FACTORS AFFECTING THE GROWTH AND YIELD OF COFFEE IN KONA, HAWAII

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INTRODUCTION

Kona, Hawaii, probably attains the highest yield per acre of any coffee-producing area in the world. Some of the facts that apparently contribute to this situation are worthy of analysis from the standpoint of possible greater application in new plantings both in Kona and in other districts.

Among these factors are (1) the growth and fruiting habits of the tree itself; (2) the effects of environmental factors, such as soils and climate, under which the tree is growing; and (3) the effects of such practices as shading, pruning, fertilization, etc., imposed on the plant by the grower.

It is our purpose to consider some of these factors and their interrelationships as they affect coffee yields in the Kona District.

GROWTH AND FRUITING HABITS OF THE COFFEE TREE

An understanding of the growth habit of the coffee tree (*Coffee arabica* var. *typica*) is basic to an analysis of the effects of season, fertilization, and pruning or other factors on tree performances.

The coffee tree exhibits dimorphic branching and growth behavior. The seedling consists of a single vertical branch, which when approximately one foot high produces two lateral branches from buds in the axils of opposite leaves at a node. From this point, the vertical branch elongates and produces pairs of leaves at successive nodes from the axils of which lateral branches are produced.

Should the vertical branch be removed (as by pruning or breakage) or bent over at a wide angle, a bud immediately below a lateral branch on the vertical will develop and grow in a vertical direction, replacing the injured or destroyed vertical. The distance between nodes at which lateral branches are produced becomes increasingly smaller as the branch elongates. It is also shorter towards the end of the season. The maximum height attained by the vertical branch will seldom exceed 18–20 feet.

The lateral branch elongates by continuing growth of the terminal bud and by formation of nodes with pairs of opposite leaves. In the axils of the leaves are found the flower buds as well as a bud from which another lateral branch (secondary lateral) may develop. Should a primary lateral branch be removed, no other branch will grow from that leaf axil of the vertical branch. Moreover, no vertical branch will grow from a lateral branch.

Fruit is produced at one node or leaf axil only during one season, and this fruit normally is produced in the season following that in which the growth was made. On young and very vigorous 3-year-old trees or vertical branches flowers and fruit may be produced from the same node in two successive seasons or on 2- and 3-year-old lateral wood, although this is uncommon. A succession of flowers may develop in one season at a node, giving rise to fruits of different size and maturity at one time. Thus, the yield per tree is related to the number of nodes at which flowers are produced and to the number of flowers and fruits produced at each node.

Pruning practices are based upon this characteristic growth behavior. When a vertical branch is removed, several new vertical branches will develop from dormant buds on the stump remaining below the cut. One, two, or even more of these new verticals may be permitted to develop (removing extra or unwanted verticals by suckering) giving rise to a *multiple vertical* tree. Thus the age of the entire top of the tree may be accurately controlled by systematic pruning.

If a vertical branch is cut back or decapitated 5–6 feet above the ground and all replacement verticals removed, a *topped tree* is formed, which produces fruit essentially on the secondary, tertiary, and later laterals from the original primary lateral branches, since no new primary laterals will develop except on new verticals. Maintenance pruning consists of removing all vertical shoots and in "thinning out" the interlocking and greatly proliferated lateral growths, thus "renewing" the bearing surface.

Based upon these growth characteristics, many systems of training have been developed ranging from "free growing" through "agobio", "secondary vertical", "topped", "multiple vertical", etc., each of which may have several variations. One or another system is generally preferred in a given country, based upon real or imagined advantages. In Kona, the multiple vertical system is used at lower elevations and the topped system at higher elevations.

The major objective of pruning a coffee tree is to encourage the production of thrifty lateral growth capable of producing heavy annual crops of fruit.

Alternate bearing or the habit of the coffee tree to produce a heavy crop in one year and to produce a light crop or to "rest" in the second year seems to be characteristic of the tree the world over. The bearing habit of coffee in Hawaii is no exception to this rule. Excessively heavy fruit production in one year is often accompanied by severe defoliation, small sunburned berries, and even dying-back of the lateral and often of the vertical branches—a condition appropriately called *dieback*. The result is that the new lateral growth on which the following year's crop will be produced is short, of small diameter, and often devoid of leaves except for several pairs at the tip of the branch. The flower buds produced at nodes without leaves are usually small and fewer in number than those on more thrifty branches. Thus the number and quality of flower buds required to produce a large crop of fruit does not exist under such circumstances.

In severe cases the tree may be so devitalized that a succeeding large crop will not be produced for two or even three years or until the bearing surface of the tree has been completely renewed. Recovery is manifested by the production of vigorous new terminal and lateral growths with many large, dark green leaves which give promise of a large crop in the following year. Thus the opposite condition of dieback is a vigorously growing, heavily foliaged tree having a large bearing capacity.

Alternate bearing is related to both the growth and fruiting habit of the tree, which in turn are affected by season and by pruning. To better understand these relationships, a diagram is given of the more or less ideal coffee tree (fig. 1).

Figure 1 illustrates the growth and fruiting characteristics of the different age portions of the coffee tree. At the right of the diagram is shown an idealized 5-year-old lateral branch, attached to the 5-year-old portion of a vertical branch. The 4-year-old lateral would, of course, be attached to the 4-year-old portion of the vertical as indicated by the lines. The "A" section represents the current year's vegetative elongation of the primary lateral; "B" the portion which grew last year and which bears fruit in the current season; "C" the 3-year-old portion of the primary lateral which bore fruit last season and which is producing a vegetative secondary lateral in the current season; "D" the 4-year-old portion of the primary lateral on which the 2-year-old secondary lateral is fruiting; and "E" represents the 5-year-old portion of the lateral branch. Occasionally secondary lateral branches will develop on the current season's growth or on the 2-year-old growth "B" of vigorous young trees, which are not illustrated in the idealized diagram.

On the left side of the diagram the same relationships are shown for verticals of different ages as well as of the different age portions of a vertical. The 1-year-old portion of a vertical produces only vegetative lateral growth "A"; the 2-year-old portion bears vegetative "A" and fruiting growth, "B", etc.

The trunk of the tree below the verticals may be many years old but the verticals themselves are maintained in a young and fruitful condition by a system of renewal pruning, whereby at the end of the fruiting season, the oldest or damaged vertical is removed completely by dehorning, leaving a 4-6-inch stub on the old trunk. From this stub, and often from the old trunk, new vertical shoots develop, one or more of which is trained to replace the vertical that was removed. Surplus vertical shoots are removed by "suckering."

In figure 1, verticals are shown ranging in age from 1 to 5 years. The verticals grow progressively less in height each year after the first or second year. *Coffee arabica* var. *typica* in Kona attains maximum height in 8 years or less when well grown and, as indicated in figure 2, the terminal elongation of the vertical becomes less and less as maximum height is approached.

From a study of figure 1 it will be apparent that as the age of the vertical branch increases, the proportion of new terminal growth and of new primary lateral growth will decrease, while on the other hand, the proportion of secondary and tertiary lateral growth will increase. Thus the tree with verticals of 5 to 8 years of age and older is characterized by a very large proportion of interlocking and tangled, fruiting secondary and tertiary laterals of rather short length, in contrast to the simplicity of the long, relatively unbranched primary lateral growth of verticals 1 to 4 years old.

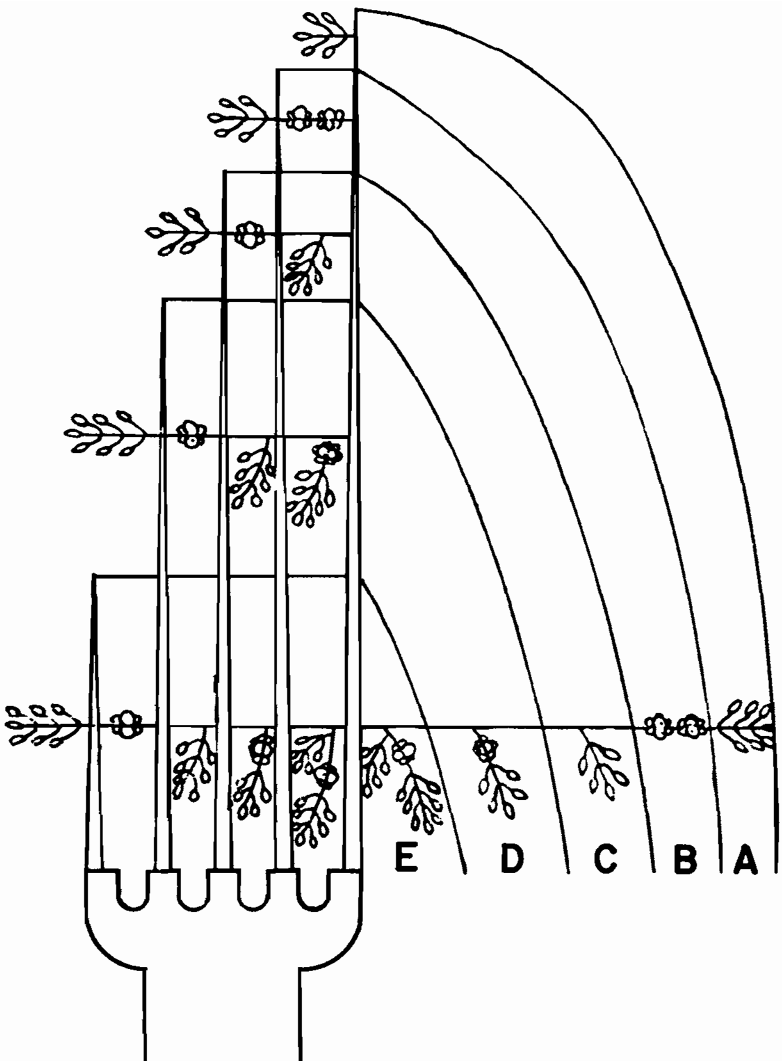

FIGURE 1. Growth and fruiting behavior of the various age portions of the coffee tree having five verticals ranging in age from 1 to 5 years. The "A" portion represents elongational vegetative growth made during the current crop season; "B" the vegetative growth made the previous season which bears the greater portion of the current crop; "C" the 3-year-old portion on which secondary lateral growths 1 year of age are produced which produce fruit; "D" the following year. The "E" section indicates the proliferation of lateral branches characteristic of old verticals.

Normally the fruiting laterals of the young verticals have a marked tendency to flower and to mature their fruit over longer periods than do the older verticals. The latter, with many but short lateral growths, tend to flower and to mature fruit over a short period, particularly at low elevations because of the uniform maturity of the bearing wood. Young trees or verticals making long vigorous lateral growths tend to flower progressively from the older to the less mature portions of the branch, thus extending the ripening period also.

The alternate bearing pattern of young vs. old trees is characteristic. As may be seen from figure 1, and as will be emphasized in later sections, practically 100 percent of the bearing surface of a 3-year-old tree is made up of a primary lateral growth, which is extremely productive. The 3-year-old vertical, therefore, is more susceptible perhaps to defoliation and dieback because of a heavy crop load. However, biennial bearing also occurs with old multiple vertical trees and with topped trees, on which the greater portion of the crop is borne on secondary and tertiary lateral growths. The greater total length of growth produced in a good but light crop year usually results in such a large crop the following year that the new growth is restricted and the following year's crop reduced, resulting in a biennial bearing cycle.

Certain of these relationships between growth and fruiting behavior of the older and generally unpruned or lightly pruned type of coffee trees were reported at some length by Beaumont (*1*). From a statistical analysis of growth and yield of two groups of unpruned trees 7 and 12 years of age from planting, the significant results were reported as follows:

1. Length of terminal and lateral growth was largely dependent upon or conditioned by the size or volume of the developing crop under normal conditions.
2. The volume of the crop was determined largely by the growth made in the preceding growing and crop season.

Later observation and experience have strongly supported the hypothesis that the volume of the crop in one year affects the following year's crop through the type and amount of growth produced.

By maintaining an equilibrium between the volume of fruit and the amount and vigor of the vegetative growth produced in the same season, more uniform annual yields and presumably maximum total yields over a period of years may be attained. Pruning and fertilization immediately suggest themselves as tools to accomplish this objective. Another would be irrigation water if such were available in Kona. However, seasonal factors and particularly the rainfall, must be considered briefly as a further background to the problem of high yield and alternate bearing.

RAINFALL AND ALTERNATE BEARING OF COFFEE

The general physical features of the Kona District of Hawaii were described by Powers *et al.* (*4*), while Ripperton *et al.* (*5*) discussed various cultural aspects of coffee production. These discussions indicated that the Kona District is not a large uniform area about which broad generalizations

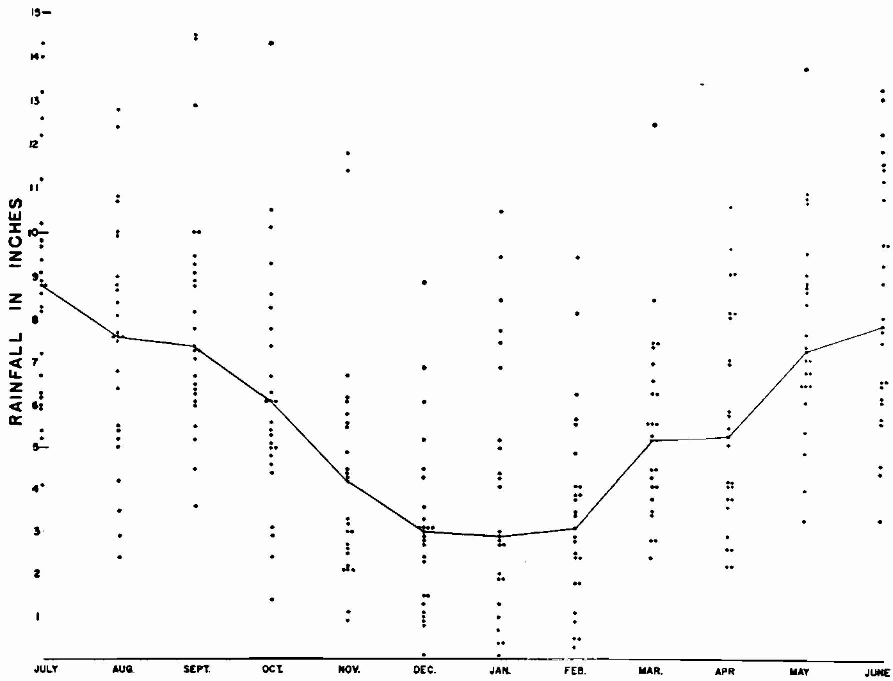

FIGURE 2. Twenty-six-year monthly rainfalls at Kainaliu, Kona, Hawaii. Medium monthly rainfalls are joined by heavy line. While the winter months of December, January, and February may receive 3 inches or less of rain in half the years, the variability characteristic of all monthly rainfalls is very large. In occasional years, combinations of unfavorable conditions in successive months may lead to partial crop failures.

may be made. The climate varies from dry, warm, and sunny at the lower, to very wet, cool, and cloudy at the higher elevations. The soils vary in age and depth along the mountainside and with elevation. In general the belt road at an elevation of 1,500 feet and with rainfall of about 70 inches is considered as the approximate mean or optimum climate and soil condition for coffee growing in Kona.

Figure 2 portrays the individual monthly rainfalls that have occurred during the past 26 years, 1931 to 1956, at Kainaliu in Kona. The median monthly rainfalls have been joined by a line. Inspection of the chart shows clearly that extreme monthly deviations have occurred in every month of the year.

However, the median rainfall line indicates a rather ideal climate for growth and yield of coffee, typified by a dry, relatively cool winter period during which the harvest is completed and the trees undergo a rest period of slow growth which seems to be favorable for fruit bud initiation. After harvest, pruning is undertaken and the first application of fertilizer made.

This period is followed by a somewhat wetter period in March and April which, with rising temperatures and heavier rains, is favorable for flowering and fruit setting. Active growth begins. Thus, the current season's crop is "set" during this period and growth is initiated which will bear the following year's crop. The rather heavy rainfalls of the summer months are favorable for growth of new wood and for development of the crop, while the progressively drier fall months are favorable for harvesting and drying of the crop.

However, as indicated by the distribution of the individual monthly rainfalls, the actual condition in any one year may deviate from the median giving rise to abnormal crop conditions.

Dean (*3*) reported that a partial regression analysis of monthly rainfall and coffee yield showed that only the rainfall occurring during the period between February and June of the preceding year was significantly related to the total coffee production of the district, and concluded that "much of the variability in annual production may be ascribed to fluctuation in the February to June rainfall occurring during the years in which the fruiting wood was produced."

With the older trees resulting from light pruning and the generally light fertilization practiced throughout the district during the period covered by Dean's analysis, rainfall played an important role in alternate bearing and undoubtedly greatly complicated the problems of establishing a balance between growth and yield.

EFFECTS OF FERTILIZATION ON YIELD AND ON ALTERNATE BEARING

One of the important factors in the high production per acre of coffee in Kona where no shade is used has been the extensive use of commercial fertilizers. Results of two experiments reported by Dean and Beaumont (*4*) conclusively demonstrated the relationship of fertilizers to total yield, but also that, in the amounts of fertilizer applied and with the pruning system used, the alternate bearing behavior of the trees was accentuated. It seems worthwhile to repeat the salient points of these experiments.

The Fukuda experiment was established in 1930 at an elevation of 1,500 feet. The experiment was a 5×5 latin square with nine trees per plot and 9-foot spacing between trees. The total annual fertilizer treatments per acre were as follows: (1) Check–No fertilizer; (2) N–160 pounds of N; (3) NP–160 pounds of N, 160 pounds of P_2O_5; (4) NK–160 pounds of N, 160 pounds of K_2O; and (5) NPK–160 pounds of N, 160 pounds of P_2O_5, 160 pounds of K_2O.

The nitrogen was supplied half from ammonium sulfate and half from sodium nitrate, the phosphorus from superphosphate, and the potash from potassium sulfate. The applications were made in February and July.

The average annual yields reported by Dean and Beaumont (*4*) for each treatment are repeated in figure 3. No significant differences between treatments were obtained until the third harvest but from then on very significant increases in yield were noted in the plots receiving potash. The very high yields in alternate years were accompanied by severe dieback. It was concluded that coffee trees fertilized with both potash and nitrogen gave significantly greater yields, but that great fluctuations in yield may be expected.

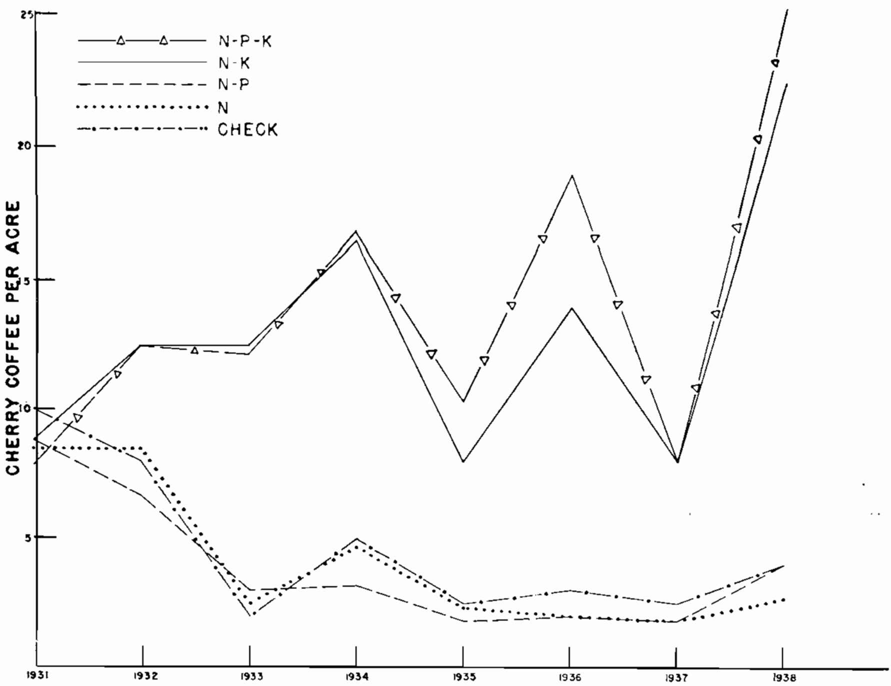

FIGURE 3. Annual yields (in 100 lbs.) of cherry coffee from differently fertilized plots of the Fukuda experiment. (Reprinted from Dean and Beaumont (*4*).)

These conclusions were further supported by a second fertilizer experiment on topped trees at an elevation of 2,200 feet where the sunlight was less and the rainfall was greater than at the Fukuda site (*4*). This experiment was established in 1934 and consisted of three randomized blocks of five treatments in 9-tree plots. The five treatments expressed as pounds per acre, per year were: (1) 80 pounds of N, 160 pounds of $P_2 0_5$, 160 pounds of K_2O; (2) 160 pounds of N, 160 pounds of P_2O_5, 160 pounds of K_2O; (3) 160 pounds of N, 160 pounds of K_2O; (4) 160 pounds of P_2O_5, 160 pounds of K_2O; (5) 160 pounds of N, 160 pounds of P_2O_5. Fertilizers were applied in February and July. The trees were pruned thoroughly at the time the fertilizer treatments were initiated.

The annual yields reported (*4*) are shown in table 1. The treatment containing no potassium was lowest and the treatment containing no nitrogen was intermediate. The NK-, NPK-, and ½ NPK-plots were essentially equal and very high yielding. The treatment receiving ½ NPK was as good as the treatments receiving the entire complement of nitrogen, indicating that at the higher elevations with less light and higher moisture the trees required less nitrogen than at lower elevations.

The very light crop of 1937–38 following the heavy crop of 1936–37 was noteworthy. As in the Fukuda experiment, trees receiving heavy fertiliza-

TABLE 1. Annual Yields of Coffee from the Differently Fertilized Plots at the Takashiba Farm*

Treatment	Yield in Successive Years		
	1935–36	1936–37	1937–38
	CWT/A	CWT/A	CWT/A
½ N-P-K	126	248	85
N-P-K	132	242	84
N-K	139	249	77
P-K	103	168	50
N-P	97	130	16
Standard errors	6	18	15
Difference required for significance	17	50	44

*Reprinted from Dean and Beaumont (*4*)

tion fell into a striking alternate bearing habit even though the conditions under which they were growing were different. It is to be noted also that the year 1936–37 is the heavy crop year in the Takashiba experiment and the light crop year in the Fukuda experiment. Thus the alternate bearing in these instances was probably not due entirely to rainfall but, in the Takashiba experiment at least, to the pruning and fertilization treatments applied in the year the experiment was initiated.

Discussion

These experiments, aside from determining the necessity of potassium together with adequate amounts of nitrogen in coffee fertilization as emphasized in the paper (*4*), also demonstrated that under the conditions of the experiments extreme alternate bearing occurred with increased yields. Evidently the fertilization together with a certain amount of pruning resulted in good growth and a light crop one year followed by a heavy crop and poor growth the following year. The multiple vertical Fukuda trees, being older and larger than the topped Takashiba trees, took somewhat longer to respond fully to the fertilization as several years passed before a definite cycle was established. It is possible that rainfall may have been instrumental in determining the initial year of good growth to be followed by the high crop year of 1933–34, in this case. But with the Takashiba trees the response was immediately noticeable and weather apparently played little or no critical part.

Alternate bearing thus appears to be a natural growth response of the tree which may be initiated by weather conditions but also by other factors and is more evident in well-fertilized trees. The disadvantages of extreme alternate bearing are obvious, and ways and means of prevention while maintaining or improving yields suggest themselves. Of these, adequacy of fertilization, systems of pruning, and a combination of these were investigated.

RELATIONSHIPS OF PRUNING AND FERTILIZATION TO YIELD

An experiment was established at the Kona Branch Experiment Station to study systems of pruning and rate of fertilization in relation to alternate bearing or conversely to maintenance of uniformly high annual yields*. Three rates of fertilization and three systems of pruning were compared.

Pruning

To determine the interrelationships of systems of pruning and fertilization, it was necessary first to devise standard or constant pruning systems comparable to Kona practices that would maintain the tree in a known and reproducible condition from year to year. After a number of preliminary trials, two systems of renewal prunings, both being examples of the multiple vertical system, were devised. These are shown diagrammatically in figure 4 and in figures 5 and 6. For purposes of discussion they will be called the A and B systems.

The A system consisted of training four verticals differing in age by one year on each tree. The system was maintained by pruning off (dehorning) the oldest or 4-year-old vertical after the crop was harvested and by training a new vertical to take its place. After one year of growth the new vertical became 1 year of age and the remaining verticals of the previous year would have completed a year of growth, thus restoring the 1–2–3–4 sequence (fig. 4*A* and fig. 5).

The B system consisted of training only three verticals differing by two years of age on each tree. The oldest vertical when 6 years of age was removed after harvest and a new vertical trained to replace it. Thus in the first year that the pruning system had become established the verticals were 1, 3, and 5 years of age, but the tree was not pruned until the following year when the verticals had attained 2, 4, and 6 years of age. The oldest was then removed and the 1, 3, 5 sequence restored by training a new vertical to replace the one removed (fig. 4*B* and fig. 6).

In a 2-year cycle the total age of the four vertical branches on a tree trained to the A system would be 20 years while on the B system the total age of the three verticals would be 21 years. However, since the 1-year-old verticals produce none and the 2-year-old verticals very little fruit, the total biennial age of the fruiting verticals of the A system is 14 years while that of the B system is 18 years, thus giving a definite yield advantage to the latter because of greater age, size, and bearing capacity. Inevitably, also, there will be created a biennial bearing effect because of the removal of the 6-year-old vertical in alternate years with the B system of pruning. Trees pruned to the A system should not exhibit biennial bearing since the ages of the verticals are the same each year.

These two pruning systems were compared with a so-called "Kona" check system which was similar to the A system except that considerable latitude

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*The authors are indebted to Mr. Robert Pahau (deceased), former Superintendent of Kona Branch Experiment Station, who assisted the senior author in conducting many trials and experiments in pruning and training and in establishing this experiment.

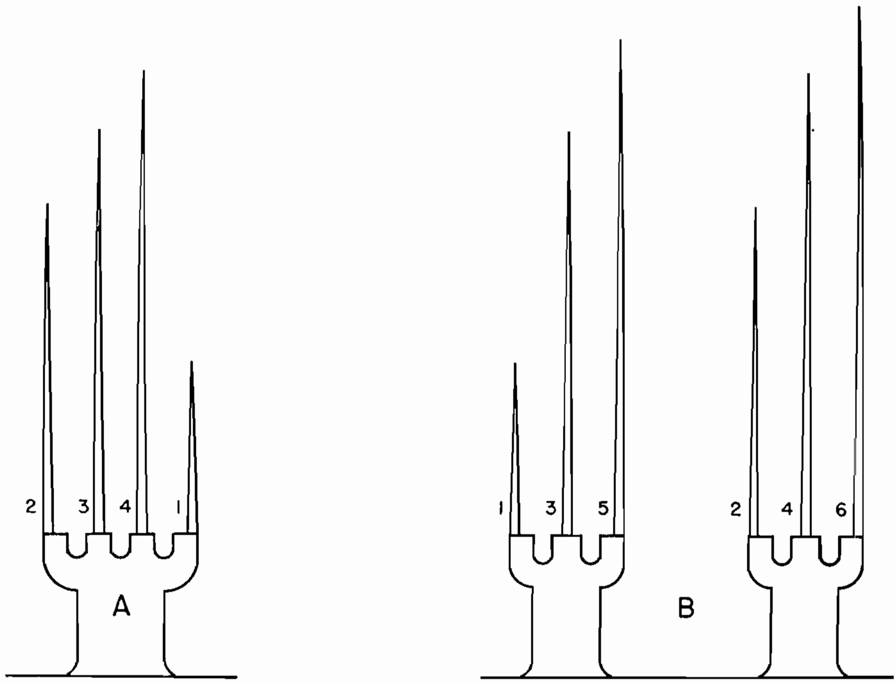

FIGURE 4. Diagram of the systems of pruning used in the fertilizer and pruning experiment. Figure "A" represents a single tree on which four verticals ranging in age from 1 to 4 years have been trained. After harvest the 4-year-old vertical will be removed and in the following year, the respective ages of the verticals from left to right will be 3, 4, 1, and 2.

Figure "B" represents a single tree in two successive years on which three verticals of ages 1, 3, and 5 years are allowed to remain for the succeeding year, becoming 2, 4, and 6 years of age. After harvest, the 6-year-old vertical is removed and the 1, 3, and 5 cycle is restored.

was allowed in the number of verticals per tree and in the exact age and condition of the vertical or verticals removed each year. The Kona check tree might contain five or more verticals, one or more of which would be 4 or 5 years of age. Thus the Kona check was pruned for greater production within the age limits set for the vertical rather than to an inflexible system.

Fertilization

Three rates of fertilization were applied to each pruning treatment and all treatments were duplicated, giving a total of 18 plots of 9 trees each. The total annual fertilization was 3, 4, and 5 pounds of an 8–4–13* formulation

*8 percent N, 4 percent P_2O_5, 13 percent K_2O. The formula was developed from results of the fertilizer experiments (*4*) and from mineral analyses of coffee fruit (*6*). This formula was used generally throughout the district at the time the experiment was in progress.

per tree applied in two applications (February and June). At the time the experiment was initiated, the 3-pound application or approximately 900 pounds per acre was considered to be about average for the district and the 5-pound application or 1,500 pounds per acre was considered to be very high.

The experiment was initiated in 1942 using trees planted in 1937 on 12 × 12-foot centers or at the rate of approximately 300 trees per acre. It required 5 years to establish the three pruning systems. The fertilizer treatments were initiated in 1942. The four years' yield records were obtained after the pruning systems had become established and the experiment was concluded, and are presented in table 2.

Presentation of Data

The data on annual yields of the three pruning systems are summarized and presented in table 2.

FIGURE 5. The "A" system immediately before pruning off the 4-year-old vertical.

FIGURE 6. The "B" system in the 2-4-6 cycle before pruning off the 6-year-old vertical.

TABLE 2. Annual Yields of Coffee Trees Pruned to Three Different Systems

Pruning System	Years				
	1947–48	1948–49	1949–50	1950–51	Average
	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A
A	125*	104	67	123	104.9†
B	107	171	44	221	135.8
Kona check	166	145	92	107	127.6
Average	133	140	68	151	

*Each figure represents the average yield of 6 plots; i.e., 2 replications of 3 fertilizer treatments expressed as yield per acre.
†Minimum difference required for significance between pruning means=11.4 CWT.

The data analyzed by means of analysis of variance demonstrated statistically significant differences in yield in different years when all pruning treatments were averaged. This difference was due in large measure to the abnormally low yield obtained in 1949-50 which reflected the conditions throughout the entire Kona District and may be accounted for by the abnormal weather in 1948 and 1949. The annual coffee yields in the Kona District for the 5 crop years of the experiment are given in table 3.

TABLE 3. Total Annual Yields of Coffee in the Kona District for the Years 1947–48 to 1951–52 Inclusive

Year	Yield
	1,000 lb.
1947–48	6,990
1948–49	5,900
1949–50	4,900
1950–51	7,500
1951–52	7,660

The yield in 1949–50 was 1 million pounds less than that of the previous year which itself was 1 million pounds lighter than the 1947–48 crop. Thus 1949–50 following a poor crop season should have been a good season on an alternate bearing cycle. The fact that it was not was due to adverse weather.

The spring months of March, April, May, and June of 1948, the year that growth was made to produce the 1949–50 crop as Dean (*3*) described, were definitely deficient in rainfall, particularly March and April with a total of 5.4 inches, while the median during the critical period was 10.5 inches. Presumably, spring growth was restricted.

The spring months of 1949 were even more severe, there being only 14.2 inches of rain during the 4 months from February to May when the median expected was 21.2. Such conditions might well reduce the flowering and fruit set for the 1949–50 crop on the already deficient growth of the preceding season. Moreover, during the 3 months of September to November, 1949, during the early period of maturing the crop a further deficiency of 6 inches of rain occurred which resulted in defoliation, dieback, and a further depletion of the crop.

Such conditions undoubtedly result in initiation of alternate bearing cycles. Thus the year 1949–50 became the lowest of two successive poor crop years. This was reflected in the annual yield records, table 2, of the A, B, and Kona check treatments. In addition, the yields of the B pruning treatment followed the age cycle of the trees which were in the 1–3–5 or low yield cycle in 1947–48, the 2–4–6 or high yield cycle in 1948–49, the 1–3–5 cycle in 1949–50 and the 2–4–6 cycle in 1950–51. Weather in 1949–50 undoubtedly contributed to the low yield of 44 CWT/A in 1949–50; but the pruning system also resulted in alternate heavy yields, judging by the low yields of 1947–48 and 1949–50 and the high yields of 1948–49 and 1950–51.

The average yields of the three pruning systems reflect the total age of verticals per tree (see page 13), and the size and prolification of the tree.

Analysis of variance showed that the interaction of pruning system and years was highly significant, indicating that the differences in yield between pruning systems were not proportionate in different years or that some treatments were less alternate bearing than others.

The effects of pruning on annual fluctuations in yield are more apparent if the abnormal yields of 1949–50 are disregarded. When this is done, the maximum difference between annual yields of the A plots of 21 CWT/A is 19 percent of the 3-year average yield while with the B system the difference of 114 CWT/A is 43 percent of its 3-year average. By this comparison, the annual yields of the A system are far more uniform than either of the other systems, and it might be concluded that "alternate bearing" while influenced by weather is also a function of the age and character of growth of the tree, and that it may be controlled, at least in part, by heavy pruning.

Discussion

It has been indicated above that a sacrifice in yield occurs due to the heavy pruning of the A system. With this system, all of the fruit is borne on laterals, none of which are more than four years of age. All of the fruit produced by the 2- and 3-year-old verticals is borne on primary lateral branches. On the 4-year-old vertical, the secondary laterals on the older portion of the primary laterals contribute materially to the high yield of the 4-year-old vertical (fig. 1). However, most of the fruit still would be produced on the 2-year-old portion of primary laterals in the characteristic large clusters distributed along the 2-year wood of the primary lateral where it is most easily picked.

In contrast the 5- and 6-year-old verticals of the trees pruned to the B system would have secondary and lateral branches in fruiting on the 4-year-old and older portions of the tree. On the 6-year-old vertical a very considerable proportion of the crop would be borne on these secondary laterals. The time required to harvest fruit from this type of tree is much greater in proportion than from the 2-year-old portion of the 3- or 4-year-old tree. In consequence, the greater yields of older trees are obtained at a disproportionately greater expenditure of harvest labor.

Trees pruned to the A system are considerably smaller as well as younger. Such trees might well be spaced closer together, thus increasing the number of trees and total yield per acre. The larger trees of the B system require the greater spacing. Thus it is logical to assume that the difference in yield of 31 CWT between the two systems of pruning might be overcome in part by closer spacing of trees pruned to the A system and perhaps a saving in harvest labor still effected.

Fertilization ranging from 900 pounds to 1,500 pounds per acre of an 8–4–13 formulation was overshadowed in its effects by those of pruning. Observations of the trees during the course of the experiment indicate that the amounts applied probably were inadequate, particularly in the "on" years when poor growth, loss of foliage, and even dieback occurred that might have been prevented by heavier applications. Thus the question arises again as to the rate of application in relation to the size or volume of the crop. However, it is doubtful whether any amount of fertilizer could have overcome or "balanced" the adverse effects of weather in 1949–50.

YIELD OF COFFEE TREES WITH ALL VERTICALS OF THE SAME AGE

With renewal systems of pruning such as those described, it is inevitable that different verticals or portions of the tree will be of different ages. It is extremely difficult to obtain yield or growth records of these different age portions or to observe what effect, if any, one vertical would have upon another or whether fertilization of the tree affected one portion of the tree more than another.

To avoid certain of these variables and to obtain more accurate information on the growth and yield performance of trees or verticals of specific ages, another experiment was designed in which age of vertical, number of verticals on tree, and rate of fertilization were the principal variables.

Materials and Methods

The trees used in the experiment were of the same age as those of the pruning and fertilizer experiment, having been planted in 1937. The spacing was 12 × 12 feet or approximately 300 trees per acre. In all there were 108 trees representing six replications of 18 treatments in individual tree plots. The treatments were: (1) number of verticals per tree (4, 6, and 8 verticals); (2) fertilization–6 treatments; and (3) age from time of dehorning.

The entire group of trees was pruned in March of 1949 by dehorning all the verticals except one on each tree. The one vertical was left as a nurse vertical to sustain the root system of the tree until the new verticals developing from the trunk had become well established, it being assumed that removal of all verticals would affect growth of the tree. In midsummer the nurse vertical was removed from half the trees to permit the actively growing renewal verticals to develop without further competition for moisture or light from the nurse vertical. On the second half of the trees the nurse vertical was allowed to remain until the fruit it was bearing had been harvested. After harvest this vertical was removed. In both cases, the lower lateral branches of the nurse vertical were removed to avoid any shading of the renewal verticals. Figure 7 (1) would represent the tree

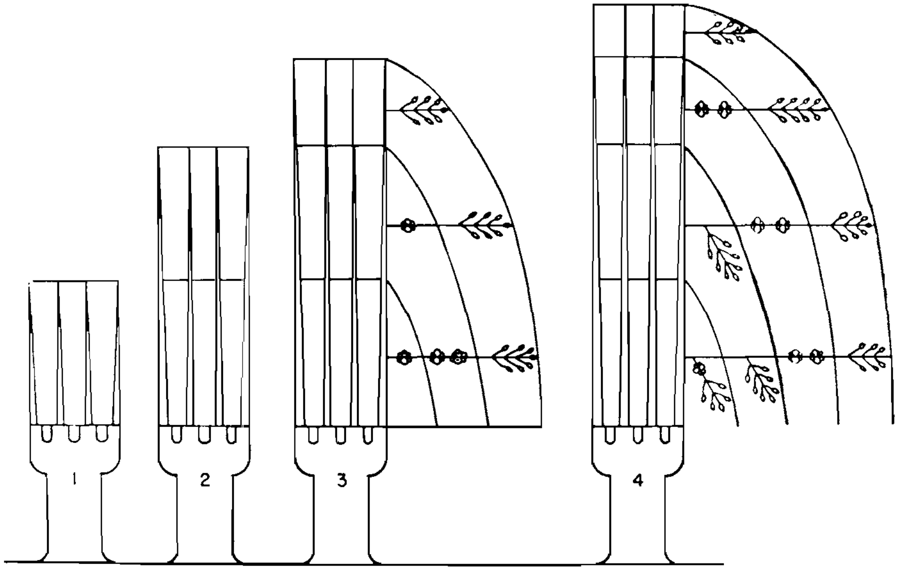

FIGURE 7. Diagram illustrating growth and fruiting behavior of a dehorned tree in successive years (1 to 4) when pruned according to the system described in the text. The "nurse" vertical would have been removed before tree 1 had completed its growth.

At the right of the diagram, the growth and fruiting behavior of the lateral branches of the 3- and 4-year-old trees is shown. Note that on the 3-year-old tree, the 3-year-old portion of the lateral branch is bearing fruit in contrast to the 3-year-old portion of the lateral on the 4-year-old tree. The 2-year-old portions of the lateral branches of the 2-year-old tree also produce fruit. (See text.)

after completion of the first year of growth and after removal of the nurse vertical. Figure 7, (2), (3), and (4), represent the growth and fruiting behavior of the tree in the 3 succeeding years (compare with fig. 4A).

During the first year of growth the suckering vertical shoots developing on the trunks of the trees were thinned out, leaving 4, 6, and 8 of the most vigorous young verticals per tree (fig. 8). These, of course, were all of the same age and all had equal sunlight exposure. The verticals were thick-stemmed and the internodes relatively short. None were weak or spindly and none bent over or requiring propping. Strong, good-diameter, lateral branches with relatively short internodes were produced on the verticals. The trees bore a surprisingly large crop the second year after dehorning. The experiment was discontinued after the fourth crop when the verticals were 5 years of age in 1954.

The 4, 6, and 8 vertical trees received six fertilizer schedules in which the basic fertilizer was a 10 N–5 P_2O_5–20 K_2O formulation applied in two applications in March and June. Four of the schedules contained supplementary ammonium sulfate applied between or after the basic applications. The schedules were as follows:

A. 3 lb. per tree per year, 1950–54
B. 1 lb. basic fertilizer per tree per year of age of tree, or 1 lb. in 1949–50, increasing to 5 lb. in 1953–54
C. 3 lb. basic fertilizer per tree per year plus ¾ lb. ammonium sulfate in July
D. 3 lb. basic fertilizer per tree per year plus ¾ lb. ammonium sulfate in April
E. 3 lb. per tree per year basic fertilizer plus ¾ lb. ammonium sulfate in April, ¾ lb. in July
F. 3 lb. basic fertilizer per tree per year plus ¾ lb. ammonium sulfate in April, ¾ lb. in July, and ¾ lb. in September

Fertilizers were applied in a 3–4-foot diameter circle around each tree and it was not felt that cross feeding could be a serious factor. Individual tree plots with six replications were used.

Presentation of Data

The data have been analyzed statistically using the method of analysis of variance and are presented in the following sections.

Effect of Nurse Vertical on Yield

The data relative to the performance of the nurse vertical and to the effect of time of removal of this vertical upon the yield of the 2- and 3-year-old dehorned trees are presented in table 4. As possibly might have been expected, the nurse vertical when left until after harvest affected the initial or second year yield of the dehorned trees, there being a statistically significant (5 percent point) depressing effect on yield when left until after harvest. The trees having greater sunlight advantage and presumably greater growth when the nurse verticals were removed in midsummer produced the greater yield in the second year.

In the third year there was no measurable effect of the nurse vertical upon yield. Moreover, the difference between the totals of the 2-year yields was within the limits to be expected by chance alone. The very heavy yield characteristic of 3-year-old verticals will be emphasized later (page 22, table 5).

The nurse verticals when allowed to remain until after harvest yielded an average of 13.1 lb. per tree which, if added to the yields obtained in the

TABLE 4. **Effect of Time of Removal of the Nurse Vertical upon the Second and Third Year Yield of Dehorned Trees***

Time of Removal of Nurse Vertical	Yield of Nurse Vertical	Yield of Dehorned Trees When Verticals Were:		Total Yield 2- and 3-year-old Trees
		2 years old	3 years old	
	lb. per tree	lb. per tree	lb. per tree	lb. per tree
Before harvest	0	16.4	80.6	97.0
After harvest	13.1†	12.0	82.6	94.6

*These data were obtained from 36 trees which were fertilized in the same manner but which are not included in the data obtained from the 108 trees described above. The trees were dehorned on a short cycle and are used here to compare only the effect of the nurse vertical upon the subsequent yield of the trees.
†Not included in total yield, column 4.

second and third years on these trees, indicated a definite advantage in retaining the nurse vertical. The yield of the nurse vertical if added to the yield the second year overcame any difference previously noted and showed

FIGURE 8. Dehorned tree at the beginning of the third growing season with six verticals all of same age. Note the vigorous 1- and 2-year-old lateral growths. The lower portion of tree was thinned out to permit photographing the verticals. Note also the unbranched laterals which simplified picking of the fruit.

an advantage in total yield favoring retaining the nurse vertical until after the fruit was harvested.

DISCUSSION

In this experiment a nurse vertical was retained on every tree; removal of all the verticals at one time would probably be a severe shock to the trees from which many would not recover satisfactorily. Unfortunately this hypothesis was not tested at the time. However, judging from the data it is probable that had all verticals been removed, leaving no nurse vertical, an even greater yield than that obtained from the trees from which the nurse verticals were removed before harvest might have been obtained. If this were true, the yield of the nurse vertical would be of no real advantage.

Later observation has shown that relatively young thrifty trees may be completely dehorned without danger and even with benefit to the renewal performance of the tree. However, very old trees when dehorned completely may die or the renewal verticals develop so slowly that the tree may not recover satisfactorily in the first year. In these circumstances a nurse vertical would seem to be definitely advantageous, if not essential.

In the experiment described above it was possible to select the best nurse vertical from among four or five verticals of different ages. Thus, the most thrifty vertical promising greatest yield was selected in most instances. After a complete pruning cycle had been completed and the trees were to be dehorned again, the selection of a nurse vertical would be limited to verticals all of one age. Such a vertical probably would not have the yielding capacity of the nurse vertical selected in the first instance.

Moreover, since all of these nurse verticals at the time of the second dehorning would be 3, 4, 5, or 6 years of age (depending upon the length of the cycle employed) most of the fruit would be borne on short primary and secondary lateral growths and would be difficult to harvest. Many of the fruiting branches would of necessity be pruned off to avoid shading the renewal verticals. Thus the gain in yield that might result from retaining the nurse verticals until after harvest would be obtained at a disproportionately high cost in labor of pruning and harvesting in the second cycle. This problem remains to be resolved in future experiments.

Yield of Dehorned Trees in Successive Years

The average yield in pounds of cherry coffee per tree in successive years from the 108 trees dehorned in 1949 is shown in table 5.

TABLE 5. Yield of Coffee Trees of Increasing Age of Vertical in Successive Years

Year	Age of Verticals	Average Yield of Cherry Coffee	
		Per Tree	Per Acre
		lb.	CWT
1949–50	Renewal Verticals 1 year old	0.0	0.0
1950–51	Renewal Verticals 2 years old	13.7	41.1
1951–52	Renewal Verticals 3 years old	81.6	244.8
1952–53	Renewal Verticals 4 years old	39.9	119.7
1953–54	Renewal Verticals 5 years old	67.7	203.1

The differences in average yield of the trees at successive harvests are of course highly significant and clearly show the interrelationship of age, growth, and yield.

The 2-year-old verticals produced a surprisingly large yield of 13.7 lb. of cherry coffee per tree as shown in table 5. Normally, the 2-year vertical in the multiple vertical system of pruning is in direct competition for sunlight and nutrients with older and heavily producing verticals on the same tree and produces little or no fruit. It previously has been observed and reported that the 2-year-old vertical produced in full light on the "bent over" or "secondary" vertical systems of pruning will produce rather well. However, the production of high quantity fruit obtained in this instance was greater than had been anticipated.

The extremely heavy production of 81.6 lb. of cherry coffee by the 3-year-old vertical trees (table 5), which was not exceeded in later years by the trees of greater age, is significant. The verticals had been grown in full light and without competition except between themselves on the same tree. During the first two years a very large and sturdy growth with heavy foliage and of great bearing potential had been made. The small crop of fruit in the second year of 13.7 lb. per tree was not a severe drain, and sufficient reserves were available to set and mature the very heavy crop of 81.6 lb. per tree in the third year. It was observed also that on 3-year-old verticals of such vigor, flowers and fruit were produced on the 3-year-old portions of the lateral branches (fig. 7, No. 3), which had produced fruit the previous season, as well as on the 2-year-old wood. The habit of flowering and fruiting at the same node two years in succession seems to be characteristic of vigorous new 3-year-old verticals when not in competition with older verticals.

The yield of the 4-year-old verticals was less than half that of the 3-year-old (table 5). This was not entirely unexpected, for as has been shown, a light crop is likely to follow a very heavy crop (*1*, *4*). Climatic conditions are not at fault in this case for the spring and summer weather were favorable. The data conclusively demonstrated that the drain on the tree to mature the heavy crop of 1951–52 was such that the trees were unable to make the new growth and to maintain the reserves that would be required to repeat the high yield in the following season. (This observation is also borne out by other data. See Fertilization.) In addition, it was observed that the 3-year-old portions of the lateral branches were not fruitful as with 3-year-old verticals.

During the light crop year of 1952–53, greater new growth and storage of reserves were possible, such that in the year 1953–54 a yield of 67.7 lb. per tree was produced. It was perhaps not significant that the average yield of the 5-year-old trees was less than that of the 3-year-old trees, for the trees had become quite large and somewhat crowded. It would be expected that large well-grown 5-year-old trees, properly spaced, may well produce more than the 3-year-old trees at the same spacing (see table 7).

The effects of the two factors of number of verticals per tree and of fertilizer schedules on yield of trees of increasing age in successive years were also analyzed statistically. In view of the extreme differences in yield with increasing age as shown in table 5, the data were analyzed separately for individual years and also for various combinations of years; i.e., 1951, 1952, 1951–1953, and 1951–1954. The results of the analyses are presented in table 6 in which the F values found may be compared with those required at the 5 percent and 10 percent points for statistical significance.

The F values for replication indicate that the six replicators were relatively uniform, there being no significant differences between them except in 1952 when the trees were 3 years of age. In all other years and combinations of years the F values were well below those required for statistical significance.

The effect of number of verticals was significant in the heavy crop years of 1952 and 1954 but not in the alternate light crop years when annual yields were analyzed separately. Significant effects were found also when three- and four-year yields are combined for analysis. Thus there can be no doubt that number of verticals, i.e., size and bearing surface of the tree, are related to yield.

TABLE 6. Statistical Significance of Differences between Treatments When Annual Yield Records Were Analyzed Separately and in Combination[1]

	F Values Found				F Required
	1951 2 yrs. old	1952 3 yrs. old	1953 4 yrs. old	1954 5 yrs. old	
Replication	1.83	10.58	2.76	1.94	3.33* 5.64†
No. of Verticals	0.80	122.60	0.02	8.76	4.10* 7.56†
Fertilizers Found	10.06	2.88	8.63	5.73	2.35* 3.29†
Verticals and Fertilizers	0.88	0.88	0.95	1.59	1.97* 2.56†
	1951	1951 + 52	1951 + 52 + 53	1951 + 52 + 53 + 54	
Replication	1.83	0.71	2.28	2.39	3.33* 5.64†
No. of Verticals	0.80	0.48	10.88	18.04	4.10* 7.56†
Fertilizers Found	10.06	5.60	7.07	1.36	2.35* 3.29†
Verticals and Fertilizers	0.88	9.01	0.37	0.93	1.97* 2.56†

*5%
†1%

[1]The authors are indebted to Mr. F. A. I. Bowers, Junior Horticulturist, Hawaii Agricultural Experiment Station, who made the numerous and detailed statistical analyses in this and subsequent data.

Significant differences due to fertilizers were demonstrated by both methods of analysis except that when the yields of the four years were analyzed together no statistically significant differences were apparent.

The first-order interaction of number of verticals and fertilizer schedules was not statistically significant by any method of analysis except when the yields of the first two years were analyzed together. It would appear, therefore, that in general, fertilizer schedules and number of verticals were positively correlated.

The detailed data on number of verticals and fertilizer schedules are presented in following sections.

Effect of Number of Verticals Per Tree on Yield

The influence of the number of verticals per tree on yield per tree in successive years or of increasing age of verticals per tree is shown in table 7.

The data in the last column of the table show conclusively that the 4-year average yield of the trees with the greater number of verticals, i.e., the larger trees, produced the greater weight of fruit. However, by analysis of the data for individual years the generalization was found to be true only in the alternately heavy crop years of 1951–52 and 1953–54. When only 2 years of age the trees were small and immature and the amount of fruit produced was apparently much the same regardless of number of verticals. When 4 years of age the plants were in the light crop year of the alternate bearing cycle imposed by the heavy crop of the preceding year. The capacity crop which was related to number of verticals and size of the tree reduced the growth and potential yield of all the trees to the same yield regardless of number of verticals per tree. Actually the variation in alternate yields was greater with the larger trees having more verticals.

These data and growth behavior of the tree gave a clearer insight into factors affecting biennial bearing of the coffee tree than had been possible before. The striking yielding ability of a vigorous 3-year-old vertical has perhaps been recognized but never fully evaluated and its importance in alternate bearing recognized.

TABLE 7. **Average Yield Per Tree in Successive Years of Trees Trained to 4, 6, and 8 Verticals**

No. of Verticals Per Tree	Yield Per Tree When Verticals Were:					
	2 yrs. old 1950–51	3 yrs. old 1951–52	4 yrs. old 1952–53	5 yrs. old 1953–54	Average 4 years 1951–54	Total 4-yr. Yields
	lb.	lb.	lb.	lb.	lb.	lb.
4	14.5	70.2	40.2	61.4	46.6	186.3
6	13.0	83.6	40.1	66.2	50.7	202.8
8	13.6	91.0	39.5	75.5	54.9	219.6
L.S.D.* 5%	N.S.†	3.0	N.S.†	7.62	3.1	12.4
L.S.D.* 1%		4.3		10.84	4.4	17.6

*L.S.D.=Least significant difference
†N.S.=No significance

Effects of Fertilization on Tree Yield

Previous data have shown the relationship between age of verticals and number of verticals per tree and yield. In each case the effects of fertilization have been disregarded in that the analysis of variance indicated no significant effects of fertilizers when data for the four successive yields are combined. However, statistically significant differential effects of fertilizers in the successive years, or perhaps more appropriately in relation to age of vertical and crop history, indicated that the trees responded differently to certain fertilization treatments at different ages or cropping conditions which were masked when the data for all ages were combined. These responses are shown by the analysis of the yield data for each age of vertical separately. When the data for six fertilization treatments were compiled by successive ages of verticals, the results shown in table 8 were found.

TABLE 8. Effects of Differential Fertilization upon Yield Performance of Dehorned Coffee Trees of Increasing Age

Age of Verticals or Tree	Average Yield Per Tree (Average 18 Trees) on Fertilizer Schedule						Av. Yield Per Tree All Fertilizer Treatments	Minimum Difference Required for Significance
	A	B	C	D	E	F		
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	
2 years	16.4	14.1	17.1	14.6	17.1	11.1	15.1	2.76* 3.68†
3 years	80.7	75.4	83.4	81.8	83.4	88.3	82.1	7.22†
4 years	29.3	29.3	36.6	52.1	45.7	46.5	39.9	9.23* 12.26†
5 years	73.8	64.6	84.4	57.0	64.9	61.5	67.7	11.6* 15.4†
Average	50.0	50.8	50.4	51.4	52.8	51.8	51.2	

*5% point
†1% point

In table 8 the data for fertilizer treatments were grouped somewhat for more ready comparison and ease of presentation. For example, treatments A and D differ only in that D received ¾ lb. supplementary ammonium sulfate in May or early enough that growth apparently was not materially affected. Treatments E and F differ from A and D in that each received supplementary ammonium sulfate in both May and July, and treatment F received in addition a third application in September. Treatments C and B were intermediate. Treatment B is of interest because it received increasing fertilization with increasing age of tree (see page 22).

The 4-year average yields per tree of the six fertilizer schedules were almost identical, there being no statistically significant differences. However, within the table, maximum differences between fertilizer schedules were significant at the 5-percent level with both 2- and 3-year-old trees, and at the 1-percent level with trees 4 and 5 years old. It is perhaps of greater interest and significance that the differences were in opposite direction in these 2 years, when successive yields are under consideration. It should be re-emphasized that the current crop is in large part a result of the size of the crop and total length of lateral growth of the preceding year, weather and other factors being equal.

While maximum differences in yield of 2-year-old trees were statistically significant, the actual yields were small and bore little or no relationship to the fertilizer schedules or to yields the following season. The poor performance of the trees receiving the C treatment was doubtless due to the trees themselves, for the fertilizer schedule itself was as good or better than A or D. Thus, the yields of the 2-year-old trees may be discounted in that they have resulted from only one season's differential fertilization following dehorning.

When 3 years of age, the trees produced uniformly heavy crops, but again maximum differences in yield between fertilizer treatments significant at the 5-percent level did not seem too logical (except in relation to the performance of the trees as 4-year-olds).

In spite of or because of the very heavy yield as 3-year-olds, the 4-year-old trees which had been and were receiving two and three supplementary applications of ammonium sulfate (treatments E and F, respectively) produced 15 or more pounds of fruit more than treatments A and D receiving none and one early application of ammonium sulfate treatment. Apparently the supplementary ammonium sulfate during the preceding heavy crop year enabled the trees to make the growth needed to produce the heavier crop the following year. The increased yield of approximately 16 lb. per tree would more than pay for the cost of the extra fertilizer applied. This seems to be the most conspicuous instance where time and rate of fertilization have tended to overcome alternate bearing rather than to aggravate the condition.

The yield response of the trees as 5-year-olds was also highly significant although here the differences were reversed when treatments A and D are compared with E and F. The trees of treatments A and D which received less fertilizer the previous season but were bearing a smaller crop were able to make the growth required to produce the remarkably high yields as 5-year-old trees. Conversely, the trees receiving treatments E and F were bearing a much heavier crop in the fourth year and in spite of the supplementary ammonium sulfate were unable to produce the fruiting wood to equal the yields of treatments A and D in the fifth year. Treatments C and B again were intermediate. The surprisingly uniform yield of treatment B, if it can be confirmed further, would justify the practice of increasing rates of fertilization with increasing age and size of tree.

DISCUSSION

The data in table 8 show conclusively that supplementary ammonium sulfate when applied in midsummer or later to trees in heavy bearing (treatments E and F) tends to maintain them in more uniform vigor and to overcome in part at least the violent biennial fluctuations in yield. It seems obvious from all results reported that the 3-year-old vertical or tree is predisposed to produce a heavy crop. The problem seems to be to maintain this vertical in a thrifty growing condition during the heavy crop year. Apparently this can be done in part with supplementary ammonium sulfate applications. Further investigation will be required to determine to what extent the high yield of the 3-year-old trees can be maintained in the fourth year by larger and perhaps more frequent applications of ammonium sulfate or by other means.

However, when the 4-year total and average yields obtained with all treatments were compared it is seen that, as originally stated, there were no outstanding effects due to fertilizer. The differences within the table seem to have been obtained at high cost and to no practical advantage when the 5-year averages alone are considered.

This, however, does not exhaust all possibilities. The experiment might have been concluded after the fourth or even the third year. If, therefore, dehorning were done at such intervals the end result would be as shown in table 9. (Experience has shown that it is impractical to maintain and to harvest an orchard having a large proportion of 5- and 6-year-old verticals. Also, if the practice of complete dehorning has merit as a system of culture (page 23, last paragraph) the length of the pruning cycle must be carefully determined.)

TABLE 9. Average Annual Yield of Coffee Trees for Varying Periods After Dehorning

Av. Annual Yield of Coffee Trees After Dehorning	Av. of Fertilizer Treatments A and D		Av. of Fertilizer Treatments E and F	
	lb. per tree	CWT/A	lb. per tree	CWT/A
First 3 years	31.1	93.3	33.3	99.9
First 4 years	30.7	92.1	36.5	109.5
All 5 years	50.4	151.2	52.4	157.2

By this analysis it appears that supplementary ammonium sulfate as in treatments E and F gave an increase of 2.2 lb. per tree or 6.6 bags per acre per year of cherry coffee more than treatments A and D if a dehorning cycle of 3 years were employed. This would hardly seem to justify the labor and cost of the extra fertilizer. If the pruning cycle were 4 years the added fertilizer would be worth 17.4 bags of cherry per year which would more than justify the practice, particularly if later experimentation determines that the extra fertilizer needed to be applied only in the third year.

A further consideration should be indicated at this time. The data presented were obtained from trees planted on 12-foot centers or approximately 300 trees per acre. Should the trees be dehorned regularly in 3- or even 4-year cycles, they would be smaller than trees 5 or 6 years of age, and more trees might be planted per acre without crowding or greatly reducing the average yield per tree. A 12 $\times$ 9-foot spacing of trees in a 4-year dehorning cycle allowing 400 trees per acre would then yield 146 CWT/A, which is a high yield even by Kona standards.

While supplementary ammonia under the conditions of this experiment seems of greatest advantage in the third year after dehorning, it undoubtedly would be an excellent horticultural practice throughout the Kona District and particularly in the lower elevations during seasons of heavy bearing to maintain growth and to prevent defoliation. Also, if trees were to be dehorned after a very heavy crop it would seem to be good insurance to maintain the trees in a thrifty condition by generous use of ammonium sulfate during the period immediately preceding the dehorning.

EFFECT OF SPACING AND FERTILIZATION ON YIELD OF COFFEE TREES IN A 4-YEAR DEHORNING CYCLE

The growth and yield responses obtained from dehorned coffee trees as described in the previous experiment seemed so promising that a test to demonstrate the practicability of the practice of dehorning successive rows in a 4-year cycle was initiated.

Spacing within the row and differential fertilization of trees of the same age and of different ages were considered to be essential factors to be investigated in the preliminary trial.

Materials and Methods

The experiment was restricted by the size and relative dimensions of the plots of land available. Each plot consisted of four rows of trees spaced 8 feet apart. The trees in the rows in each plot were spaced at 4-, 5-, 6- or 8-foot intervals and there were 9 to as many as 16 trees per row depending upon the width of the field and the spacing.

Each plot of four rows was separated from the next by a row of trees planted at the same spacing as the plot immediately adjoining on the upper side. These trees were trained according to the Kona system (fig. 4A). Plots were duplicated giving a total of eight plots of four rows each.

The four rows of each plot were dehorned in successive years; the first was dehorned in 1951, the second in 1952, the third in 1953, and the fourth in 1954. In 1955 the first row was again dehorned after the first official 1954–55 harvest of the four-row plot. In 1956 the second row was dehorned after the 1955–56 harvest. No nurse verticals were left and dehorning in 1956 was accomplished by use of a power saw rather than the hand saw used in previous years. The above sequence of dehorning will be referred to as the 4-year dehorning cycle in contrast to possible 3- or 5-year cycles.

The 4-year dehorning cycle may be diagrammed as in figure 7 except that the numbers would represent rows of trees of the designated ages in one year rather than the same tree at successive years of age. The appearance of the rows of trees may be visualized also from figures 9 and 10.

The number of trees per acre at the spacings used would be as shown in table 10.

Close spacing between and within rows was practiced, anticipating that the trees might be stunted by dehorning and heavy cropping. Actually the reverse seemed to be true, and it has been found that 8 feet between rows is too close.

Three fertilizer schedules were applied to sub-plots of each plot as shown in table 11.

FIGURE 9. Plot showing 4-year-old dehorning cycle.

Adjoining trees in the row receiving different fertilizer schedules were separated by digging a shallow trench to prevent cross feeding. However, the different-age rows were not trenched as the fertilizer was spread along the row and it was not felt that cross feeding between rows would be a serious problem.

In table 11 it is seen that the average rate of fertilization of the four rows of the dehorning cycle is the same as the annual rate applied to the Kona check trees. The rates of application to the dehorned trees were based in part on observation and experience gained from the previous experiment as well as upon the close spacing practiced.

Presentation of Results

Because of space limitations the experiment may be considered only as an observation test of the growth and yield as well as other responses of the trees. The trees grew unusually well under the fertilization programs and in no way seemed to be adversely affected by the dehorning.

During the course of the experiment, from 1949–1956, it has become apparent that (a) when the 4-year dehorning cycle is employed the 8-foot spacing between rows is too close, particularly under the soil and climatic conditions of the station; (b) the so-called Kona checks adversely affected adjoining test rows by shading; and (c) a 1, 3, 2, 4 sequence of pruning the rows might be of greater advantage from the standpoint of competition between rows and of greater efficiency of sunlight utilization. It was felt that the yield of the 3- and 4-year-old rows was somewhat restricted by mutual shading as well as by shade from the Kona check rows, when adjacent to the 3- or 4-year rows. Nevertheless, it seems worthwhile to present the data for the different age trees in the dehorning cycle and for spacing within the row with the above limitations in mind.

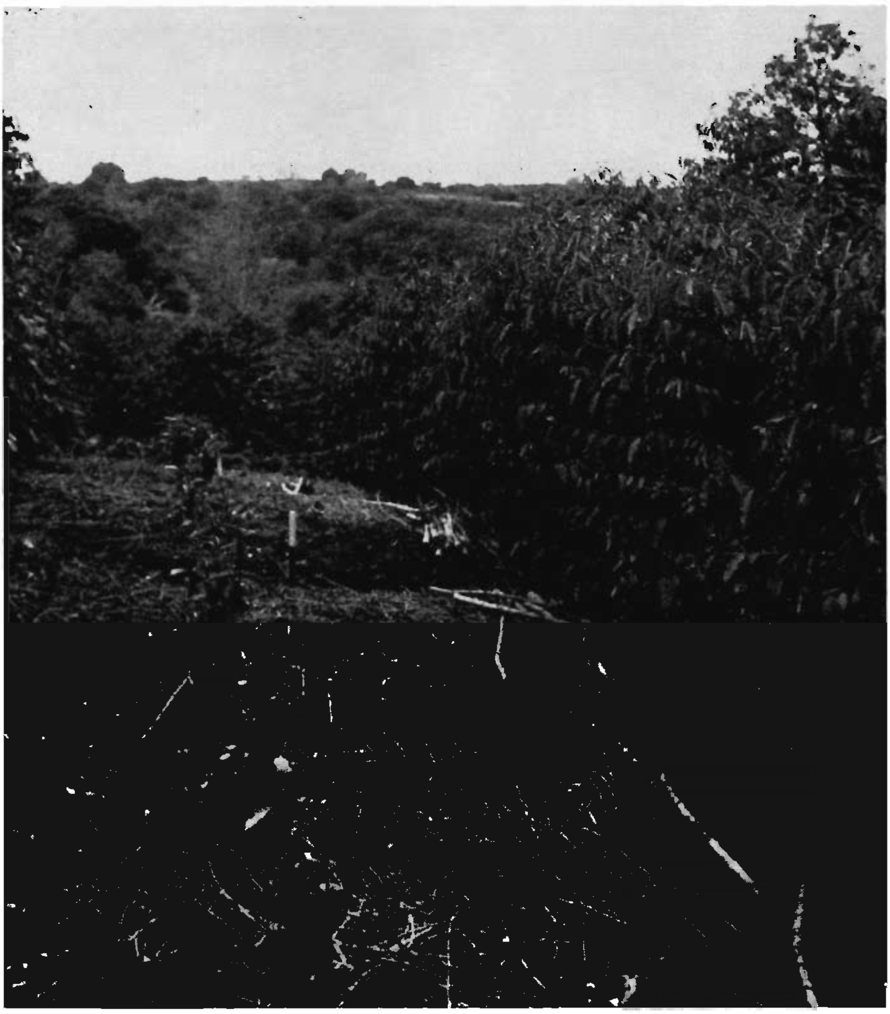

FIGURE 10. Two rows of the 4-year dehorning cycle showing the 4-year-old row of the previous year having been dehorned and the renewal verticals developing to form the new 1-year-old trees. At right is the 2-year-old row that was dehorned 1 year previously. Note the excellent growth of the 2-year-old row which will produce at the rate of 40 to 50 CWT/A of cherry coffee.

TABLE 10. **Number of Trees Per Acre at 4-, 5-, 6-, and 8-foot Spacing in the Row and 8 Feet between Rows**

Spacing Feet	Number of Trees Per Acre
8 × 4	1,361
8 × 5	1,089
8 × 6	907
8 × 8	680

TABLE 11. **Fertilizer Schedules Followed for Each Age Row of Trees**

	Fertilizer Treatment Schedules			
Age of Tree	A	B	C	
Years	lb. per acre	lb. per acre	lb. per acre	
1	400*	600*	400*	200†
2	800	1200	800	400 lb.
3	1400	2100	1400	700 lb.
4	1400	2100	1400	700 lb.
Kona Check	1000	1500	1000	500 lb.

*The basic fertilizer was a 10–5–20 (N-P_2O_5-K_2O) formulation applied in two applications, ½ on March 1 and ½ on June 1.

†Supplementary ammonium sulfate was applied ⅓ on April 15, ⅓ on July 15, and ⅓ on September 1.

The field and the design are such that no differences due to fertilization were apparent.*

Yield Data

The yield data for two complete harvests are presented in table 12 as CWT cherry coffee per acre by age of row per plot without regard to differential fertilizer treatments. The 1-, 2-, 3-, and 4-year-old rows of 1955 becoming the 2-, 3-, 4-, and 1-year-old rows, respectively, of 1956. The average yield of rows 1 to 3 years of age, inclusive, and of rows 1 to 4 years of age, inclusive, are given in the table in order that comparative yields of the 4-year and of a probable 3-year cycle may be compared. Obviously, however, the yield of a 3-year dehorning cycle might be quite different from that of the first 3 years of a 4-year cycle. The yields of the rows of trees trained to the Kona system at the various spacings in the row are given in column 3 of the table. Further limitations in the data are indicated in the table.

With these reservations and those noted in the table, a study of the data revealed very little if any effect of spacing in the row upon yield. The Kona trained spacings were unreliable because of obvious field defects. The dehorned rows also showed little or no practical difference in yield due to

*Data for 1956–57 when combined with those of the crops reported herein show statistically significant increases in yield due to fertilizer schedules B and C over A, thus substantiating earlier work (page 28).

TABLE 12. Yield of Cherry Coffee of Trees Pruned to the Kona System and of the Rows of Trees in a 4-Year Dehorning Cycle When Planted at Four Spacings in the Row with Rows Eight Feet Apart

Spacing of Plants in Row	Harvest Year	Kona System	Dehorning System					
			1-Year-Old Row	2-Year-Old Row	3-Year-Old Row	4-Year-Old Row	Av. Rows 1–3 Years	Av. Rows 1–4 Years
Feet		CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A
4	1954–55	191.4*†	0	53.6†	352.3†	244.0†		
	1955–56	188.8*	0	47.0	347.5	181.7		
	Av.	190.1*	0	50.3	349.9	212.8	133.4	153.2
5	1954–55	131.0	0	56.9	326.1	217.9		
	1955–56	189.5	0	45.5	331.6	188.3		
	Av.	160.2	0	51.2	345.6	203.1	132.3	150.0
6	1954–55	151.6	0	39.8	357.1	187.8		
	1955–56	171.5	0	44.7	328.3	184.7		
	Av.	161.6	0	42.4	342.7	186.2	128.4	142.8
8	1954–55	124.1‡	0	29.0‡	269.5‡	189.8		
	1955–56	99.8‡	0	33.0‡	260.9‡	190.3		
	Av.	144.0	0	31.0	265.0‡	190.0	98.7‡	121.5‡

*High yield due to outside position of one row.

†Figures represent the average of duplicate plots.

‡Low yields due to poor soil condition at one end of field.

spacing within the row when the 3-row and 4-row averages are considered with the possible exception of the 8-foot spacing which was low because of other factors in addition to spacing. With 50 percent more trees per acre there was little if any yield advantage of a 4-foot over the 6-foot spacing. Perhaps the close spacing between rows minimized differences in spacing within rows.

Of particular significance were the extremely high yields of the 3-year-old dehorned trees which, when averaged with the yields of the 1- and 2-year-olds, indicated the yield per acre that might be expected on a field scale for a 3-year dehorning cycle. While the yield per acre of approximately 130 bags was low compared with that of the older* Kona pruned trees, they were very high when it is considered that practically the entire crop was borne on one-third of the trees planted. The 4-year dehorning cycle gave surprisingly good yields for the 4-year-old row itself and for the average of the four rows when compared to Kona pruned trees. These results substantiate the statement made earlier that close spacing of dehorned trees (i.e., closer than 12 $\times$ 12 feet) would increase yield per acre.

The good yield of the 4-year-old trees following the very heavy yields of the 3-year-olds in this experiment was encouraging. Perhaps the closer spacing reduced the individual tree yield in the third year to such an extent as to permit the higher yield of the tree in the fourth year. The four-row average yield is in line with that which might have been anticipated from the earlier experiment by increasing the number of plants per acre.

Growth Data

To analyze any differences in rate or character of growth due to the dehorning system of pruning with resultant differential yield performance, a further study of growth of the trees similar to that previously reported was made. In contrast to the previous study (2) only 4-year-old verticals were selected and sectioned into their various age components. One 4-year vertical from each of eight trees in each pruning system was selected after harvest, or a total of 16 verticals. Suitable verticals of the Kona trees were more difficult to find because many had been either broken or bent in preceding years. Also, good verticals could be found only in the wider spacings. Thus there is a definite bias in the data favoring the Kona system, in that malformed verticals were disregarded while with the dehorned trees malformed verticals rarely occurred. Thus this method of selection tends to mask certain weaknesses in the Kona system which are largely attributable to training replacement verticals in shade and in competition with older verticals on the same tree. The data are presented in numerical and graphic form in figure 11.

A detailed study and comparison of these data representing the 4-year-old vertical from the two systems of training (Kona versus dehorned) show a remarkable similarity in spite of the drastic differences in pruning and culture. Other than the difference of 14.7 inches in height favoring the

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*Older because of the 4-year-old vertical in the Kona tree.

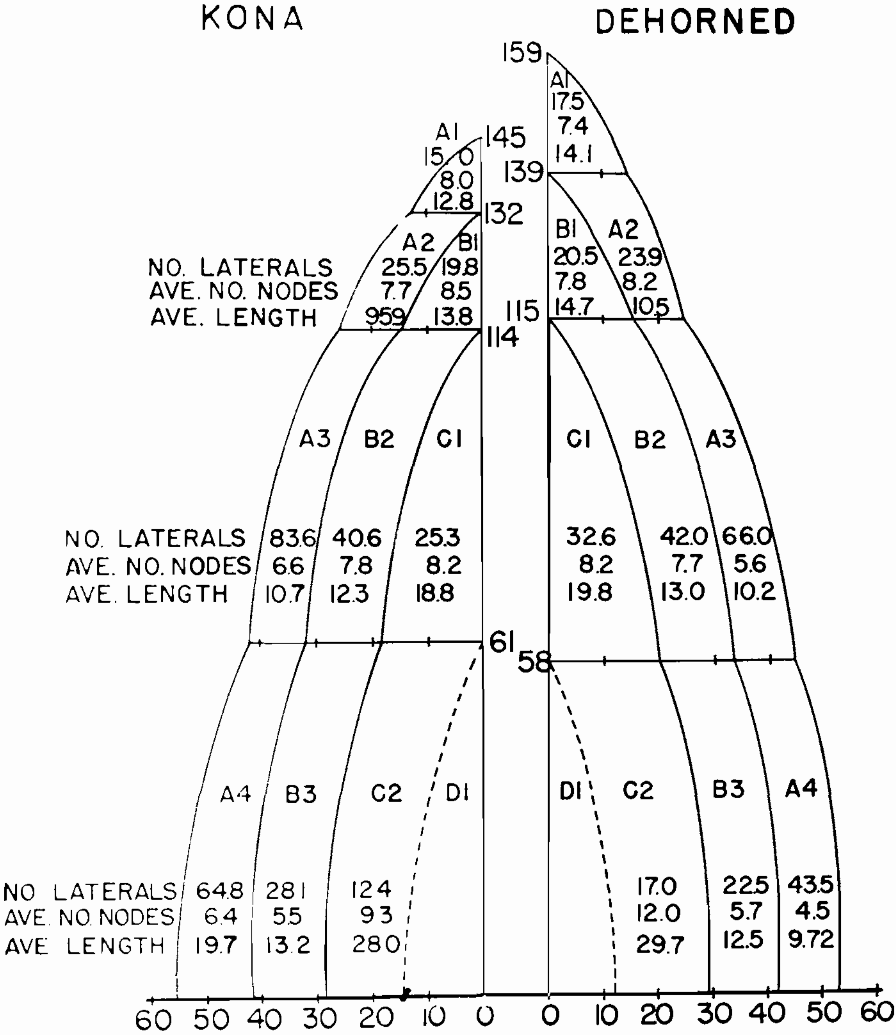

FIGURE 11. Diagram of growth behavior of the 4-year-old verticals on trees pruned by dehorning and by the Kona system. As in figure 8, the A, B, C, and D areas represent the 1-, 2-, 3-, and 4-year-old portions, respectively, of the lateral and vertical branches. The figures in each section give the average number of laterals of each age; the average number of nodes per lateral; and the average length in inches of lateral. The cumulative height in inches of the vertical is shown on the vertical lines and shows the 4-year vertical of the dehorned tree to be taller than the 4-year-old vertical of the Kona tree. In the C and D portions of the vertical of the dehorned tree, the greater number of laterals indicates a higher potential yield in the third year, while in the A and B sections, the greater number of primary and secondary laterals of the Kona tree indicates a greater potential yield the fourth year. (See text.)

dehorned tree and the greater proliferation of secondary lateral growth favoring the Kona tree as indicated by comparison of sections B_3, A_4, and A_3, the two types of verticals are essentially equal. Moreover, these differences are not in great contrast to the findings reported earlier (*2*) when verticals of four ages were composited.

The two methods of measurement indicate remarkably similar over-all results and in fact emphasize the rather significant fact that the two types of training result in essentially the same type of 4-year vertical. Actually the average 4-year-old vertical of the dehorned tree was as good if not better than that of the Kona tree, particularly if the number of bent or broken verticals in the Kona trees is considered. However, from data accumulated to date, the fact remains that the Kona type trees yield somewhat better than the dehorned tree.

Discussion

The above test represents the initial trial of a system of coffee culture which involves not only the practice of dehorning but of spacing plants in the row and of differential fertilization. The system recognizes the growth and bearing habit of the tree and the apparent need to apply fertilizers of the kind and amount required for the potential crop on each age of tree as well as that required to produce the growth for a succeeding crop. Extensive observations have resulted from these initial experiments which are being tested in new experimental plantings. Some of these observations may be stated as follows:

When a 1, 2, 3, 4 sequence of dehorning in the rows in the 4-year cycle is followed, at higher and cloudy elevations, a spacing of 8 feet between rows is too close, resulting in shading and presumably a lower yield of the 3- and 4-year-old verticals, particularly under conditions of good soil and heavy fertilization. The lower branches in particular are shaded and do not produce as well as they might with better light and the trees tend to grow very tall. The shading resulting from close spacing between rows apparently minimizes the effect of spacing within the row, since the yields of trees spaced 4, 5, and 6 feet within the row were approximately equal. However, with a wider spacing between the rows, it is possible that spacing within the row would become more significant; on poor soils with less vigorous growth, closer spacing within the row also might result in higher yields.

Not only would the wider spacing between rows possibly increase yield but it also would contribute to ease of harvesting and to ease of other field operations. It has been noted that when dehorning is employed, the renewal verticals developing in full light are very sturdy and seldom if ever require artificial support. However, the common practice of bending over the verticals to harvest the fruit would not be possible without breakage, and a ladder would be required. With wider spacing between rows and good light conditions it is possible that the trees would produce more fruit close to the ground and would not grow quite so tall. Also, with the wide space available because of the dehorned row it might be possible to bend over the oldest verticals for ease of harvesting even at the possible expense of some breakage since the vertical would later be removed by dehorning and no permament damage to the tree would result.

SUMMARY AND CONCLUSIONS

In preceding sections an attempt has been made to evaluate a number of factors affecting the growth and yield performance of the coffee tree (*Coffee arabica* var. *typica*) in the Kona District of Hawaii. The discussion is based primarily on trees growing under favorable light, moisture, and soil conditions at 1,500 feet elevation and without competition of shade trees. Responses of the trees were not affected by fungus diseases or destructive insects.

Fertilized, unpruned trees naturally fall into a rather extreme alternate bearing cycle because of the dominant inverse relationship of yield and growth in the same year. Adverse weather is a definite factor in initiating alternate bearing cycles.

The alternate bearing habit occurred with topped trees and was aggravated by fertilization. These experiments demonstrated conclusively the importance of fertilization to improve yield of coffee trees but also emphasized the problem of controlling in some degree the alternate bearing tendency of the plant aggravated by heavy cropping. Control of the size and age of tree by pruning and of the growth or vigor of the trees by fertilization was attempted.

In a pruning experiment in which total age of the verticals per tree was one variate and rate of fertilization the other, those treatments that reduced the age of the oldest vertical even though the average age per tree of all verticals was approximately equal tended to equalize alternate bearing but also reduced total yield. The trees with younger verticals but with more verticals per tree yielded less but more uniformly than trees with fewer but older verticals. The reduction in yield was considerable and it was postulated that the difference might be overcome by closer spacing of the more heavily pruned and smaller trees and still retain uniform annual yield.

Age of vertical is an important consideration not only in the type of growth produced, bearing habit, and yield of the tree, but also in relation to management. The responses of given ages of verticals to various treatments were studied in a replicated experiment in which number of verticals per tree, various fertilizer practices, and number of verticals were variables.

Heavy fertilization, i.e., supplementary applications of ammonium sulfate in the third or heavy crop year increased the yield in the fourth year, i.e., tended to overcome alternate bearing. Similar treatment in the fourth year did not prove profitable.

When the yields of the 5 years or five ages of trees are totaled there seem to be but minor differential effects of fertilizer since even the minimum applications seemed fairly adequate. However, if the experiment were concluded after the fourth year, the total yield of the treatments receiving the late applications of ammonia in the third year would more than justify the expenditure for supplementary ammonium fertilizer. Moreover, judging by appearance and condition of the tree, the treatment would seem to be a good horticultural practice, in that defoliation, sunburn of the fruit, and dieback were alleviated or prevented.

The 5-year average yield during which the trees were increasing in age from 1 to 5 years may of course be compared with the annual yield of a tree having five verticals ranging in age from 1 to 5 years. While such checks could not be maintained, it is apparent by comparison with yields in the previous experiment that no great sacrifice in yield occurred due to the dehorning. It is again apparent also that should the pruning cycle be concluded after the fourth or even the third year the trees would be smaller and could be spaced closer than the 12 × 12-foot spacing employed. For example, a 12 × 9-foot spacing would increase the yield of the third and fourth treatments by about 25 percent, which would seem to justify the practice of dehorning on a yield basis alone.

These facts, combined with the great hardiness and response of the dehorned trees, led immediately to the test of dehorning successive rows of trees in plots of four rows with trees spaced at different distances within the row and fertilized in proportion to age.

Due to soil variability and limited experimental area, no statistically significant differences due to either fertilization or spacing were demonstrated in an experiment testing a 4-year dehorning cycle. Spacings 4, 5, and 6 feet in the row were approximately equal. Yields of a possible 3-year dehorning cycle compared with a 4-year cycle favored the 4-year cycle as in the previous experiment because of the greater proportionate yield of the 4-year-old trees. The yield of the Kona pruned trees was consistently greater than the average 4-year yield of the dehorned trees. However, even the 8 × 8-foot planting distance was obviously too close for Kona pruned trees.

Growth measurements of 4-year-old verticals taken from Kona and dehorned trees were practically identical in most respects, indicating that dehorning apparently does not affect growth materially even though the apparent yield may be reduced somewhat.

Observation indicated that the 3- and 4-year-old rows shaded each other and that dehorning of alternate rows, i.e., in a 1-3-2-4 sequence, might yield better results. Under the conditions of the test, the 8-foot spacing between rows is too close for the 4-year dehorning cycle but undoubtedly would be about right for a 3-year dehorning cycle.

Heavy fertilization of the 3-year-old row would seem to be a good horticultural practice in that it helps to maintain the growth and foliage of the third year and if so contributes to the yield of the fourth year. Should the rows be dehorned after the third year crop, they would be more likely to respond if the trees were in good physical condition due to fertilization.

The test demonstrated that under Kona conditions the systematic dehorning of rows of trees as a commercial practice may be entirely feasible so far as health and vigor of the tree is concerned, that no material sacrifice in yield occurs, and that other advantages may materialize.

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