluvias y el rendimiento del año siguiente, la cual era significativa en algunos casos y en otros se aproximaba a serlo. Las correlaciones fueron siempre negativas. Cuando se hicieron co -

relaciones entre lluvia y rendimiento del mismo año, los resultados variaron de correlaciones negativas a positivas, ninguna alcanzó al nivel del 5%. Esto indica que existe una correlación negativa entre las lluvias y el rendimiento del siguiente año, y no hay correlación entre lluvias y rendi - miento en el mismo año. Se cree que la correlación en el primero, es resultado del efecto de las lluvias en el crecimiento.

Recientemente se ha iniciado un estudio suplementario del efecto de fertilizantes nitrogenados y caída de los frutos. Hasta ahora no se ha encontrado una prueba definitiva que compruebe o no las explicaciones dadas arriba para explicar los fenómenos de crecimiento característicos del café. Ha mostrado que la madurez del fruto o la lixiviación del nitrato o ambos factores son la causa probable del descenso de la curva de crecimiento al comienzo de la estación lluviosa. Sinembargo, hay partes de este estudio suplementario que no pueden ser explicadas muy facilmente por uno u otro de los dos factores. Se necesita más información antes de que este estudio pueda ser analizado con propiedad.

Debe hacerse notar que todas las explicaciones de las curvas de crecimiento que se han dado en este estudio son hipótesis, basadas en observaciones sobre un período de un

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The statistics used in this paper was simple correlations, between rainfall and growth and between rainfall and yield, employing the formula;

$$r = \frac{SX_1 X_2}{\sqrt{(SX_1^2)(SX_2^2)}}$$

This formula was taken from Chapter 7 of <u>Statistical Methods</u> by George W. Snedecor, Ames, Iowa, the Collegiate Press, 1946.

PLOT A PLANT NUMBER 6

Branch	a	b	c	d	e	f
DATE: July 12, 1948 old	71.5	80.0	0	0	6.5	17.5
new	24.0	51.0	51.0	30.0	15.5	12.5
flush	0.5	0.5	5.5	7.5	4.5	1.5
July 19	0.5	0.5	1.0	1.0	2.0	0
26	0.5	0.5	0.5	1.0	2.0	0
Aug. 3	0.5	0.5	0.5	0	1.5	0
9	0	0	0.5	0.5	0	0
16	0	0	0.5	1.0	0	0
23	0	0	0.5	0	0	0
30	0	0	0.5	0.5	0	0
Sept. 6	0	0	0.5	0	0	0
13	0	0	0	0	0	0
21	0	0	0.5	0	0	0
27	0	0	0.5	0	0	0
Oct. 4	0	0	0	0	0	0
11	0	0	0	0	0	0
18	0	0	0	0	0	0
25	0	0	0	0	0	0
Nov. 1	0	0	0	0	0	0
8	0	0	0	0	0	0
15	0	0	0	0	0	0
22	0	0	0	0	0	0
29	0	0	0	0	0	0
Dec. 6	0	0	0	0	Branch destroyed	0
13	0	0	0	0.5		0
20	0	0	0.5	0		0
27	0	0	0.5	0.5		Branch pruned by mistake
1949 Jan. 4	0	0	0.5	0	branches replaced	
Jan. 10	0	0	1.0	0.5	33.0-11.5	23-5.50

TABLE No.1. GROWTH*, AS EXPRESSED IN TERMINAL ELONGATION OF LATERAL BRANCHES, OF COFFEE IN THE TURRIALBA AREA.

Date	Growth	Date	Growth	Date	Growth
1948					
July 19	.72	Nov. 15	.04	March 14	.81
26	.44	22	.06	21	.81
Aug. 2	.43	29	.07	28	.75
9	.31	Dec. 6	.08	Apl. 4	.63
16	.21	13	.09	11	.61
23	.15	20	.09	18	.54
30	.13	27	.06	25	.49
Sept. 6	.09	1949 Jan. 3	.06	May 2	.56
13	.09	10	.10	9	.70
20	.10	17	.11	16	.78
27	.10	24	.25	23	.84
Oct. 4	.11	31	.62	30	.92
11	.11	Feb. 7	.62	June 6	.81
18	.08	14	.72	13	.47
25	.04	21	.74	20	.37
Nov. 1	.03	28	.79	27	.23
8	.02	Mar. 7	.87		

* Arithmetical mean or average terminal elongation or growth of all branches measured. This included results obtained from a total of 50 trees, measuring selected branches from 3 portions of each tree

** See also figure No.1

TABLE No. 2. SEVEN YEARS RAINFALL IN INCHES AND YIELD IN FANEGAS[*] PER MANZANA OF 6 FINCAS IN THE TURRIALBA AREA

	1939	1940	1941	1942	1943	1944	1945	1946	Correlation between rainfall and yield; of the same year	of the following year
RAINFALL	91	69	102	88	105	146	83	96		
FINCA No.										
1		12.4	22.2	17.4	21.1	11.3	14.2	18.4	-.089[*]	-.575[*]
2		11.2	17.2	18.1	14.6	12.9	16.3	19.7	-.107	-.096
3		8.7	17.2	15.5	15.1	15.0	10.8	33.0	+.183	-.423
4		14.4	21.9	21.7	16.5	13.4	7.2	13.8	+.039	-.733
5		8.6	18.2	26.2	13.9	15.8	6.9	22.0	+.220	-.472
6		14.1	20.8	17.2	20.6	17.5	11.1	22.1	+.386	-.826

* One fanega is the equivalent of 200 liters

** For 5 d.f. the 5% level of significance is .754 and the 1% level of significance is .874

See also figure No. 7

TABLE NO. 3. TEWENTY-ONE YEARS RAINFALL IN INCHES AND YIELD OF COFFEE IN FANEGAS* PER MANZANA OF A FINCA IN THE TURRIALBA AREA.

YEAR	RAINFALL	YIELD	YEAR	RAINFALL	YIELD
1927	130		1938	109	21.2
1928	138	11.3	1939	91	19.5
1929	86	12.7	1940	69	14.1
1930	89	5.9	1941	102	20.8
1931	88	9.2	1942	88	17.2
1932	101	12.2	1943	105	20.6
1933	90	9.5	1944	146	17.5
1934	83	13.4	1945	83	11.1
1935	90	9.0	1946	96	22.1
1936	68	25.5	1947	64	16.5
1937	76	11.4	1948	88	15.5

* A fanega is the equivalent of 200 liters.

** See also figure No. 8

TABLE NO. 4. MEAN GROWTH OF COFFEE GROWTH UNDER 4 DIFFERENT TREATMENTS. PRELIMINARY RESULTS OF A STILL INCOMPLETED EXPERIMENT DTUDYING EFFECTS OF DEFRUCTIFICATION AND OF ADDITION OF NITRATE FERTILIZERS ON GROWTH TO EXPLAIN THE VARIATION NOTED IN THE YEARLY GROWTH CURVE.#

	UNTREATED PLOTS				DEFRUCTIFICATION PLOTS			
Date	Plot 1	Plot 2	Plot 3	Mean for treatment	Plot 1	Plot 2	Plot 3	Mean for treatment
June 14	.25	.41	.82	.49	1.13	1.15	.65	.98
28	.35	.61	.93	.64	1.63	1.72	1.62	1.66
July 12	.52	1.13	.57	.74	2.22	1.90	2.02	2.04
26	.48	.78	.50	.59	2.06	1.57	1.52	1.72
Aug. 9	.22	.58	.22	.34	1.42	1.12	.62	1.04

	PLOTS RECEIVING HEAVY FERTILIZATION				PLOTS RECEIVING LIGHT FERTILIZATION			
Date	Plot 1	Plot 2	Plot 3	Mean for treatment	Plot 1	Plot 2	Plot 3	Mean for treatment
June 14	.85	.57	.71	.71	.40	.32	.66	.45
28	1.46	.62	.95	1.01	.93	1.26	.79	.99
July 12	1.72	.85	1.10	1.23	.95	1.48	1.13	1.19
26	.84	.90	.57	.77	.70	.70	.95	.78
Aug. 9	.40	.58	.22	.40	.52	.20	.48	.39

#See also Fig. 10

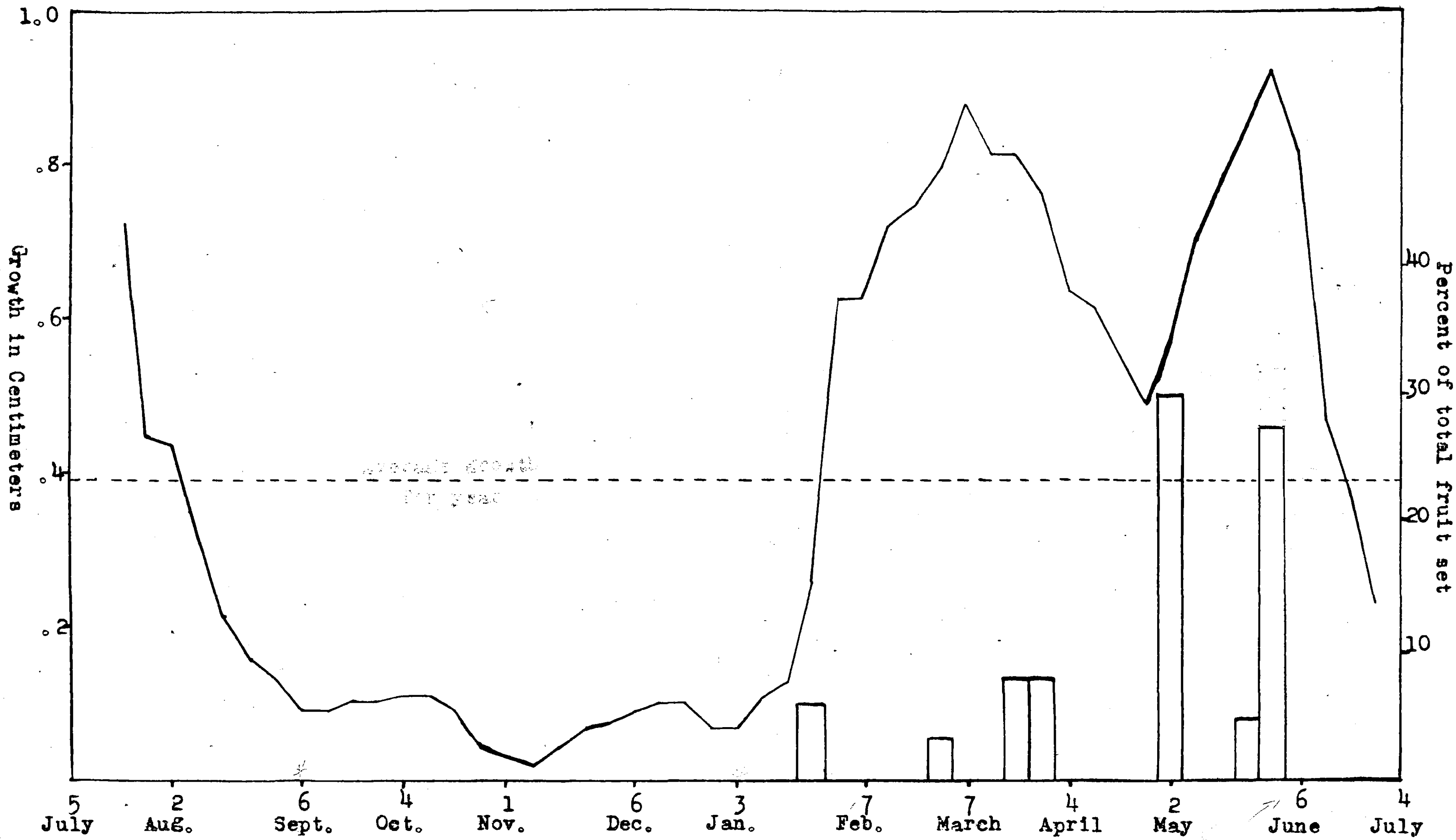

Fig. 1. Average weekly growth of lateral branches, with bar grafts of percent of total fruit set by date.

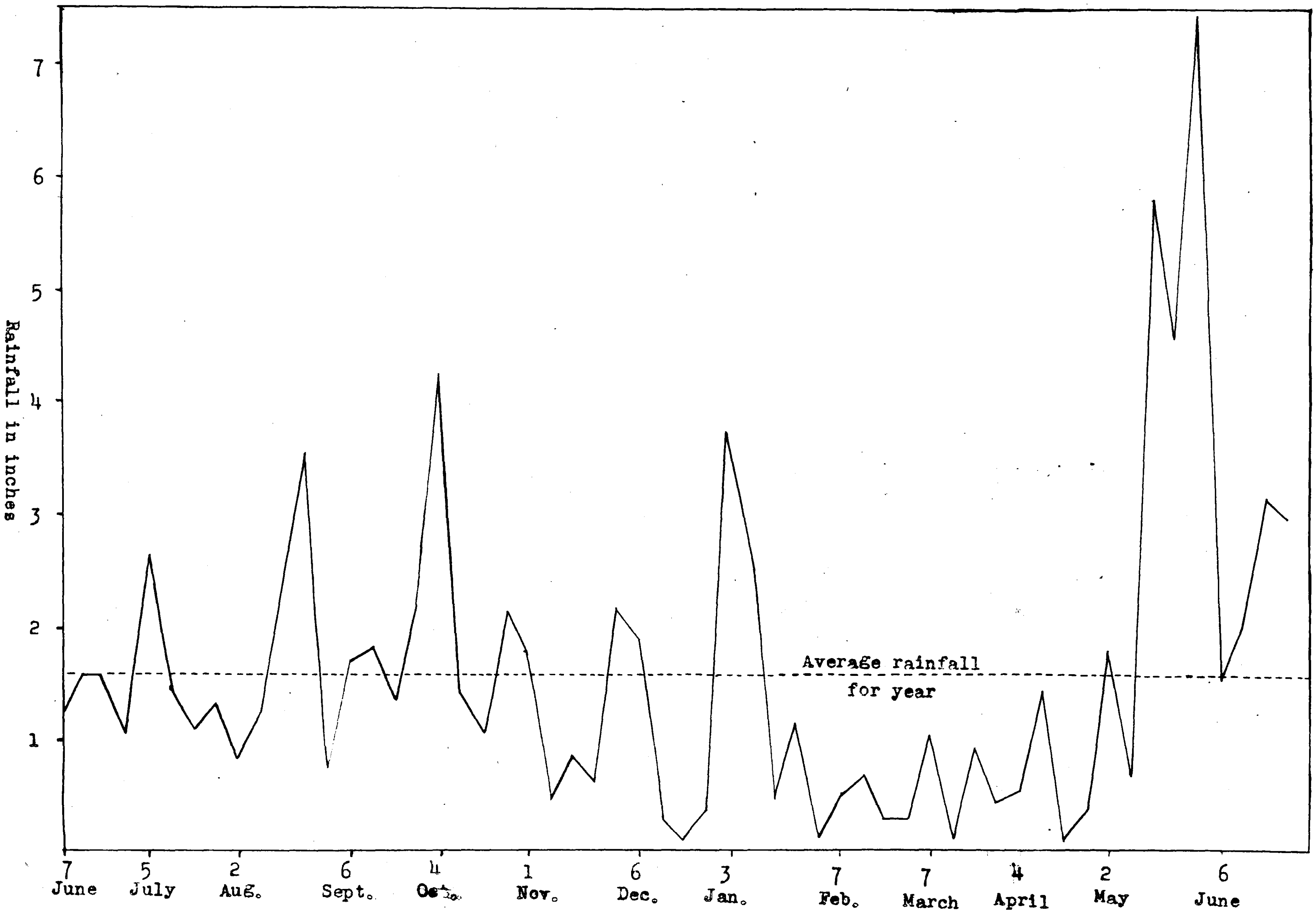

Fig. 2. Weekly rainfall Turrialba, June 7, 1948 to June 27, 1949

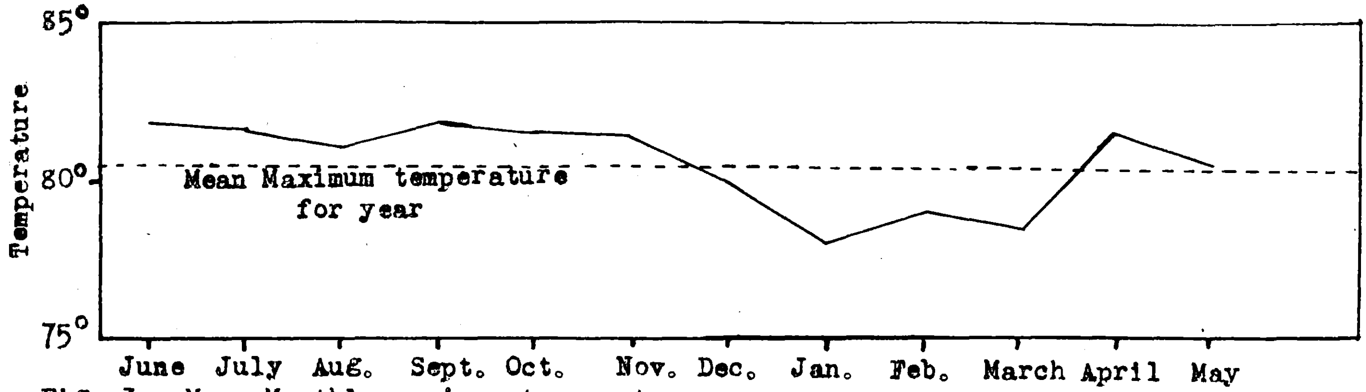

Fig. 3. Mean Monthly maximum temperature.

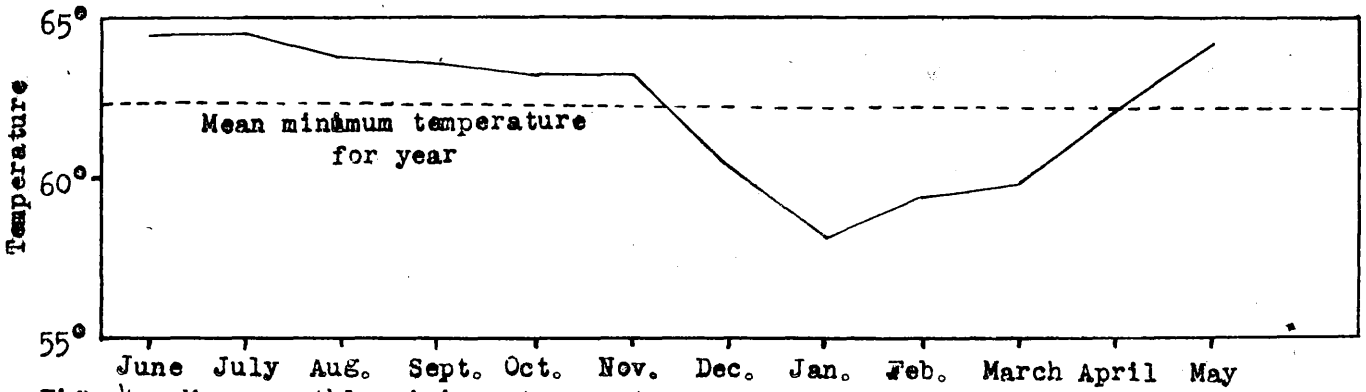

Fig. 4. Mean monthly minimum temperature.

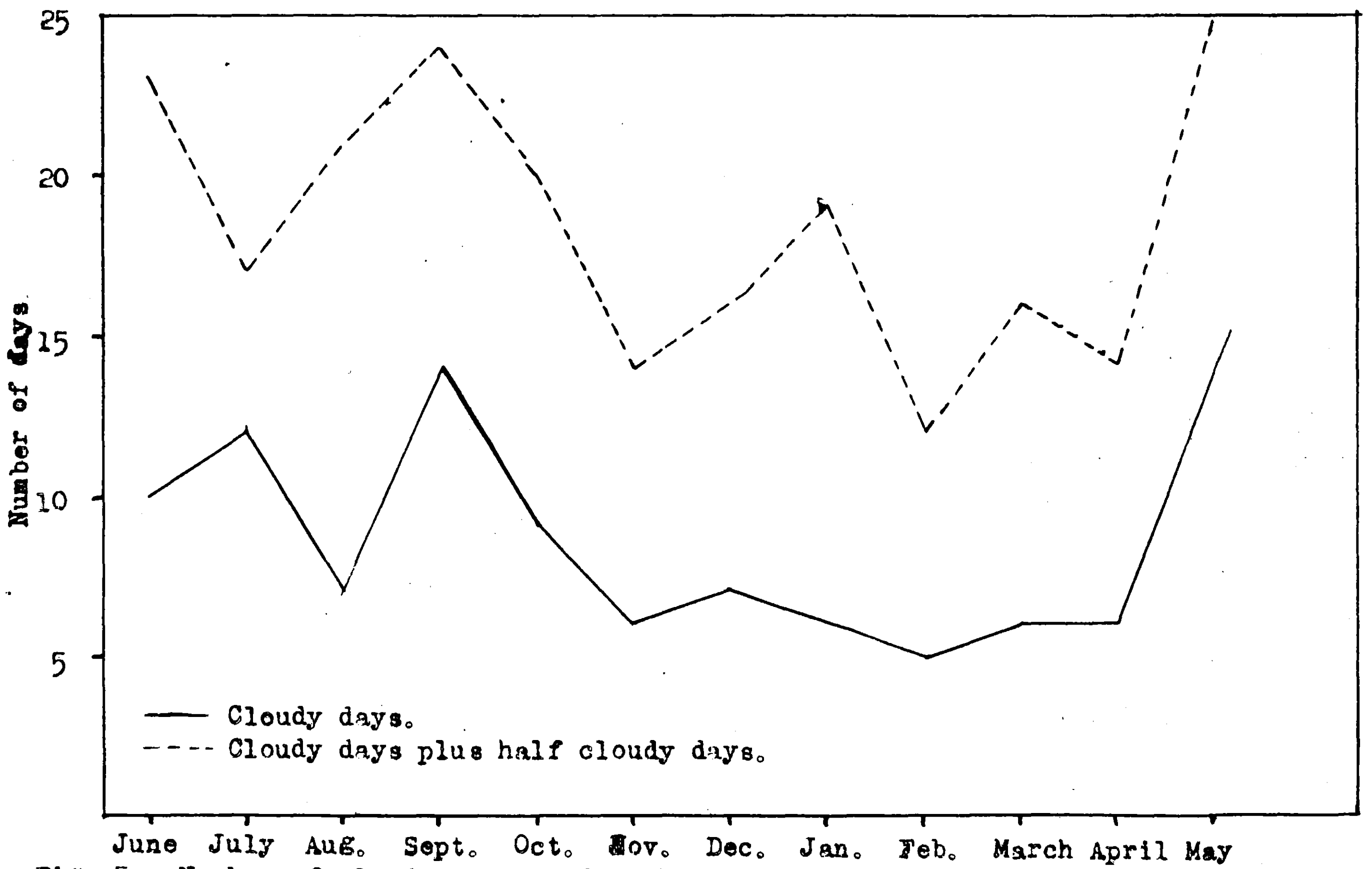

Fig. 5. Number of cloudy days, and number of cloudy plus half-cloudy days.

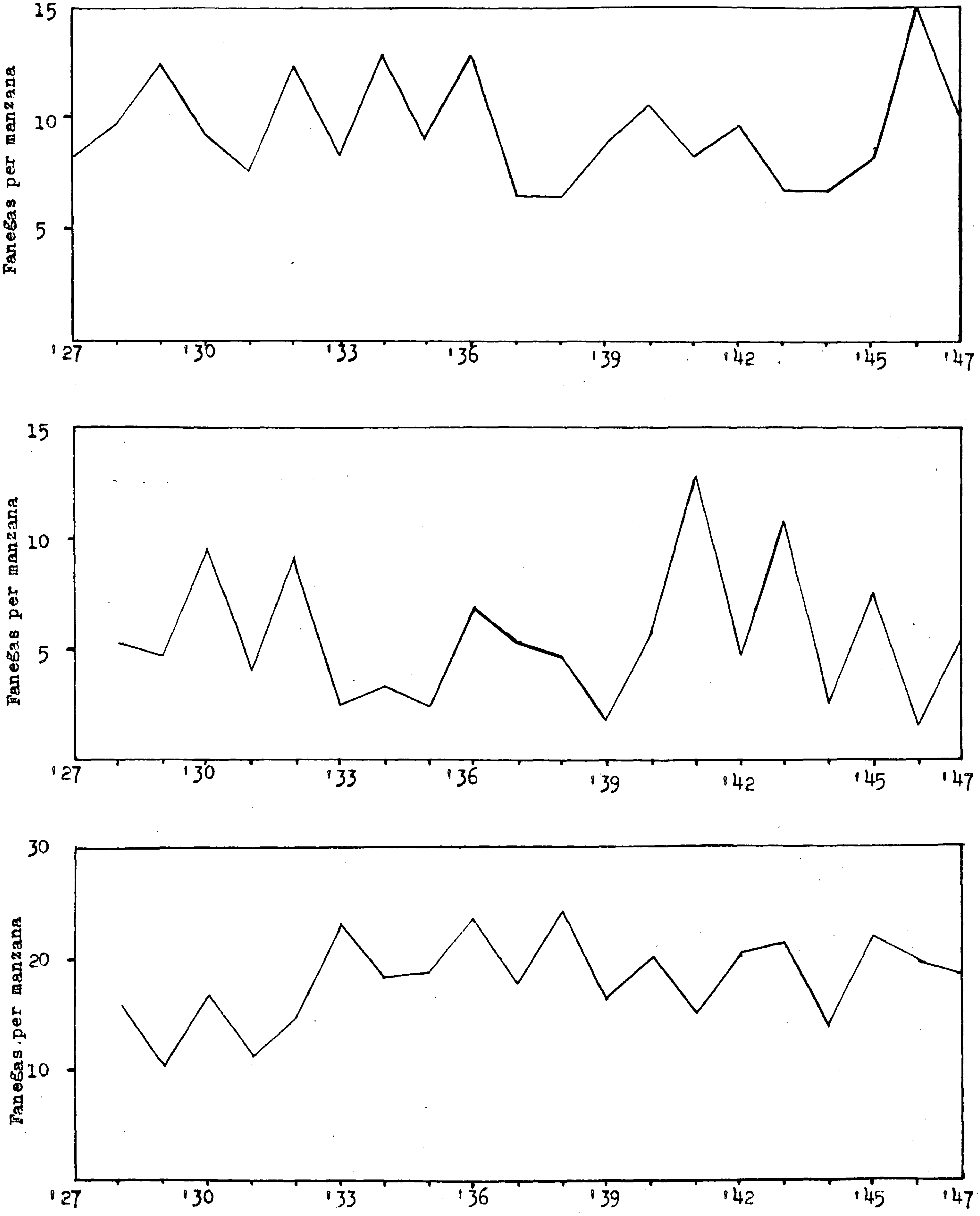

Fig. 6. Yield in fanegas per manzana, for 3 fincas in the Meseta Central of Costa Rica, 20 year period.

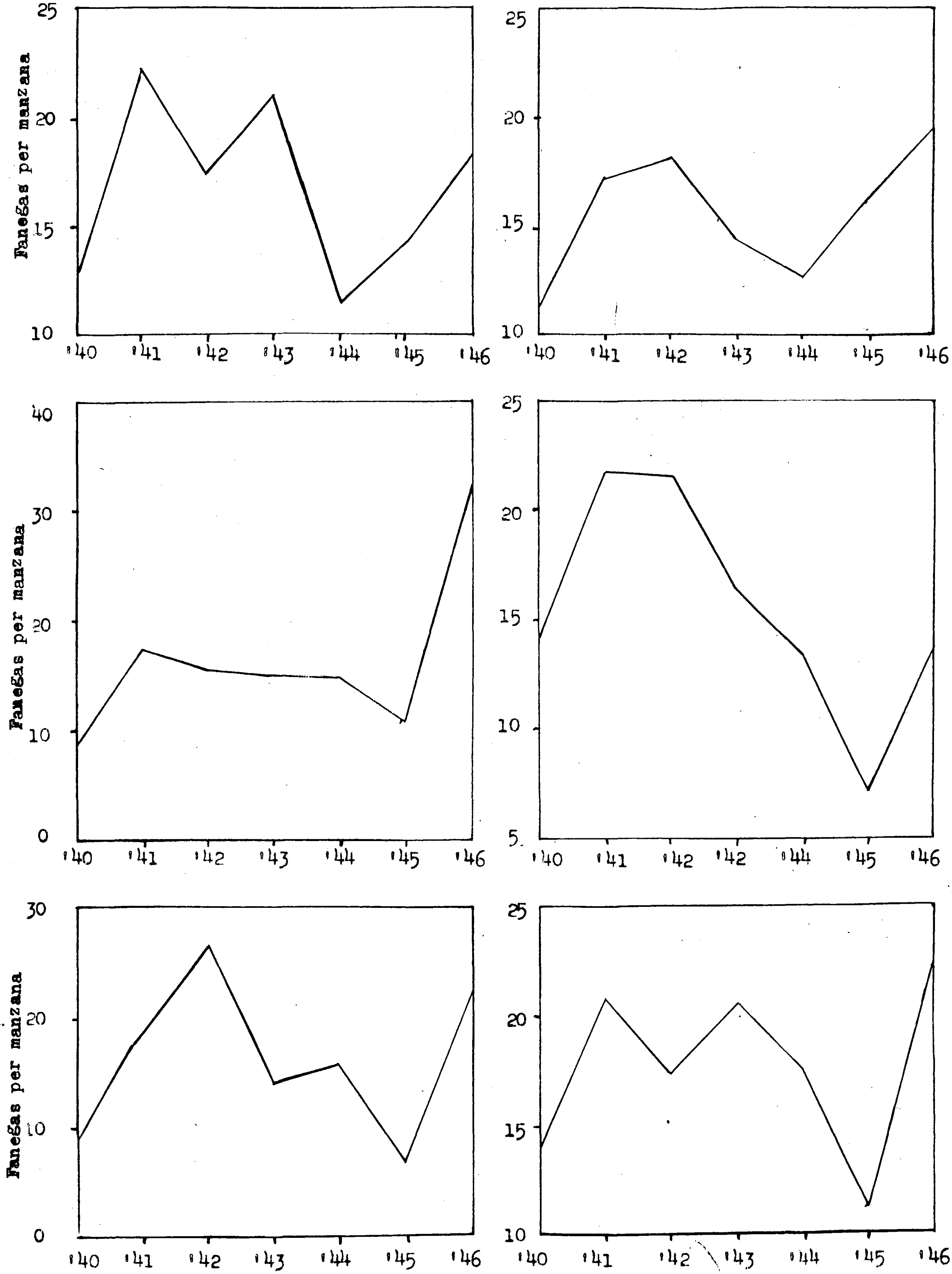

Fig. 7. Yield in fanegas per manzana, 6 fincas in Turrialba Area, 7 year period.

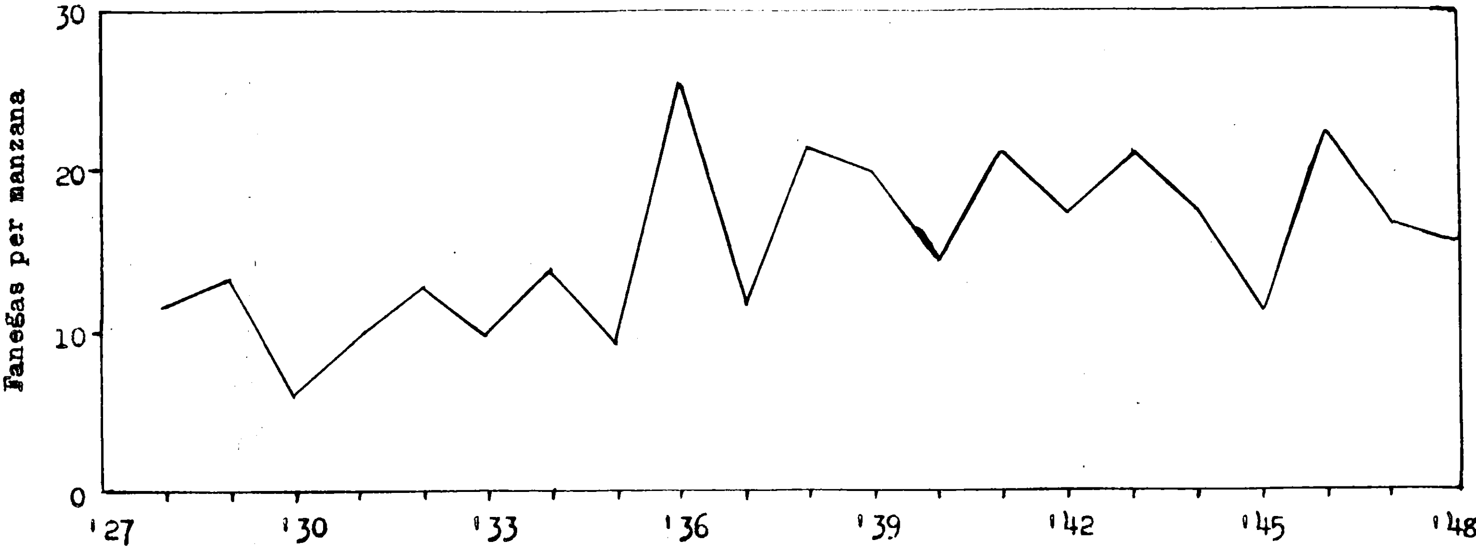

Fig. 8. 21 years yield in fanegas per manzana of finca #7, Turrialba Area.

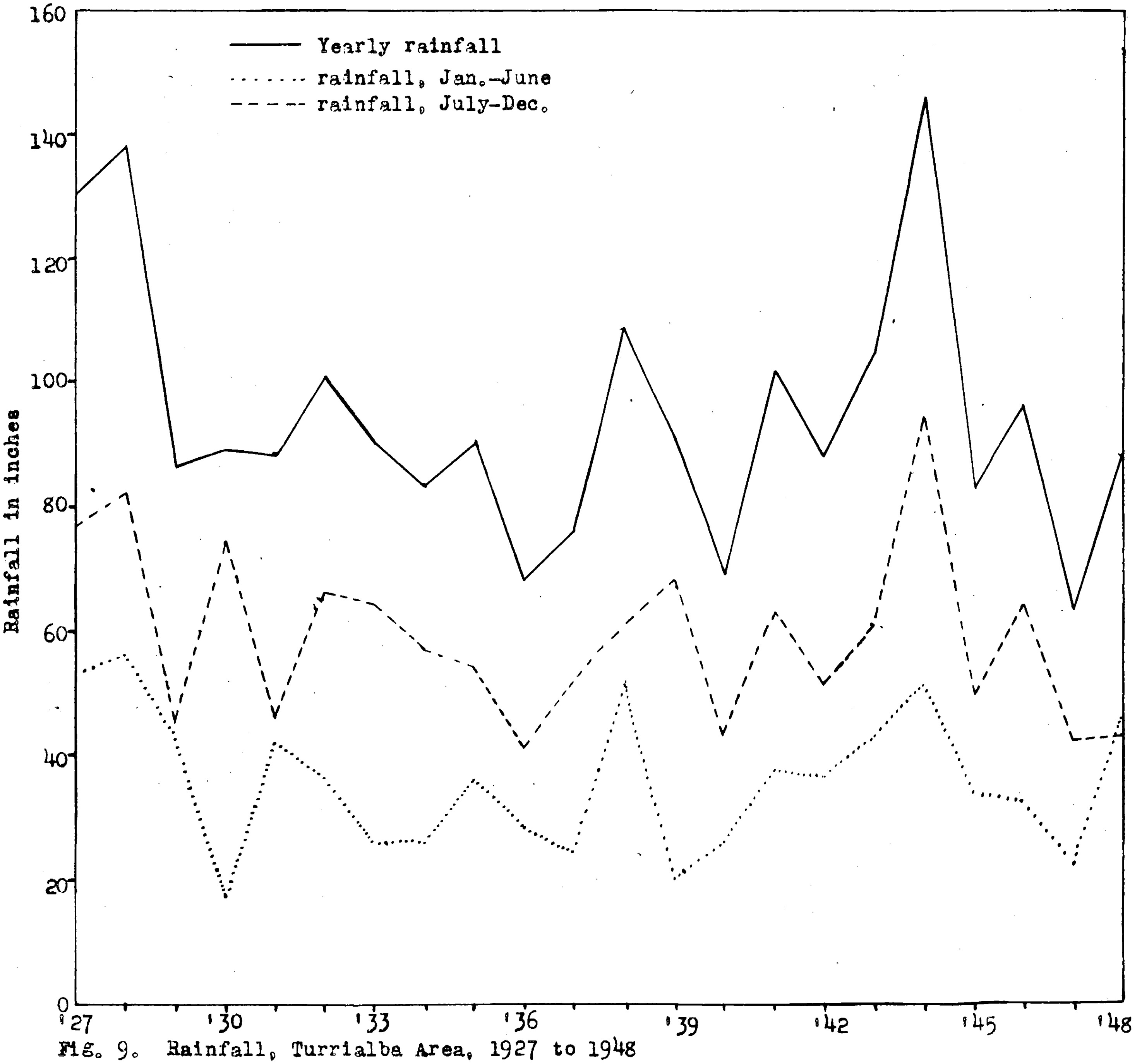

Fig. 9. Rainfall, Turrialba Area, 1927 to 1948

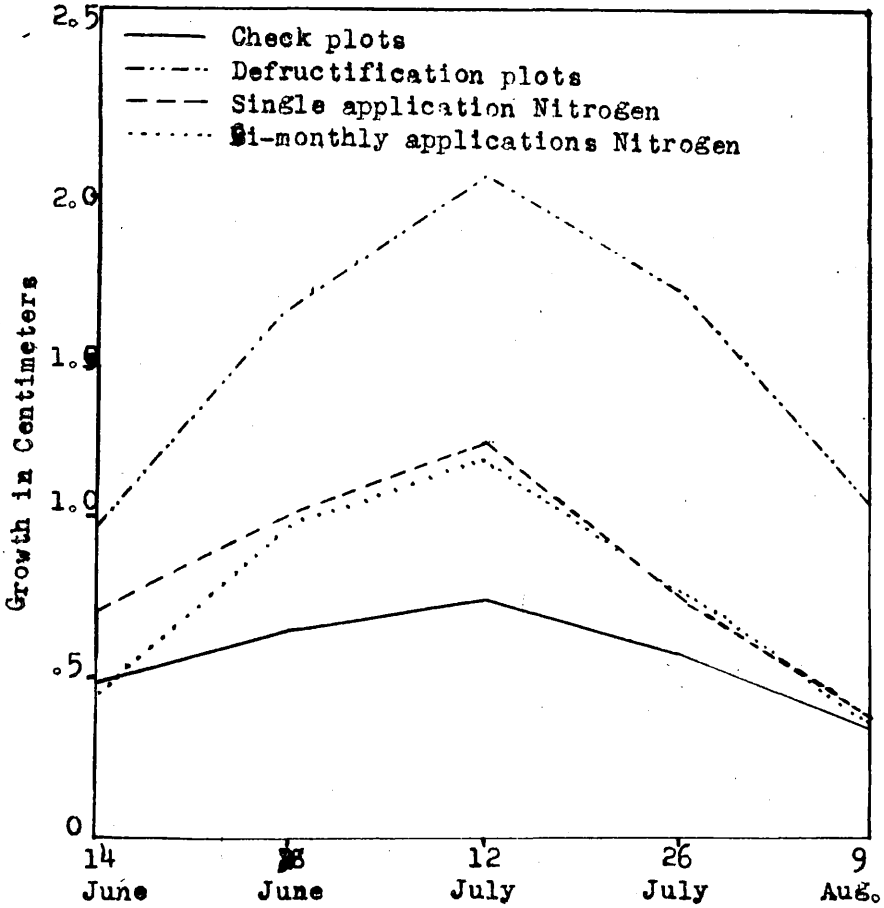

Fig. 10. Average growth of lateral branches of (A) check plots; (B) defructification plots; (C) Plots with single heavy application nitrogen fertilizer; and (D) Plots with bi-monthly light application of nitrogen fertilizer.