HAWAII AGRICULTURAL EXPERIMENT STATION
HONOLULU, HAWAII

Under the joint supervision of the
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BULLETIN NO. 75

COFFEE CULTURAL PRACTICES IN THE KONA DISTRICT OF HAWAII

By

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and
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INTRODUCTION

Coffee production is an established export industry in no less than 52 different countries throughout the tropics. One country, however, Brazil, produces 70 percent of the total world output. The coffee-producing area of Brazil is situated chiefly on a vast plateau, unbroken by gullies or ridges. Cheap, plentiful land and adequate transportation facilities have made possible the development of a modern agricultural industry. The ideal climate obviates the need of shade and production costs are very low. Cultivation is effected by machinery. Fertilization and pruning are reduced to a minimum. Harvesting consists of stripping all the coffee cherries from the trees at one time. A single plantation often comprises 2,000 to 3,000 acres.

In contrast to the Brazilian coffee industry, production in other countries is essentially one of small areas in upland hilly country, relatively inaccessible and generally unadapted to extensive methods of production. Many of these countries, however, produce coffees of exceptional flavor and quality, the so-called mild coffees of commerce. These are especially adapted to blending with the cheaper Brazilian coffees, so that in spite of higher costs, such districts occupy an important place in the world coffee markets.

Cultural methods differ widely in the various countries due to the great differences in climate, geography, and economic conditions. The methods employed are largely the outgrowth of experience of the individual growers of each district. There exists little fundamental information based on careful and exact field experiments with which to substantiate the present cultural methods or to recommend changes in the methods.

Since the establishment of the substation at Kainaliu in the Kona District, Island of Hawaii, in 1930, the Hawaii Agricultural Experiment Station has been conducting numerous experiments on the various phases of coffee culture. These include investigations of soils, fertilizers, pruning, composting of coffee pulp, importation of new varieties, propagation of coffee by vegetative means, budding, and grafting. Some of these investigations will require many years before complete results can be obtained. In a number of instances, they have already yielded information of practical value.

It is the purpose of this bulletin to present the tentative results of the station's experiments on the various phases of coffee cultural methods in the Kona District. In addition, the cultural methods used in other parts of the world are described and these are compared with the methods used by the Kona coffee grower. These latter represent the consensus of the most successful and progressive planters of the district and can thus serve as a guide to coffee culture, based on the best information available. This practical information, together with the fundamental scientific data regarding the coffee plant that is gradually being accumulated, constitutes a sound basis for improvement in the cultural practices of the Kona District.

REQUIREMENTS OF CLIMATE AND SOIL FOR COFFEE CULTURE

Coffea arabica, the species grown in Kona and the principal commercial coffee of the world trade, requires what has been aptly called "a temperate climate in the tropics." It will grow under a wide range of conditions as to altitude, temperature, and rainfall, but any great deviation from the optimum seriously affects growth, yields, and quality of coffee. Commercial plantings exist throughout the tropics and subtropics from 28° N. latitude to 38° S. latitude. Many different kinds of climates are encountered; for example, the monsoon climate of India with its definitely dry and wet seasons, the island climates such as that of Hawaii, moderated by the surrounding ocean, and the continental climates of Brazil and East Africa, with their greater fluctuations in temperature.

Altitude. Coffee plantings are found from sea level to an altitude of 7,000 feet. In the Kenya region of East Africa, the plantings are all above 4,000 feet up to 7,000 feet; in Malay, 2,000 feet to 4,000 feet; in Colombia and Costa Rica, from 3,000 to 6,000 feet. In Brazil, the famous Sao Paulo region is from 1,800 to 3,000 feet above sea level. In the Rio de Janeiro section, however, the coffee area extends as low as 800 feet. The most desirable altitude varies with the district. The importance of altitude is chiefly in its effect on temperature, rainfall, and humidity, but it has been said that the atmospheric pressure also has an effect, the lower pressure of the higher levels stimulating the growth of the coffee tree. Of the three commercial species, *C. liberica*, *C. robusta*, and *C. arabica*, the first two are best adapted to lowlands. In Malay, *liberica* is planted in the coastal region and *robusta* between 1,000 and 2,000 feet altitude. *Arabica*, which is the only species grown in the Kona District, is best suited to high altitudes.

TEMPERATURE. This is an important factor. The average annual temperature of most of the important coffee-growing districts is about 70°. In Sao Paulo, the greatest of the coffee-producing states of Brazil, the annual average temperature is 68°; the average minimum is 63°, and the average maximum, 77°. Temperature extremes of 50° or 85° are not prohibitive but greatly retard growth and yields. Frosts and cold winds are particularly damaging; a few hours with the temperature close to freezing will kill the coffee trees or retard their growth for several years. One of the chief needs for shade in coffee culture in many regions is to reduce fluctuations in temperature. It reduces excessive day temperatures and protects the trees against cold night winds.

RAINFALL. Successful coffee production is possible with as little as 30 inches of rain or as much as 100 inches annually. In most regions it varies from 40 to 70 inches. Distribution is a more important factor than total rainfall. Definite seasons, one wet and one dry, are generally regarded as most desirable in that the cycle of vegetative growth, flowering, maturing of fruit, and rest period of the tree is a definite one. With uniform distribution of rainfall, a certain amount of flowering and fruiting occurs throughout the year. In Sao Paulo, the ideal distribution of rainfall is said to be from 8 to 14 inches rainfall per month for 6 months after the first blossom, from 2 to 4 inches during the next 3 months, and none during the following 3 months, which is the picking season. Rain during this season starts premature flowering. In Colombia, rainfall distribution produces two crops, one in spring and one in the fall, with some picking throughout the year. In most places, however, one crop is produced, maturing over a period of from 3 to 4 months, five pickings being generally necessary. While coffee requires plentiful moisture, an excess is undesirable because it stimulates vegetative growth at the expense of fruiting.

TOPOGRAPHY AND SOIL. It is universally agreed that coffee requires a soil with good drainage. In flat areas or on very heavy clay soils, the trees die out. Unless the soil is very loose and open, the topography must be sufficiently rough and sloping to permit drainage. This fact, together with the need for higher altitudes, has restricted the coffee-producing regions of the world to the hilly uplands and in a few instances, to high, relatively level plateaus with deep, porous soils.

Coffee Quality as Affected by Location

The flavor or "cupping quality" of coffee is greatly affected by climate and soil. In Brazil, the Santos coffee is grown chiefly on deep, porous soils at elevations of 1,800 feet or above. Its flavor is characteristically mellow and "soft" in contrast to the "hard" coffee, with a rank, penetrating flavor, grown at the lower elevations adjoining Rio de Janeiro. In each of the countries producing the so-called "mild" coffees, various grades are established. These grades are based on the exact locality in which the coffee is grown. Generally speaking, the finest flavors are produced in the highest altitudes. Beans grown in the upper regions are heavy and flinty, with a high acidity and a strong flavor, characteristics desirable for blending. The lower altitudes produce lighter beans with less acid flavors, which command a distinctly lower price. Coffee flavor is subject to considerable variation in the same locality from time to time, depending on the weather. The soft, mellow Santos coffee tends to become harsh and "rioy" during periods of dry weather.

Hawaiian-grown coffee is rated as among the finest. Ukers, in his book *All About Coffee* states, "All Hawaiian coffee is high grade and is generally large bean, blue-green in color when new crop and yellow-brown when aged. It makes a handsome roast and has a fine flavor that is smooth and not too acid. It blends well with any high-grade mild coffee. Old Kona coffee is said by some trade authorities to be equal to either Mocha or 'Old Government Java.' "

PHYSICAL FEATURES OF THE KONA DISTRICT AFFECTING COFFEE CULTURE

The Kona District, situated on the leeward slopes of the two volcanic mountains, Hualalai and Mauna Loa, includes a series of climatic zones. The slope is relatively steep, 700 ft. to 1,500 ft. to the mile, so that the zones are rather narrow and roughly parallel to the coast line. The lowest zone, which extends from sea level to about 800 feet, receives from 25 to 40 inches of rainfall a year and is too arid and hot for coffee culture. The next zone, referred to as the "lower humid zone," lies between 800 and about 2,200 feet altitude. The annual rainfall increases from about 40 inches a year at the lower edge to 80 inches or more at the upper. This zone, which is about 2 miles wide and some 25 miles in length, contains all the present coffee plantings in Kona. Above this is the so-called rain belt, a narrow strip less than a mile wide in which the heavy rains and limited sunshine render agriculture impossible most of the year. Above the rain belt lies the "upper humid zone". Here the conditions are reversed and the rainfall decreases with increasing altitude. This zone resembles the lower humid zone in rainfall and general climate except for the effect of greater altitude. Above this, beginning at about 4,000 feet, is the "upper arid zone," where the rainfall has dropped to 40 inches or less. These two upper zones are at present used only for grazing.

This zoning effect is due to the fact that the two mountains to the windward are sufficiently high, Mount Hualalai being 8,251 feet and Mauna Loa, 13,675 feet, to completely deflect the normal trade winds and give to the district its mild, equable climate. Instead of the trade winds, there is the so-called "land-sea breeze" system of air circulation resulting from the different rates of warming and cooling of land and sea. Each morning there is a gentle breeze from sea to land, while in the afternoon the direction is reversed, from land to sea. Each morning the warm moisture-laden air comes in from the sea. As the air rises, it cools and clouds begin to form. As the process continues, a continuous cloud blanket forms along the slope, beginning at an elevation of about 2,500 feet and gradually spreading out to sea. Rain begins to fall in the early afternoon and continues throughout the day, gradually progressing down the slope with the seaward movement of the cloud blanket. During the night the clouds are gradually dispelled. This cloud blanket forms almost daily during the warm summer months when the coffee trees are maturing their crop and are in most need of shade. It is thus possible to grow coffee at altitudes as low as 800 feet without shade trees. Except for an occasional Kona storm from the south, the climate of the district is remarkably quiet and balmy, the gentle land-sea breezes being the only form of air circulation.

Figure 1 shows the distribution of rainfall throughout the year at Kealakekua (1,500 ft.). Figure 2 shows the variation in the annual amount of rainfall over a period of 15 years. It is interesting to note that the rainy season is the reverse of that of the districts which are touched by the trade winds. In the latter, the winter months, beginning with November and extending through March, are the wet months and the summer months are dry. In Kona, the months of November to March are relatively dry. The rains begin in March or April and continue well through September or October. Thus the periods of ample rainfall coincide with the warm spring and summer months when the coffee tree is blossoming, maturing its crop, and making its greatest vegetative growth. During the dry months, from November to February, the coffee is picked. The tree during this period almost ceases its vegetative growth and enters into a semi-rest period until the spring rains stimulate blossoming for the new crop. This situation approaches the conditions generally regarded as ideal for coffee, namely, a moist humid period of about 6 months during the blossoming and maturing of the crop, a decrease in rainfall during the subsequent 3 months, followed by 3 months of dry weather to facilitate picking.

The average annual temperature at Kealakekua (24 year average) is 68.5°F. The average minimum is 60.6°, and the average maximum, 76.8°. These figures coincide almost exactly with what is considered the best in Brazil, where the most desirable average annual temperature is given as 68°; 63° the average minimum; and 77° the average maximum. The highest and lowest temperatures recorded at Kealakekua in 24 years are 88° and 48° respectively. Neither of these extremes is near the limit at which actual injury to the coffee plant results.

The number of cloudy days in a year (days with .01 inch or more of rainfall) averages 176 at Kealakekua. Reference to Figure 1 shows that this fluctuates with the total rainfall, the greatest number being during the summer months. Variation in annual rainfall

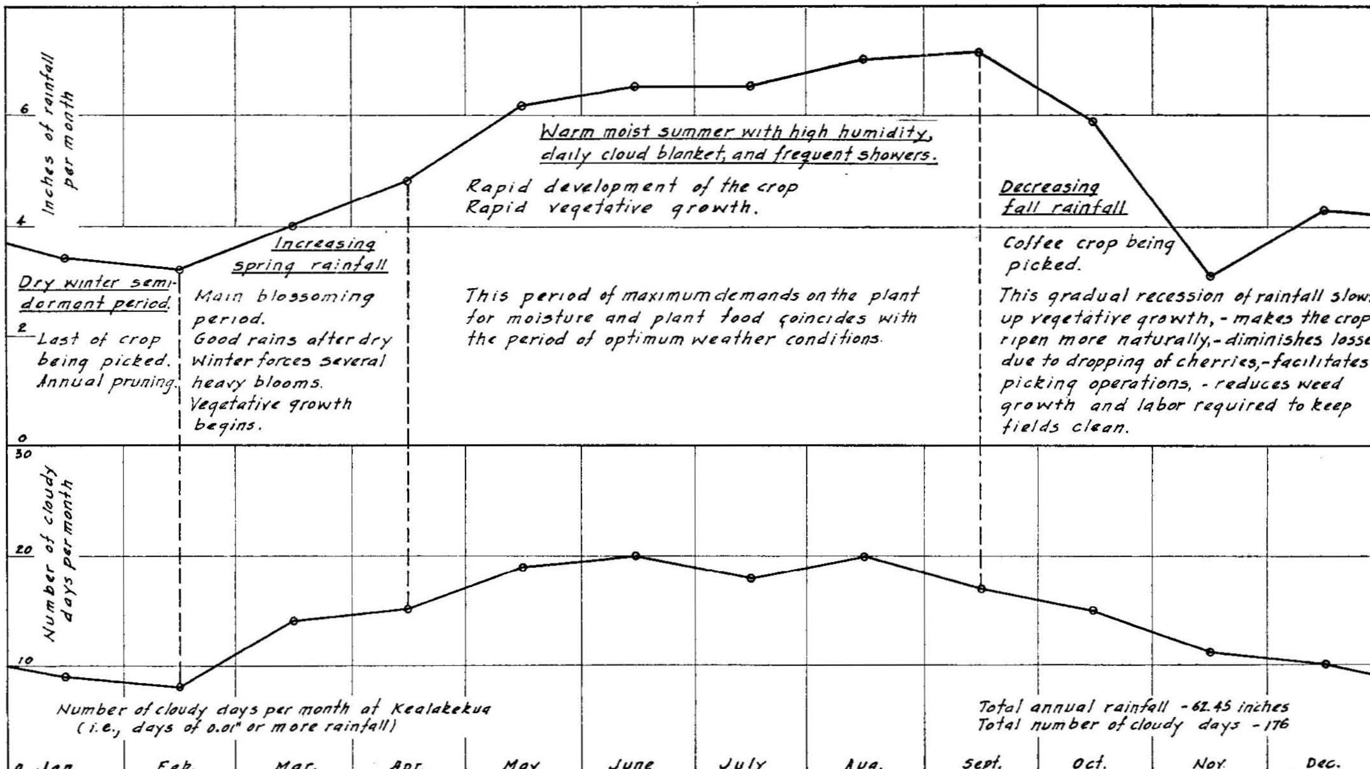

FIGURE 1—Showing distribution of rainfall throughout the year at Kealakekua (altitude, 1500 ft.) and how this distribution is ideally adapted to coffee culture.

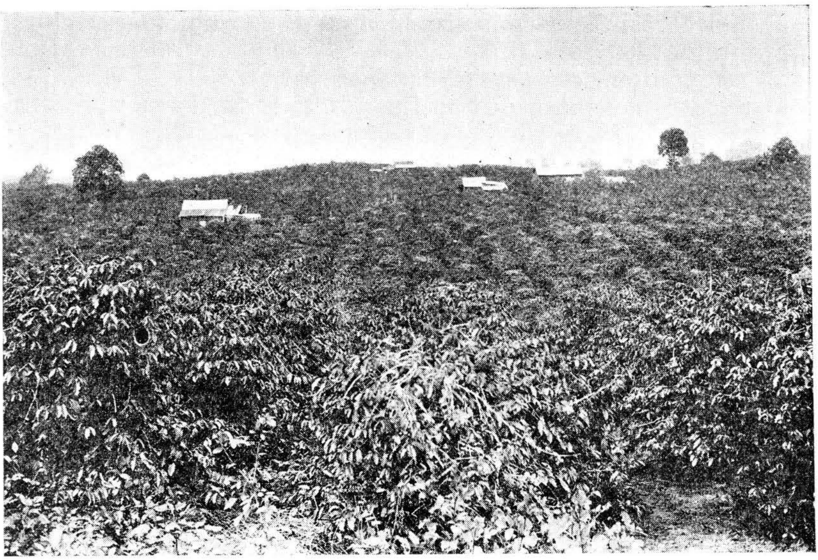

Plate 1. Growing Coffee without shade in Kona. The daily cloud blanket and frequent showers of the Kona District furnish the shade and high humidity so desirable in coffee culture. This photograph was taken from an altitude of 2,200 ft. looking down toward the sea.

(Fig. 2) is considerable, but the lowest figure, 45 inches in 1919, is still within the limits prescribed for coffee. These climatological data are for the altitude of 1,500 feet, which roughly parallels the main Government road. Most of the present coffee area lies within a range of 500 feet in altitude on either side.

Relation of Coffee Cultural Methods to Climatic Zones

The great differences in climate which occur with relatively small differences in altitude obviously have a marked effect on coffee culture. At the lower edge of the present coffee plantings, there is an excess of sunshine with a minimum of moisture. Here the problem is to conserve moisture, adopt pruning methods which produce more shade and the greatest production for a given amount of vegetative growth. At the upper edge, there is often a surplus of rainfall with limited sunshine. Here the problem is to provide good ventilation and to prevent excessive vegetative growth. The various pruning systems used are, to a considerable extent, an adaptation to these climatic factors. In the lower levels the rainfall is very seasonal giving rise to periods of profuse blossoming, fruiting, and rapid vegetative growth. The dry periods which follow produce semi-dormancy of the tree. Such conditions result in dieback of the coffee tree and maximum labor requirements for short periods. In the upper levels, the climate is much less seasonal, with the result that blooming, fruiting, and growth proceed to a certain extent throughout the year. Here the problems are those of excessive costs of frequent prunings, of transportation, etc.

Thus far, little attempt has been made to vary fertilizer practice with the zone. The present practice is to use a fertilizer of uniform composition for the high humid areas as well as the low, dry sections. It seems probable that the results of further experimentation will show the feasibility of adapting the fertilizer formula to the climatic zone.

HOW THE COFFEE TREE GROWS

The coffee plant produces two kinds of branches, verticals (also called uprights, shoots or stems) and laterals. The vertical stem, as it develops, produces lateral branches. These develop in pairs in the axils of the leaves. They can set on only as the stem is developing, and if one is destroyed, a new one cannot develop in its place. New stems emerge from the leaf axils of the parent vertical, just beneath the laterals. These may set on at any time during the life of the parent vertical. On old stumps these new stems result from the development of so-called adventitious buds. Stumps 50 years old are still capable of producing a profusion of such buds. In the axils of the leaves of the primary lateral branches are buds which develop into secondary lateral branches, identical in form with the primary laterals. Similarly, tertiary laterals develop on the secondaries. This sublateral development may take place at any time during the life of the parent lateral. One or several can develop at each node.

In the early growth of a vertical, the development of other verticals on its surface is inhibited by the terminal (or end) bud. Given good growing conditions, this inhibition is effective until the terminal growth of the parent has largely ceased. The side verticals then begin to develop along the stem, the lowest usually being the most vigorous. If, however, the terminal bud is removed before it has lost its vigor, the shoots setting on closest to the top develop the most rapidly.

The effect of light on the development of buds has been studied by different investigators and, contrary to the general belief, is not important. If the vertical is bent over from the upright position 40 degrees or more, the terminal bud loses its inhibitory power and the side buds then develop. Under such conditions, the buds lowest down develop more rapidly than those higher up and, once they begin to grow, they become as vigorous as the parent, even though it is returned to an upright position. In case the vertical is bent over and held down, the terminal bud loses its vigor. The side verticals on the upward slope (i.e., from the base of the tree to the top of the arch) develop vigorously. On the down slope, buds develop weakly or not at all. Girdling the vertical, notching, or otherwise bruising the surface induces development of side verticals.

In lateral development, the terminal bud of the primary lateral inhibits development of secondary laterals until its vigor has receded. If the terminal lateral bud is removed while it is still vigorous, the secondary laterals nearest the end will develop the most vigorously. If terminal growth has lost its vigor, the sub-laterals closest to the vertical will be more vigorous. With either vertical or lateral,

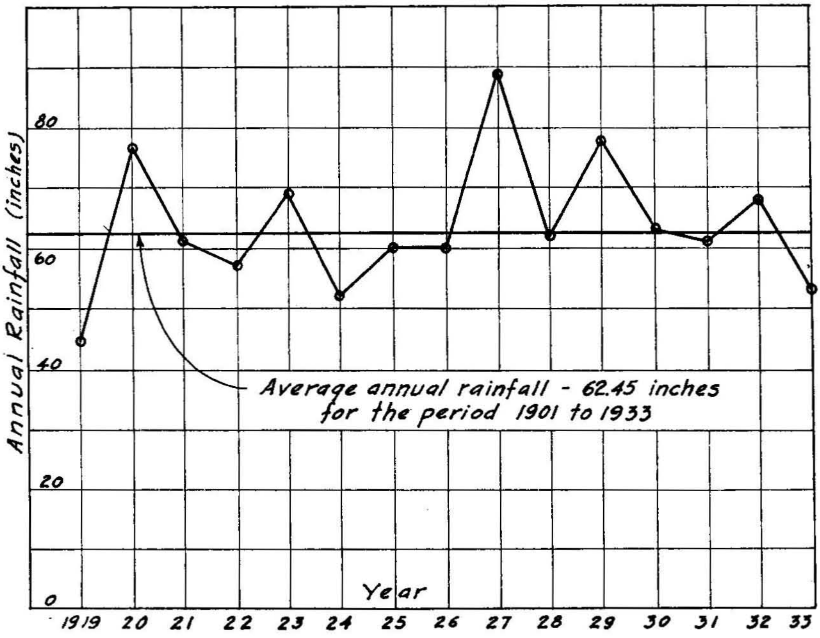

FIGURE 2—Fluctuations in annual rainfall at Kealakekua (altitude, 1500 ft.) during the period 1919-1933.

the strong development of a side shoot or sub-lateral causes the growth of that portion of the parent beyond it to become very weak.

In every plant, the above-ground part of the tree and the root system tend to balance one another. Pruning operations, which remove a certain part of the top growth, thus create an unbalanced condition, and the plant endeavors to restore the balance through development of vegetative buds. Pruning of laterals back to the first or second node forces sublateral development more quickly and vigorously than if the lateral is left unpruned. Likewise, if a vertical is removed, strong development of numerous new shoots on the stump begins, provided of course the tree is in a good, healthy condition. The greater the amount of wood removed, the greater will be the unbalance and the greater will be the tendency to develop new wood. Hence the saying, "Pruning begets more pruning." Growth may be forced into different parts of the tree by different pruning methods. The topping system, whereby the vertical is cut off at 6 or 7 feet, and no more verticals allowed to set on, forces strong development of lateral growth. The laterals in the top section of a vertical may be made more vigorous by pruning off the lower laterals close to the vertical.

While light may have little effect in forcing the development of buds, it is a vital factor in its effect on the new growth. Inadequate light causes weak, slender growth of both verticals and laterals, with long internodes. This means few laterals on the verticals and small bearing surface on the laterals. With adequate light, the new growth is stocky and shortnoded, with numerous laterals and plentiful bearing surface. One of the chief problems in the management of the coffee tree is the proper regulation of light. Opening up the top growth through pruning not only stimulates the development of vegetative buds, but makes them develop more sturdily because of the greater amount of light available.

Fruit buds develop in the leaf axils of the laterals chiefly in the growth produced during the previous season. The aim of the various cultural operations, such as pruning and fertilizing, is to produce on each tree enough new wood each year to provide ample bearing surface without an excess sufficient to cause overbearing. The relation of fruiting to vegetative growth is greatly influenced by temperature, rainfall, soil, fertilizers, as well as light intensity. With the proper balance of these factors, bumper crops result. With high rainfall, excessive shade, and rich soil, vegetative growth is overstimulated at the expense of fruiting. Low rainfall, strong light, and a less rich soil tend to stimulate fruiting and repress vegetative growth.

STARTING A NEW COFFEE ORCHARD IN KONA

Selecting the Site

The value of land for coffee culture in Kona is largely dependent on altitude. Below 800 to 1,000 feet, limited rainfall and an excess of sunshine limit the growth of the tree. Above 2,200 feet, the excess of rain and lack of sufficient sunshine limit production. Other things being equal, the central belt is the most desirable. Accessibility is an important factor. With the advent of the automobile and the building of new roads, frontage on the main Government road is not so important as heretofore. Some sort of road, or at least a good trail to a not too distant road, is an important factor in the cost of transportation of crop and supplies. The nature of the vegetation on the proposed site should be taken into consideration, as the cost of clearing varies tremendously with the kind and amount of growth.

A deep, fine-textured soil is not necessary for coffee. An admixture of rocks is regarded as desirable. It is generally true that with proper climatic conditions good yields of coffee can be produced in Kona, even though the layer of soil overlying the rocky subsoil is shallow. However, extreme rockiness, especially in the form of large massive outcrops, is undesirable. Excessive steepness of slope also adds to the difficulties and costs of coffee culture.

Clearing and Preparing the Land

Having selected the land for planting coffee, clearing the vegetation consists chiefly of removing guava and lantana bushes which cover practically all the uncultivated areas in Kona. This in most instances is a hard and expensive task. As the land is generally rugged and rocky, power stump-pullers are almost never used, and nearly all clearing is done with crude hand implements. In felling a large guava tree, the lower branches are first removed with a heavy sickle or ax. The root system is then partly severed and the tree pulled over. As any portion of a guava root is capable of producing sprouts, if left in the ground, the greatest care must be taken to grub out the entire root system. Lantana is easier to eradicate than guava since it does not send up sprouts from the roots. After all the growth is loosened, it is gathered together into piles. The trunks of the large guava bushes are cut into short sections and placed on top of the piles. This packs them and results in more efficient burning. Thorough burning of all vegetation facilitates subsequent operations, in addition to killing insects and weeds.

During the last few years, some farmers have been using a sodium arsenite paste as an aid in killing the large guava stumps. The paste is prepared by mixing equal weights of white arsenic and caustic soda with just enough water to produce the proper consistency. The guava tree is cut off close to the ground and the paste daubed on the fresh cut. The poison is gradually carried down into the crown and root system and sometimes many stumps are killed with no further treatment. It is usually necessary, however, to follow this with hand work to remove the live roots or with several sprayings with sodium arsenite as soon as new shoots emerge. It is necessary to leave the old dead stumps in the ground for a year or two, after which they are rotted sufficiently to be easily pulled out. This arsenite poisoning system of clearing, although not used extensively, is reported to have effected savings of $50 an acre in some instances. It should not be used if catch cropping between the young coffee is to be followed in the first few years, since the presence of the old stumps greatly hampers such operations. Costs of clearing vary greatly depending on the type and amount of vegetation. Amounts varying from $75 an acre to as high as $350 have been reported, $150 being a general average.

With the completion of the clearing, the potential coffee field presents a discouraging spectacle. Huge outcrops of massive lava protrude here and there. Rocks of varying sizes are mixed in with the soil, often half covering its surface. How many of these rocks should be removed is a problem. Some planters spend months at the task. Sledge hammer, iron bar, pick-ax, and other implements are used in loosening boulders weighing from 50 to 500 lbs. These are neatly built into stone walls, terraces, or used for road-building. Even the small stones the size of an egg are picked up. The field gradually becomes neat. Bounded by stone walls and terraces, it assumes the appearance of a great checker-board. Many growers contend that, although the initial cost is high, the greater facility with which subsequent weeding, pruning, harvesting, and fertilizing operations are accomplished justifies the procedure. Others claim that rocks should not be removed because the coffee trees appear to be benefited by their presence in the soil.

The various operations of digging out the tree stumps and guava roots, together with the removal of the rocks, result in considerable stirring of the soil. Some growers say that this is sufficient and that any further digging adds to the danger of gullying on the steep slopes and increases the tendency of the soil to dry out. Other growers work over the entire soil mass thoroughly, at the same time removing the rocks, together with the remaining small roots of guava and lantana. Where rocks make up a major part of the entire soil mass, as is the case in many fields, little can be accomplished in the way of turning over the soil or removing rocks.

Lining

It is a problem to line the field with anything like a systematic spacing of the trees, owing to the stony surface and rugged, sloping contour of the land. Notwithstanding these difficulties, the holes are generally dug with great regularity. Sometimes a terrace is built up and filled in with soil for a single tree, in order to maintain uniformity of spacing.

Long ropes or strong strings are used in lining the field. These strings are marked with red rags or other materials at the distances decided upon between the plants. Stakes are driven in to mark the position of each plant. The line is then moved forward to the distance decided upon between the rows and stakes are driven in as before. In most places, the scheme of planting is on the corners of a square; that is, the same distance between trees in both directions with the rows at right angles to one another. In some countries the triangular arrangement is used, whereby the rows make an angle of 60 degrees with one another. This arrangement permits more trees to be planted to each acre and a more effective use of soil area and available sunlight. On a steep slope, it has a disadvantage in that most cultural operations, building of rock fences, trails, etc., are more easily accomplished either with the slope or at right angles to it.

Spacing

The factors which determine spacing are altitude, rainfall, and the amount of fertilizer. Forty to fifty years ago, when most of the orchards were planted below 1,500 feet altitude, spacings were 6 by 6 feet to 7 by 8 feet. With limited rainfall and no commercial fertilizer, the trees did not grow large and such spacings were sufficient. During the last two decades, the extension of the coffee planting into the higher altitude, together with the use of large amounts of fertilizers, has rendered such close spacings entirely inadequate and it is a constant fight on the part of the farmer to keep his trees from completely closing in. Hence most of the recent plantings have been spaced at 8 by 9 to 9 by 10 feet at 1,500 feet elevation and as much as 10 by 12 feet at elevations of 2,000 feet or more. In the very dry sections, 7 by 8 feet is still adequate. Close spacing under these conditions lessens evaporation from the soil.

It is coming to be recognized that in many fields in Kona sunlight is the limiting factor in effective production. The new verticals extend higher and higher in their attempt to reach sunlight. This produces a large amount of long-noded and unproductive wood. In order to keep the overhead growth opened up, it is necessary to remove a considerable amount of productive wood. With wider spacing, the coffee tree tends to spread outward. The center of the tree thus opens up of its own accord and the new growth is sturdy, short-noded and prolific. The bearing surface is low and the crop easy to pick. One grower, who has both 9 by 9 feet and 10 by 12 feet spacings, states that at the end of the sixth year, total production for the two was practically equal. He is of the opinion that in the next 6-year period, the wider spacing will outyield the closer. In addition, he points to the greater value of intercrops he has harvested from the 10 by 12 spaced field, as well as the greater ease of picking.

Holing

Holes for the young coffee trees are dug with pick-ax, shovel, and hoe, the size of the hole varying from 1 to 2 cubic feet. Where the surface consists of rock outcrops, it is necessary to open holes with crow-bar and pick and carry in the soil. Some growers give careful attention to separating the surface soil, putting it above the hole while the subsoil is terraced on the lower side. They usually dig the hole from 2 to 3 months before planting in order that the earth may be mellowed. About 2 weeks to one month before planting, surface soil is carefully freed of stones and filled into the hole until a mound slightly higher than the ground level is formed. After the soil is well settled, the field is ready for planting. Other growers will not take all this trouble of preparation. The holes are often dug the same day as the planting. No particular attention is paid to the separating of the top soil from the subsoil. The tree is inserted in the freshly dug hole, the mass of soil shoveled back in, and the planting is complete.

Sources of Planting Material

VOLUNTEER SEEDLINGS. Probably 75 percent of the farmers use volunteer seedlings which grow in abundance on the stone piles in the coffee fields. These seedlings are very easy to secure without damaging the root system. The roots are compacted among the small stones and, by first carefully removing the stones, the plant may be removed with its root system intact. In selecting the seedlings, planters discard those taller than a foot, as they are usually too lanky and weak. The ideal size is from 3 to 8 inches. These are transferred to the nursery beds in the young fields, using spacings of 18 inches to 2 feet between plants. Such seedlings are usually quite vigorous, in fact some farmers prefer them to plants produced from seed germinated in the nursery. Planting material is also secured from abandoned old fields where seedlings are growing wild among guavas and other weeds. They range in height from 1 to 4 feet and are transplanted directly to the field. As most of these wild seedlings have been growing under shade or among grass and weeds, they are spindly and ragged and make an unsightly appearance compared with the seedlings produced in the nursery.

With any of the foregoing sources of seed, the coffee grower takes the risk of uncertain strain, of undesirable growth, and fruiting characters inherent in the parent stock. Sometimes this is not serious but in other instances the grower finds his new fields a heterogeneous mixture, which requires subsequent replacing at a much greater expense than if he had used a selected source of seed.

STARTING COFFEE PLANTS FROM SEEDS. Usually the planter selects his seed from the fresh coffee cherry as it is brought in bags from the field. Nothing is known as to the source of seed except the field from which it came. Selection is made chiefly on the basis of size, the larger beans being selected since they command a higher price on the coffee market. This system has little to recommend it and the farmer is no better off than if he had used volunteer seedlings.

There are a very few growers, probably not more than five in the whole district of Kona, who select the seeds from outstanding trees of their orchards. These trees are never less than 10 years old, and are selected on the basis of such desirable characteristics as vigorous verticals, strong laterals with at least 15 bearing nodes and with short internodes, uniform medium sized leaves, berries at each node (numbering at least 10), berries not reduced in size on the old verticals, and uniform shape of berries. The tree must also have produced a good crop annually over a period of several years. These characters are generally determined by observation rather than by actual measurement or record. Moreover, it is probable that many of the outstanding qualities just mentioned are the result of unusually favorable conditions as to soil, moisture, and the like, rather than to inherent characters in the tree. At least, such selection does tend to reduce undesirable characteristics to a minimum, and fields planted with such selections have proved more uniform and prolific than where no selection was practiced.

Only ripe berries are used for seed. To prevent injury, they are either pulped by hand or by a loosely gauged pulper. The seeds are then soaked in water for about 10 hours or are mixed with wood ashes and washed immediately. Both methods will effectively remove the slimy coating adhering to the bean. All beans which float in water are discarded, as they are malformed. The seeds are then dried for 2 or 3 days in the shade or are planted immediately.

A seed-bed is prepared large enough to start seedlings for the entire planting. A bed of 20 by 4 feet provides ample space for a 5-acre farm. This may be located in the open but should be well shaded. Rocks are removed from the bed and the soil is well pulverized. The surface is smoothed and the seeds thinly broadcast. They are covered with a layer of very fine soil ½ to 1 inch in depth, and the surface made firm with a board. Too thick a covering of soil is detrimental as the plants will have long weak stems at the time of transplanting. The seed-bed is then covered with a gunny sack or a layer of dried coffee leaves, 2 to 3 inches thick, to conserve moisture, discourage weeds, and to lessen the danger of washing away of seeds during heavy rainfall or clumsy watering. The best time to plant the seed is between April and June, as from then on throughout the summer rainfall is usually sufficient. During dry periods, the seed bed must be watered with a sprinkler once a day. The coffee bean requires 4 to 8 weeks to germinate. Usually about 70 percent germination may be expected.

Between 2 and 3 months after planting, the plants will have developed their cotyledonous leaves and the first pair of true leaves should be about ⅛ to ¼ inch in length. The seedlings then are ready for transplanting to nursery beds. Farmers contend that best results are obtained if the first pair of true leaves are only partially developed; probably there is less injury to the root system at this early stage.

The nursery bed is usually made in a young coffee field 2 to 3 years of age. Generally a double row of seedlings is planted in the well-pulverized soil between rows of coffee trees. The plants are spaced 4 inches apart in rows with 2 feet between the rows. It is claimed by most farmers that two transplantings in the nursery bed harden the plants, develop better root systems, and make the young coffee trees more resistant to adverse conditions. Hence, 4 months after the first transplanting, they are again transplanted. Great care is taken in moving the plants. The bed is watered first and the plants are gently removed without disturbing the root system. They are then spaced 18 inches to 2 feet. In case only one transplanting is to be made in the nursery bed, the wider spacing is used in the transplanting of the seedlings from the seed bed. Instead of planting all the seedlings in one part of the farm, nursery beds of small size are sometimes scattered all over the field. This method permits the grower to make the final transplanting with greater facility and the least injury to the seedlings. There is no necessity of building artificial shade for the young plants as in most other countries.

Coffee planters prefer to raise seedlings in the same locality as the field to be planted as they contend that seedlings brought in from different climatic and soil conditions do not grow well. They never plant in the low elevations seedlings grown in high altitudes, although plants grown in a low elevation are reputed to do very well in a high elevation.

It is unanimously agreed that the second season nursery plant is the most desirable age for planting. They are then about 24 months old, 2 to 3 feet high, and with wood sufficiently hardened to stand transplanting well. The grower figures also that he saves a years' expense of weeding and other operations by keeping the plants in the nursery bed the second year.

TRANSPLANTING. Transplanting from the nursery bed to the field is generally done during the months of May, June, and July. After the first of May there is nearly always sufficient rainfall. The cloud blanket and gentle afternoon rains that fall almost daily are ideal for the young plants. Planting after July is usually hazardous, as it allows too short a growing period before the dry season, which begins in November and continues on through February or March.

The coffee plant is rather a hardy plant and will stand considerable abuse in transplanting. The seedlings will usually survive if they are hand-pulled from the nursery bed and transplanted with bare roots. The good farmers maintain that such methods often set the plant back a full year. The utmost of care in transplanting will pay big dividends in vigorous uniform trees and early crops, they maintain. On the day transplanting is to be done it is best to water the nursery bed liberally. The plants can then be removed from the ground with a minimum of damage to the root system. It is agreed that the best method is to transplant with a ball of soil adhering to the roots. This means considerable extra labor and is scarcely possible if the seedlings are purchased and transported for any distance. Usually the planter is careful to prune back the taproot and long lateral roots so as to prevent them from doubling up when they are placed in the hole. Some growers take additional steps to provide a strong and compact root system before transplanting. One method is to fertilize a month before transplanting. Occasionally there are individuals who cut the taproot a month or so prior to digging, by forcing a sharp spade diagonally under the plant and tipping it slightly. This treatment is reported to encourage the development of many rootlets in a restricted area close to the plant. Such a root system can be transplanted with a ball of soil attached with the minimum of effort. One grower states that trees which have been carefully transplanted with soil attached will yield 10 bags (of 100 lbs. each) more of coffee cherry the next season, which pays for the added effort.

The plants are placed in the previously prepared holes and roots are carefully spread out, if bare of earth. All growers are agreed

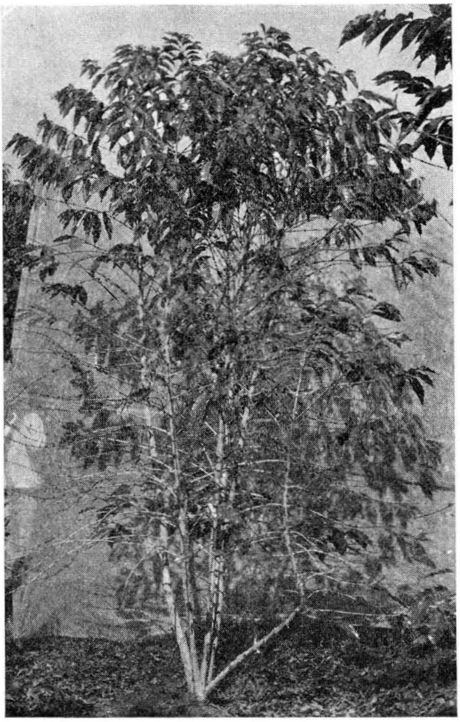

Plate 2. Planting Coffee Seedlings at an angle to bring out new verticals. This practice causes the development of new verticals and thus increase the bearing surface in the early growth of the tree. The original vertical (the bent one on the right), ceases to grow to any extent after the development of the verticals at its base.

that plants should not be set deeper in the ground than they were in the nursery bed. In fact, they prefer to plant in a mound a little higher, than the surface of the soil. The seedlings are usually planted erect but in recent years a few planters have followed the practice of planting them at an angle of about 40 degrees from the vertical. This stimulates the development of side verticals. Three to five of the new vertical shoots are allowed to develop close to the base of the original stem. (See Plate 2). These shoots grow rapidly and form a low bush with a large bearing surface. If the plant is placed erect, there will be usually one vertical for the first 3 or 4 years. Yields by the leaning method are often nearly double that of the upright planting for the first 2 or 3 crops.

A novel source of planting material is the old trees in abandoned coffee fields. These are dug up with only footlong stubs of the old root system. The trunk is cut off about 2 feet above ground level and the stump planted in the new field in the same manner as young seedlings. Such stumps show remarkably quick growth and often come into heavy bearing sooner than the seedlings. Just how long these stumps will be capable of strong growth and heavy production is not known. There are some indications that they lose their vigor sooner than new seedlings.

PRUNING

The coffee tree assumes a remarkable variety of shapes and sizes depending on the system of pruning used. Left without pruning, *Coffee arabica* grows into a tree with a height of 15 to 20 feet, a spread nearly as great, and a well developed permanent trunk and scaffold branches. Under different systems of pruning, it may be topped at 4 to 6 feet, the growth extending outward instead of upward; it may be held to one trunk or made to produce six or eight smaller trunks; it may be bent over and held down with stakes and wires and made to send up a series of verticals along the prostrate trunk; it may vary from a permanent tree to a large bush with only a permanent stump and cane-like uprights which are pruned off at relatively frequent intervals.

It is generally agreed that trees, such as coffee, which bear on second year wood need more drastic pruning than those which bear on older wood or short spurs. There is no direct evidence that pruning actually increases yields of fruit trees. Many recent experiments with various fruits have proved that yields are often reduced more or less in proportion to the severity of the pruning. An experiment with coffee in Puerto Rico showed that the trees without pruning gave higher yields than those which had been pruned. Various attempts have been made to grow coffee on a commercial scale without pruning, but these have ultimately been abandoned. There are reasons, aside from the question of yields, which justify pruning. Left unpruned, a coffee tree becomes a mass of dead and crossed branches. Growth becomes very dense, and the bearing surface is forced higher and higher. Such conditions make picking difficult and costly and result in cherries of small size and poor quality. The poor circulation of air which results stimulates diseases and insects. In many localities, tall unpruned trees receive excessive damage from wind injury.

Pruning makes it possible to produce a regulated growth, with the best adaptation to existing conditions of climate and soil. It makes for ease of picking by concentrating the bearing surface and bringing it to a lower level. It improves the quality and size of the bean. Under conditions of close planting, pruning makes for better utilization of limited sunlight and adapts the tree to the particular economic situation existing. For example, some pruning types are best adapted to intensive, high production systems; others to extensive, low yielding systems; some are adapted to plentiful and cheap labor; others to scarce and high-priced labor.

Pruning Systems of the Kona District

Coffee pruning may be divided into topped and untopped systems. In the topped system, all growth of verticals is suppressed, and the bearing surface, after the first two or three crops, is entirely on sublaterals rather than primary laterals. In the untopped systems, new wood is produced by bringing out new verticals, and the bearing surface is on primary laterals to a considerable degree.

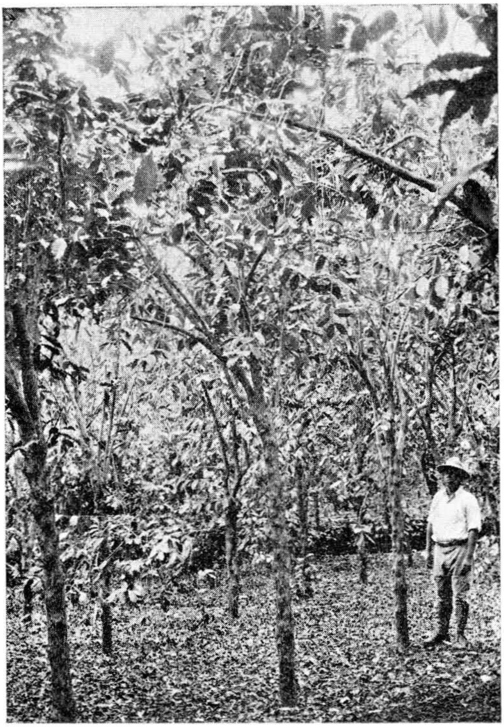

Plate 3. Secondary Vertical Pruning System. In this system the trunk and main branches are seldom cut. The bearing surface is on small secondary verticals high up in the tree. The overhead shade prevents development of desirable new verticals on the lower part of the tree so that the new bearing wood develops in the upper part of the tree.

Classification of coffee pruning into systems is thus based on certain essentials of growth, such as bearing surface, age, and number of verticals, amount of tree which is permanent, etc. The division between any two systems is obviously arbitrary. One system gradually blends into another. In actual field practice, the grower generally uses a combination of systems. His chief motive is to cut out unproductive wood and save the best new growth available for the coming crop, regardless of whether it is of the type he most desires.

Division into systems, however, provides a means whereby a systematic study can be made of the different factors involved in the general problem of pruning.

SECONDARY VERTICAL SYSTEM (also called the Holualoa system). In this system (See Fig. 3 and Plate 3), the main framework of the tree is more or less permanent. It consists of old verticals which have bent outward, giving the plant the shape and spread of a small tree—the natural shape of a coffee tree when allowed to grow unpruned. The new growth consists mostly of short stocky verticals, so-called secondary verticals, setting on high up on the upper side of the old verticals. The canopy-like spread of the tree shades the new verticals setting on lower in the tree, and they develop weak and slender with little bearing surface until they reach the light. Often an 8- to 10-foot vertical, setting on low, has no more bearing surface than a 2-foot secondary vertical setting on high up. The bearing surface is thus largely in the top of the tree and consists chiefly of the primary laterals of these short secondary verticals.

Pruning operations in this system are less drastic than in most of the other systems, consisting largely of cutting back the bare, unproductive secondary verticals to the point where a good new vertical is setting on. Usually this restricts the pruning to small wood in the upper part of the tree. At intervals, however, an entire branch becomes unproductive, and it is cut back to within a foot or so of the main trunk. The slender vertical which sets on the stumped branch gradually thickens and bends outward, giving rise to development of secondary verticals on its upper side.

The secondary vertical system is used almost exclusively in the low dry belt in Kona. Here the tree is able to produce only limited new growth. Under such conditions, the secondary vertical provides the maximum of bearing surface for a given amount of new wood. Since more of the tree is permanent, it is less affected by severe drought than the other systems. Because of shading, it has the further advantage of low costs of weeding. Its chief disadvantage is the difficulty of picking, as well as pruning, due to the excessive height of the bearing surface. It is not an intensive system, but it is well suited to climatic conditions which preclude very heavy yields, and it makes only moderate demands as to fertilizer and general upkeep.

The secondary vertical system varies from no pruning on one extreme to the multiple vertical system on the other. As it approaches the latter, more and more of the old verticals are removed and new verticals are brought out lower on the tree.

MULTIPLE VERTICAL SYSTEM (also called Captain Cook or primary vertical system). In this system, (See Fig. 3 and Plate 4), only the main trunk to a height of 2 or 3 feet is permanent. The remainder of the tree, which consists of new verticals developing from the old trunk, is removed at more or less regular intervals of from 2 to 4 years. In the ideal situation, a new vertical sets on close to the base of the parent vertical one year before the latter is cut off. Under the favorable conditions that exist in Kona, such a young vertical will grow from 4 to 6 feet tall in one year, so that, with the removal of the parent, at the end of the season's crop, the new vertical will be ready to bear the following crop.

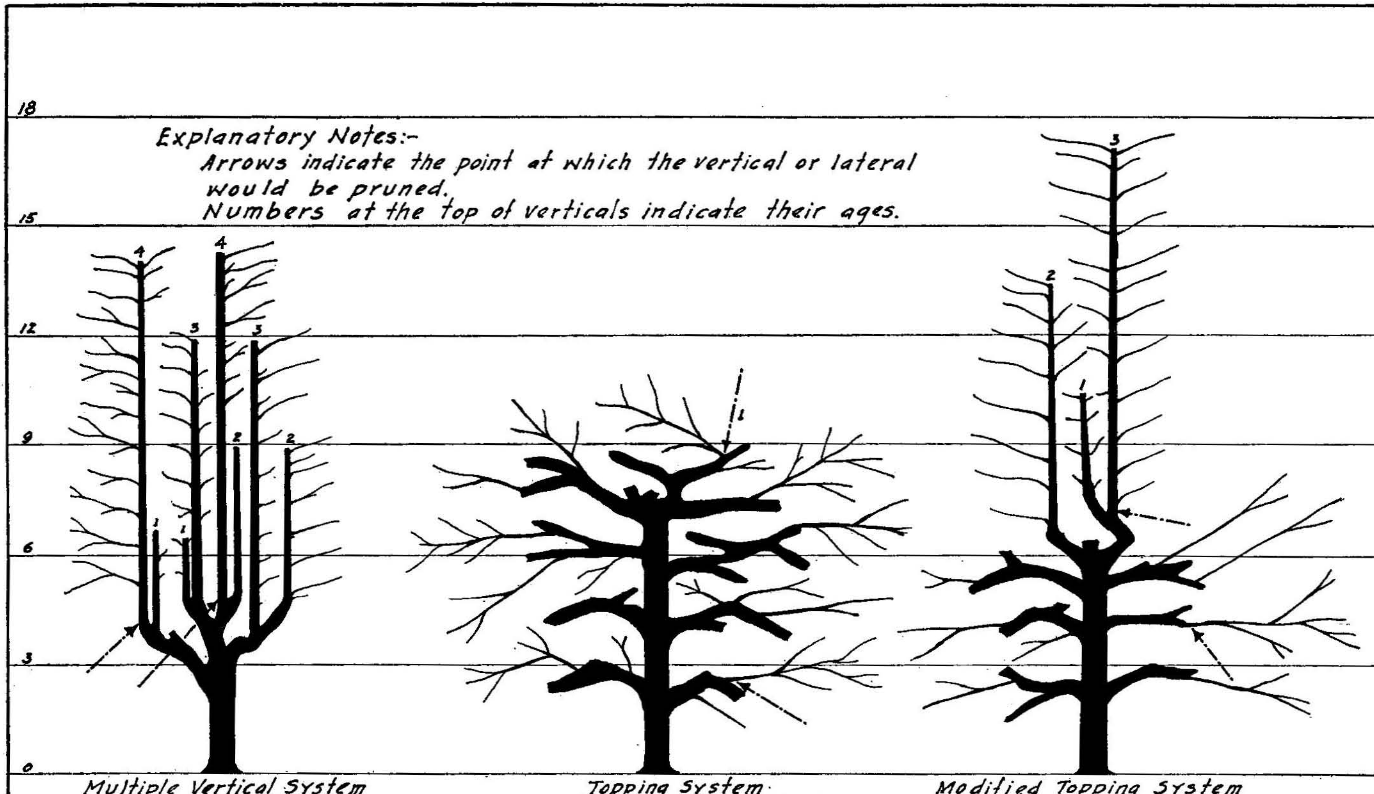

FIGURE 3—Coffee pruning systems used in the Kona District.

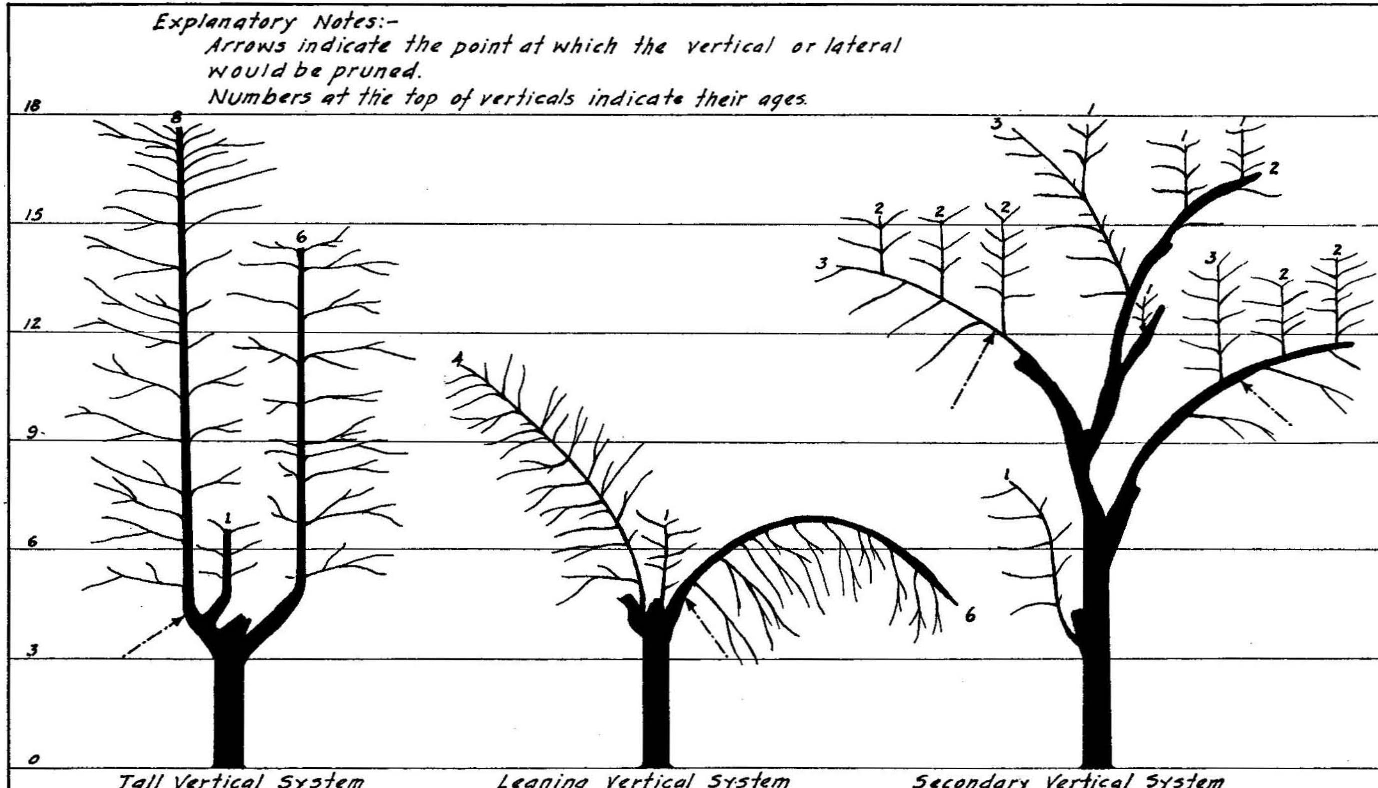

FIGURE 3—Coffee pruning systems used in the Kona District.

The growth cycle of a single vertical under favorable conditions is as follows (See Fig. 4) : first year, a vigorous growth—4 to 6 feet tall with only primary laterals; second year, a good crop of coffee, a 2-foot growth at the top of the vertical, lateral growth of the terminal buds on the primary laterals of the previous year, little secondary lateral development unless dieback has caused the death of the terminal lateral buds; third year, a heavy crop of coffee on primary laterals, very short growth at the top, much secondary lateral development on the first year primary laterals at the base of the tree; fourth year, a heavy crop of coffee chiefly on secondary laterals. Apical growth by this time has largely ceased, and secondary

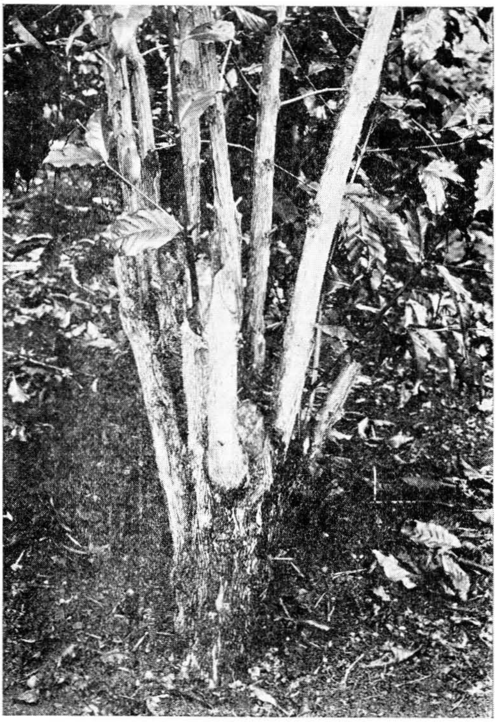

Plate 4. Multiple Vertical Pruning System. Showing the old thickened stump of a coffee tree 30 or 40 years old. The only permanent part of the tree is this stump which is not more than 2½ ft. in height. There are eight verticals emerging from the old stump, the oldest of which is 3 years old. The essential of this system is the bringing out of a succession of new verticals from the old trunk not to exceed 3 or 4 ft. from the ground.

lateral development gives the vertical a characteristic dense, bushy appearance, quite different from the relatively open appearance with only primary lateral development. This change in bearing surface from primary to secondary laterals is significant in that the cherry from vigorous, primary laterals is appreciably larger than that from secondaries and commands a higher price. Many writers advocate pruning systems which permit only primary lateral development chiefly on account of the factor of size of cherry.

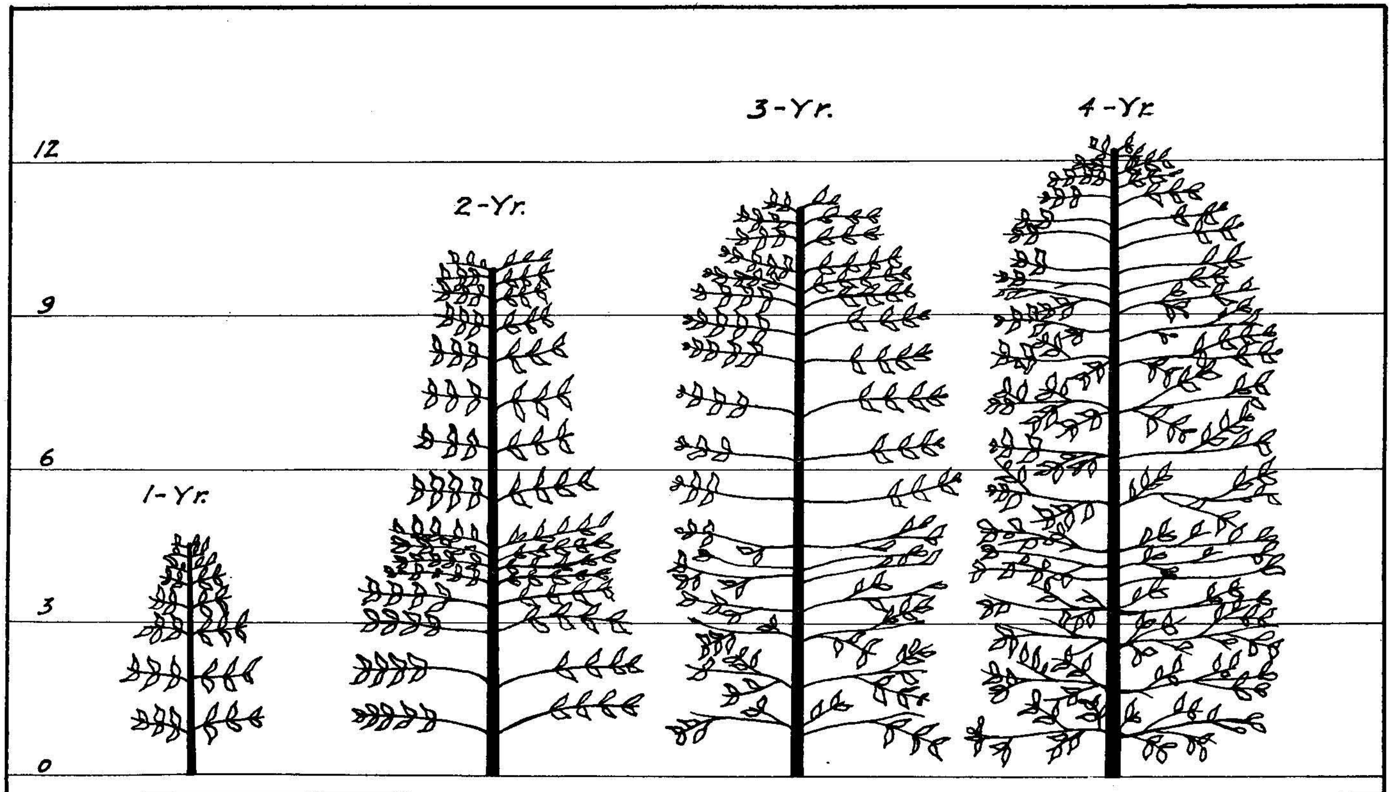

FIGURE 4—Development of a vertical.

Ideally, this removal of old verticals and the production of new ones should result in a systematic pruning procedure, the same number of verticals being removed and brought out each year. For example, if two new verticals were brought out each year and all verticals were removed at the end of their fourth year, the tree would at all times have two verticals in its first year, two in its second, two in the third, and two in its fourth year. In practice, this is seldom practicable. Variability of seasons is one of the two chief reasons for this. A season unusually favorable for fruiting may cause excessive dieback on a vertical in its second or third year with little development of new wood, in which case the bare and exhausted vertical is removed before the end of the fourth year. Conversely, a light crop on a fourth year vertical causes the setting on of much new wood and tempts the farmer to permit the vertical to remain an extra year. The removal of too many or too few verticals in any one year thus upsets the cycle. The other cause for irregularity in the pruning procedure is the uncertainty of the development of new shoots on the old vertical during its last year. Very often a new shoot does not develop; or, if it develops, it may be an undesirable type so that, rather than cut off the 4-year-old vertical for an entire year with this part of his tree out of production, the grower allows the old vertical to remain an additional year in hope that a desirable new shoot will develop.

In this pruning system, the ideal is for the new verticals to set on not more than 3 feet from the ground. This keeps the growth lower and, with enough sunlight, develops stronger verticals. The tendency, however, is for the new growth to be on the upper part of the old verticals. This is due to the fact that the parent vertical tends to become top-heavy, as it grows taller, and to bend over. Since the greatest bend is in the upper part, the greatest development of new shoots is there.

To produce low-setting verticals, several methods can be employed. The parent can be left on until it loses its vigor, in which case low-setting verticals will develop of their own accord. Another method is to remove the lower laterals. This causes the vertical to become top-heavy and bend over with the weight of the crop at the top. The same result is accomplished by removing all laterals on the inner side of the upright. The combined effect of bending and unbalance produced by pruning, stimulates the development of buds on the lower as well as the upper part of the parent stem. Cutting a notch in the old stem often causes development of adventitious buds just below the notch. Girdling (See Plate 5), that is, removing a strip of bark about one inch wide so as to completely or partially girdle the old vertical, is another method of accomplishing the same purpose. Some growers saw partly through the old vertical and then break it over. It is claimed that the partially severed vertical will mature its crop and at the same time stimulate new verticals. The surest way to produce a desirable, low-setting shoot is to remove the old vertical completely. Development of new buds is sure and, with ample sunlight resulting from the opening up of the center of the tree, the growth is sturdy and short-noded.

Comparison of these various methods of producing new verticals is being made by the Hawaii Agricultural Experiment Station in

Kona. It has been found that with the girdling method about 80 percent of all the trees set on new shoots below the girdle. It was apparent, however, that unless physiological conditions are right, the new shoot develops very slowly. Some farmers state that any mutilation of the old vertical, such as girdling, notching, or breaking over, affects its crop, making smaller berries and increasing dieback. The experiments have not progressed far enough to show if such methods have any practical advantage over the usual practice of completely removing the old vertical. It is generally believed that the most desirable time for the development of new shoots is

Plate 5. Forcing the development of low setting verticals by girdling. If the old vertical is girdled in January or February, (about the time of pruning), new shoots will generally develop below the girdle. A new bark soon develops over the girdle and the old vertical does not die. The same result can be accomplished by cutting a notch in the old vertical.

the early spring soon after pruning has been completed. Vegetative growth normally begins at this time and the new uprights receive added impetus from pruning. Pruning also reduces the overhead shade to a minimum. The additional light makes for sturdier growth.

The multiple vertical system obviously offers a great range of possibilities for variation. By changing the number of verticals to be carried by the tree, the age at which they are to be removed, and the height at which the verticals are allowed to develop, a great variation in the type of tree results. The fundamental characteristic, however, is that new verticals are brought out low on the trunk, and that there is a more or less systematic development of new verticals and removal of old.

Opinions differ as to the best number of verticals to carry on a tree, the best age at which to remove the old verticals, and so forth. Without doubt, the various environmental factors of soil and climate must be taken into account, as well as the characteristics of the individual tree. It is universally agreed, however, that systematic pruning whereby a fixed amount of wood is removed each year will reduce yields due primarily to variable seasons.

In actual practice, the grower prunes each tree on the basis of the present crop and the need for new wood for the coming crop, the ideal being the stimulation of ample new growth with the least possible sacrifice of the present crop. Hence a vertical may be left on an additional year if it has plenty of bearing wood, or it may be removed at the end of the second or third year if it is too badly depleted. Pruning consists largely of removing old verticals once a year and removing excess shoots several times throughout the year. Very little thinning of the laterals is done. For this reason, pruning is a relatively easy task, requiring neither the time nor the skill necessary in some of the other systems. This system merges into the secondary vertical system if the grower allows high-setting verticals to develop. It may also approach the leaning vertical or the tall vertical systems if the verticals are allowed to remain for a protracted period.

The multiple vertical system is an intensive system. The drastic pruning and forcing out of strong new verticals each year requires an ideal climate, the best of care, and heavy application of fertilizers. Its advantages are heavy yields, fine quality and large sized cherries, ease of picking, and a minimum of labor for pruning. Its disadvantages are a tendency toward excessive dieback, particularly during dry periods, and high fertilizer requirements. This is essentially a central zone system in Kona. It is not adapted to the low dry zone, but does extend to places well into the upper wet zone.

Tall vertical system. In this system (See Fig. 3) the number of verticals is restricted to two or three which are allowed to remain until they are no longer productive. The vertical remains in an upright position and not in a bent position. This, and the fact that no new shoots are developing at the base of the tree to sap its vigor, causes the vertical to continue to grow at the top. After the third year, the bearing surface is mostly sub-lateral and the vertical takes on the characteristic bushy appearance. It is essential in this system that the upright make a sturdy growth. A slender vertical becomes top-heavy and bends over. Excessive dieback is also undesirable as it kills the lower laterals and weakens the entire vertical. The age at which a vertical should be removed depends on its vigor. Many verticals are productive for 7 or 8 years. New verticals are brought out close to the ground, as in the multiple vertical system. A modification of this system is to top the old vertical at 6 or 8 feet so as to remove the unproductive upper part and allow the

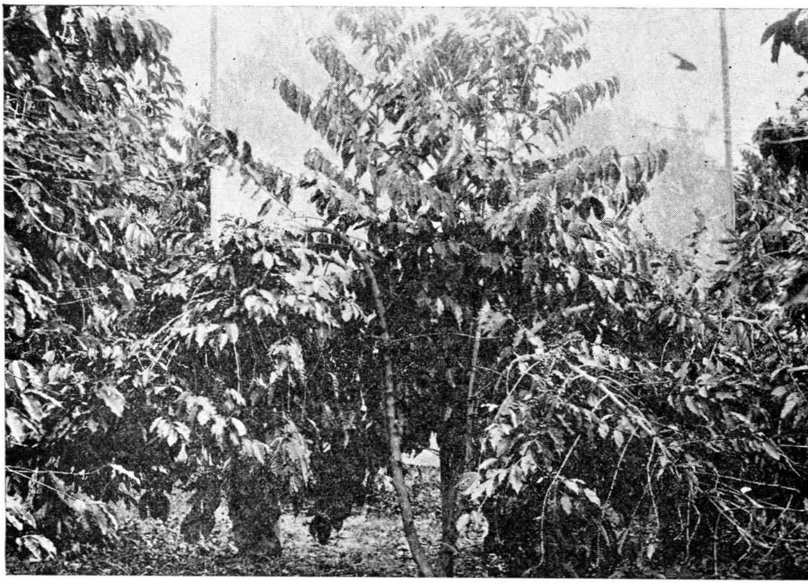

Plate 6. Leaning Vertical Pruning System. After the vertical has attained a considerable height (at about the end of the third year) the weight of the crop in the upper part causes it to bend over. It often remains so after the crop is removed or it can be weighted down. This leaning vertical ceases to grow at the top but continues to bear on sublaterals. It is thus easy to pick and to prune. Note the sturdy development of new verticals due to ample light in the center of the tree.

lower half, which is often full of vigorous bearing wood, to remain for a year or two longer.

This system is found between 1,500 to 2,000 feet level, where there is the proper proportion of shade and moisture to produce vigorous growth without much dieback. Pruning is not as drastic as in the multiple vertical system and the yields are good. Its chief disadvantage is the difficulty of picking, which necessitates the use of tall ladders. One of the advantages is said to be the more gradual ripening of the crop which makes for greater utilization of the farmer's own labor. It merges into the multiple vertical system as the age of the vertical is decreased and the number increased. It approaches the leaning vertical system if the tall verticals, which tend to bend over during a heavy crop, remain in that position.

Leaning vertical system (also called the Honaunau system). (See Fig. 3 and Plate 6). Under Kona conditions, a single vertical may bear as much as 20 pounds of coffee cherry, with much of this weight on the upper half. This often causes it to bend over. When the crop is picked, it returns more or less to the upright, but with continuous cropping, remains permanently bent to the horizontal. As soon as this happens, the terminal bud ceases to grow to any extent. The laterals on the top side of the leaning trunk bend over and hang down on either side. The bearing surface is on the sublaterals. A certain amount of pruning of the laterals is necessary to bring out new wood. It also facilitates picking and increases the

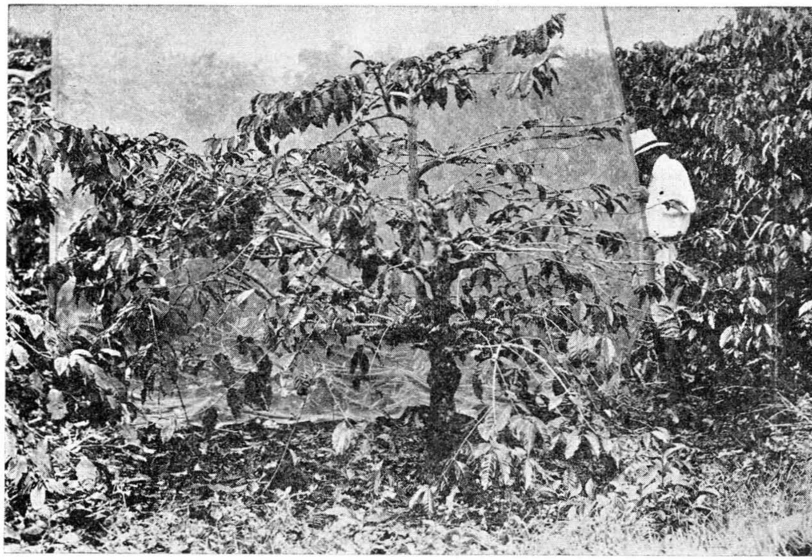

Plate 7. Topping Pruning System. Showing the old trunk and old thickened lateral branches of a coffee tree about 30 years old. This tree was formerly topped at 4 ft. The height has been raised to 6½ ft. by bringing out a new vertical, which was subsequently topped at the desired height. The topped tree is subjected to the drastic pruning shown above once every 2 to 4 years. In addition it is necessary to prune after each crop and make several thinnings throughout the year to prevent shading out of the lower branches.

size of the cherry. It is essential that the verticals which develop on the bent-over trunk should be rubbed off at frequent intervals. Failure to do this quickly saps the vitality of the tree.

There are from one to three such leaning verticals to each tree. The age at which they are removed is variable. Some remain as long as 8 years; others are cut off sooner. When it is desired to remove an old vertical, a new one is allowed to develop low down on its trunk a year before the parent is removed. Usually no difficulty is encountered in bringing out new verticals in this system, and the center of the tree is sufficiently open to give ample sunlight for sturdy growth.

As long as the vertical returns to an upright position after the removal of the weight of the coffee crop, it still makes apical growth so that many of the verticals attain a height of 12 to 15 feet. before they become true leaning verticals. Others that bend over earlier in their growth are consequently shorter. Experiments are under way to determine the feasibility of forcing the new verticals to bend over by weighting them down after they have attained sufficient height.

The chief advantage of the leaning vertical system is the ease of picking, as well as pruning. These operations can be effected without the use of a ladder. Like the tall vertical system, the new verticals must not be denuded of laterals due to dieback. One of the disadvantages of the system is said to be the small size of the cherry borne on the sub-laterals. The leaning vertical system is found mostly in the central zone.

TOPPING SYSTEM. In this system (See Fig. 3 and Plate 7) usually a single vertical is allowed to develop and the young tree is topped at from 6 to 8 feet. Growers disagree as to the best method of topping. Some say that the terminal bud should be pinched off when the tree has attained the proper height, while others believe it is better to allow the tree to grow untopped until about two crops have been removed, and then to cut off the top at the height desired. The cut should be made just above the node. Any part of the remaining internode shrivels and dies and is likely to allow rot to set in. With the exclusion of all upward growth, development of the laterals is rapid. Secondary laterals soon develop in profusion and must be thinned out. The usual rule is to remove all sub-laterals which set on within 6 inches of the main trunk to permit free passage of air through the center of the tree.

When the primary laterals have yielded two or three good crops, they are 4 or 5 feet long and the terminal growth is very short. They are then pruned back to within 1 or 2 feet from the main stem, or to the point where a good, strong secondary lateral is setting on. Care is taken that the secondaries do not become so numerous as to shade out the lower branches. Those which cross each other are also eliminated as they are hard to manage and increase the difficulty of picking the coffee. These primary and secondary laterals gradually increase in diameter from the thickness of a lead pencil to 2 inches or more. The permanent part of the tree is thus the old trunk and the stubby, thickened laterals from 1 to 2 feet long. The bearing wood consists of the sub-laterals which grow on these permanent branches.

Pruning operations consist of cutting back these sub-laterals every third or fourth year to, or close to, the permanent branches. The first year the new sub-lateral makes chiefly terminal growth. Subsequently, the growth consists of secondary and tertiary laterals. When the entire branch begins to lose its vigor, it is pruned off back to the permanent branches of the tree. The heaviest pruning is done after completion of harvesting. At 2- to 3-month intervals throughout the year, thinning is necessary. This consists of removing with shears the excess sub-laterals which develop just back of the point of removal of the old sub-lateral. Verticals setting on the old trunk must also be removed at intervals. Ideally, the same amount of wood should be removed each year but, practically, it is advisable to prune according to the amount of unproductive wood a tree contains. Some growers contend that a drastic pruning once in 5 or 6 years is a beneficial thing. Although the yield the following season is materially reduced, the subsequent three or four crops are said to more than make up for this both in high yields and in better quality. In any case, care is used to restrict the bearing wood to what the tree can support without exhausting itself. Overbearing may cause a tree to suffer both in quantity and quality of coffee for two or three crops following.

Frequently a type of branch develops which has an appearance intermediate between a lateral and a true vertical. It develops on the lateral but grows upward from the horizontal at an angle of from 20 to 40 degrees. The growth is very rapid and vigorous and many side branches are produced. Most growers regard this type of growth as undesirable and do not allow it to develop if other types are available. They state that it is short-lived, producing only one good crop and then becoming bare and unproductive. It also tends to weaken the adjoining branches.

The secret of success with the topping system is the pruning. Unless special care is taken, the shade of the top branches becomes so dense that the lower ones are gradually killed. The most successful Kona growers are especially adept at this method, maintaining sturdy branches and bearing sub-laterals throughout the entire trunk.

Plate 8. Producing a Strong Lateral Framework on a Topped Tree. Half of the laterals were removed as the young tree developed and only a few of the sublaterals allowed to grow. The tree was topped at 8 ft. Note the thick sturdy stems of the laterals and the heavy set of cherry with no dieback. This system should produce trees of long life and heavy yielding capacity. The only objections to this system are the smaller yields for the first two or three crops and the higher weeding costs.

The topping system usually results in long life of coffee trees compared with some of the other systems. In many sections in Kona there are 30- to 40-year-old topped trees which have borne continuously with no renewal of top-growth other than the systematic pruning of laterals. Occasionally a tree loses its vigor; in this case a new vertical is allowed to develop along its trunk and a partial or complete new top is formed. The same practice is employed in case it is desired to raise the height of the topped tree, say, from 6 to 8 feet. (See Plate 7).

An interesting innovation in the topping system is being used by one Kona grower. About half of the laterals were removed as the young tree developed, two consecutive pairs being kept and the next two pairs removed. The trees were topped at about 8 feet and care has been taken to prevent excess sub-laterals from developing. A strong, symmetrical system of primary laterals has thus been developed, which, with the ample spacing of 10 by 12 feet, offers a fine opportunity for producing trees of long and heavy bearing ca-

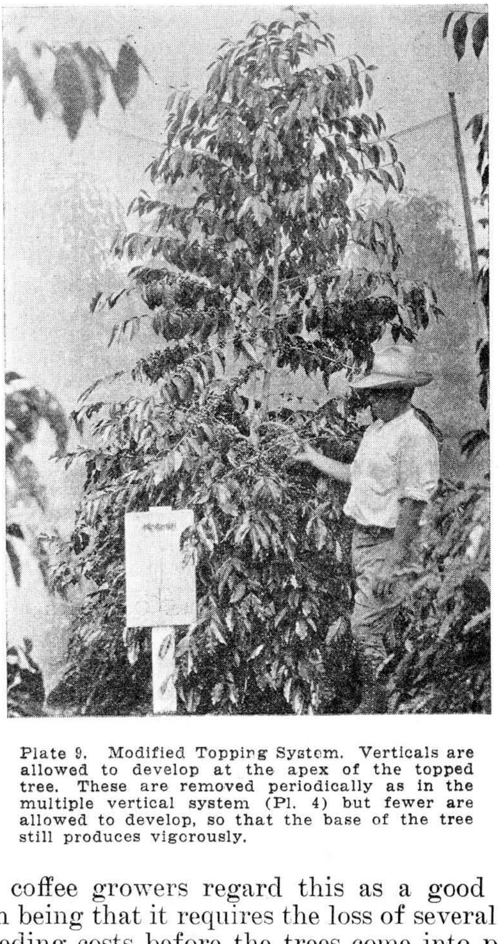

Plate 9. Modified Topping System. Verticals are allowed to develop at the apex of the topped tree. These are removed periodically as in the multiple vertical system (Pl. 4) but fewer are allowed to develop, so that the base of the tree still produces vigorously.

pacity. Kona coffee growers regard this as a good system, their chief objection being that it requires the loss of several partial crops with high weeding costs before the trees come into profitable production. (See Plate 8).

The topping system is used almost entirely in the high wet locations and extends in some places well into the central zone. It is ordinarily stated that the topped tree has the advantage over the non-topped in the wet sections in that it does not exhibit such excessive vegetative growth. Kona growers do not agree on this point, however. Many claim that non-topped trees are equally well adapted to these wet, cool areas. At one time, topping was practiced all along the government road at 1,500 feet, but it has been largely displaced by non-topped systems up to about 2,000 feet.

Under the climatic conditions which exist in the upper zone, the bearing period is a long one. Although the main crop is harvested in the period from February to June, an appreciable amount of fruiting occurs throughout the other months. This permits the grower to utilize his own labors to the maximum.

The proper use of the topping system, results in many advantages, such as high yields, long-lived trees, good quality of cherry. If the tree has been properly pruned, the fruit is easy to pick. A topped field shades out practically all weeds and grass. The system has one serious disadvantage, however, and that is the excessive time required in pruning. As many as 20 man days per acre are required for the main pruning and the several thinnings as compared with 6 man days for the multiple vertical system. Considerable skill is required in pruning the topped tree. Failure to prune consistently results in an umbrella-like growth which kills inside growth.

MODIFIED TOPPING SYSTEM. This system (See Fig. 3 and Plate 9) is a combination of the topping and the multiple vertical systems. It develops naturally on a topped tree if the verticals setting on near the apex are not removed. The lower part of the tree is in all respects like a topped tree, the upper part like a multiple vertical except that fewer verticals are maintained, usually not more than three.

Little appears to be known about this system but it seems to offer promise especially for the central zone. More of the tree is left permanent than with the multiple vertical system and it would seem that a more uniform bearing surface could be maintained with less danger of excessive dieback. The bearing season should also be somewhat more prolonged, which is a decided advantage.

Pruning Systems of Other Countries

Some of the pruning systems used in other countries are similar to those used in Hawaii. Others have no counterpart locally. The latter are also included in this bulletin with the thought that they may have some adaptation to local conditions.

TOPPING SYSTEM. This is apparently the most universally used system throughout the mild coffee-producing countries. In Colombia, Malay, Kenya Colony and Uganda in East Africa, India, and Ceylon, topping is referred to as the common system. In most of these countries, coffee is grown under shade. Under such conditions, it is generally stated that topped coffee is easier to manage than non-topped. The same general objection against this system is noted in other countries as in Kona: the excessive labor costs of pruning. It is stated that in Kenya 12 to 15 trees a day is one man's work. For this reason, there is a trend in some countries toward the non-topped systems.

The tendency in topping seems to be to prune rather lightly until the trees have taken on the undesirable umbrella condition, with all growth shaded out within the tree, in which case, drastic pruning must be undertaken to rejuvenate it. The height at which the tree is topped varies from 4½ to 8 feet, the lesser height being used for poorer soils. In establishing the system, the tree is allowed to grow about 2 feet taller than the desired height for topping, so that the cut can be made on "brown wood". Under conditions which force very rapid growth of the young tree, capping is practiced (that is, pinching off the terminal bud). This stops upward growth for the time being and makes the laterals sturdier. Only one of the two verticals setting on at the node just below the cap is allowed to develop. If necessary, the vertical which develops is also capped. The first capping is done at about 2½ feet and the second at 4 feet with the final topping at 6 feet.

Multiple vertical system. In a number of countries where changing economic conditions have limited the supply of cheap labor, the multiple vertical system is coming into use because of the minimum of time, as well as of skilled labor, required for pruning. This system is advocated only where optimum conditions prevail so that new verticals develop rapidly and vigorously. Rich soil, adequate moisture, and warmth are regarded as essentials. With less favorable conditions, the topping system is preferred.

Agobiada system. (The word "agobiada" from the verb "agobiar" to bend). This system is commonly used in Guatemala. It can be begun the first or second year after planting. The young tree is bent over nearly to the ground and held with a forked stick. The laterals touching the ground are pruned off. This bending of the tree forces out a series of verticals along the upper side of the trunk. Generally about three of these verticals along the upward portion of the bend are selected. Usually no further development of the terminal bud of the bent over stem takes place. As the uprights become unproductive, they are cut off and new ones brought out either from the prostrate stem or the basal nodes of the upright verticals. The bearing surface is essentially on primary laterals. If all the verticals on the original prostrate stem lose vigor it may be cut off to within a foot of the ground and a new stem allowed to develop, which is subsequently bent over as with the young plant. It is essential that the excess verticals, which always develop on a bent stem, be rubbed off when they are small, as they greatly weaken the plant and decrease the yields.

The advantages of this system are said to be the same as those of the multiple vertical, namely, low cost of pruning and ease of picking. It is claimed by some that bending over shortens the life of the tree. The same principle of bending over of the new plant to force out several shoots is practiced by the Kona coffee planters, when they set the new seedling at an angle. (See Plate 2).

Costa Rica system. (Also called multiple trunk or bush system). The young seedling is capped first at about 1 foot above the ground and two verticals from the top node are allowed to develop, a light bamboo stick serving to hold them apart. These two verticals are capped at about the fifth node above the first cap, and two verticals brought out at the top node of each. The uppermost pair of laterals is removed to stimulate the development of the verticals. These four verticals are again capped at the fifth node. The top laterals in this case are not removed, their presence resulting in slower growth of the final verticals, which develop, now numbering eight in all. These are allowed to attain their full height and constitute the chief bearing surface. They are allowed to remain until bearing on the primary laterals has largely ceased and are then cut back to the fourth node of the parent stem and two new verticals allowed to develop on each. This process is repeated until all nodes of the several cappings have been used up. In ordinary practice, the primary laterals about the base of the tree are cut off close to the vertical after the second heavy crop to force growth into the top verticals. Some writers contend that sub-laterals should be developed by pruning back to the first or second node.

This system is said to have the advantage of cheap pruning costs. Skilled labor is not required for either pruning or removing of excess shoots. It is stated that there is less fluctuation in yields than with other systems. It is recommended for the warmer sections of Costa Rica in preference to the topping system, where the latter incites too much sub-lateral development.

REJUVENATION OF RUN-DOWN COFFEE ORCHARDS

Hundreds of acres of coffee orchard, 35 to 70 years old, are found in Kona which are not producing crops large enough to pay costs of production. Along the Kailua road, Kahaluu, Kamalumalu, Holualoa, lower Keopu, portions of Honalo, Kealakekua and Honaunau are good examples. Most of these fields are planted with the Hawaiian strain of coffee, and it is generally accepted that this strain is inferior to the Guatemalan in production. Entire replacement of the old plantings of the Hawaiian strain with good new seedlings of the Guatemalan would be a sound investment of time and money.

The more progressive growers are continually on the lookout for trees which have lost their vigor and, either by building up or by replacement of a tree here and there, the whole orchard is kept up to a high state of production for an indefinite length of time. In many of the poorer orchards, the whole field has gone back and drastic methods are required to bring it back into profitable production. Following are the leading methods practiced in Kona in the rejuvenation of old fields:

Removing Old Trees and Replanting With New Seedlings

The old trees are cut off close to the ground or dug out and removed from the field. New holes are dug in the interspaces between the former planting. In less than 6 years, the new orchard will be in full production, greatly exceeding that of the old orchard. The trees will be uniform in size, shape, and vigor, and will continue producing for the next 30 years or more. But to remove the old trees means the loss of about four crops. Increased production would make up this loss in 10 years or less but in most cases that is too long a period for the growers in Kona where the average length of lease is only 15 years. Already heavily in debt, they dare not increase their obligations regardless of the ultimate gain. Where a new lease has been taken on an abandoned coffee orchard, this method is often used in preference to bringing the old trees back into production. Since the latter requires from 2 to 4 years, replanting with new seedlings often costs but little more and a much better orchard results.

The advantages of removing the old trees and planting new seedlings are: trees of improved Guatemalan strain can be planted in place of the poor Hawaiian strain; the orchard will have more uniform trees; planting distances may be altered from 7 feet by 7 feet found in nearly all old plantings to the wider spacings of 9 or 10 feet square now advocated; long years of increased production are assured; the quality of product is raised as coffee from young trees is more uniformly high grade than that from the old trees. The disadvantages of this method are: total loss of three or more crops, depending on the size of the seedlings and their growth; and high cost of planting and weeding during the first 3 years without any income from the coffee.

Planting of New Seedlings Among the Old Coffee and Gradually Removing the Old Trees

This is the most popular method of replanting the old field. Five hundred acres in Kona are today being rejuvenated under this system.

Holes for the new plant should be made between the old trees several months before planting. Usually the spacing distances are changed to 9 by 9 feet or greater squares. The hole should be at least 2 cubic feet in size and filled with surface soil and humus a month before planting. The best time to plant is during the months of May, June, and July. Nearly 100 percent of the seedlings grow since they are set in the shade of the old trees. When applying fertilizer to the old trees, a handful is broadcast around the new seedlings.

It is not necessary to change regular field operations during the first season; but in the second year the new seedlings will be from 3 to 5 feet in height and unless a few branches from the old trees are removed to give sunlight, the new plants will become spindly and weak. If well seasoned 2-year-old seedlings are planted, 1 to 2 pounds of cherry coffee will be produced by each plant during the second year. By the third year, if moderate pruning of the branches of the old trees had been undertaken, about 3 to 5 pounds of cherries a tree can be expected. During the year, every other row of old trees should be removed to give sunlight. In the fourth year, if enough pruning of old trees has been done, the new trees are of sufficient size to bear a heavy crop and the remaining half of the old trees should be removed. In the majority of cases, planters do not remove enough of the branches from the old trees, as it means reduction in the size of the crop. This is especially true in the second and third year, if the old trees have a good-sized crop.

If removing the old trees is delayed until the fourth, fifth, and sixth year, the new seedlings invariably require reconditioning. The spindly growth has little bearing surface and is too weak to sustain additional top-growth. The plants are generally cut down to within 6 or 7 inches of the ground to develop a whole new top. This process is wasteful and unduly prolongs the period of renewing the orchard.

It is reported that when the new seedlings are planted, the old trees appear to show renewed vigor. The shoots which develop are stronger and often bear a heavy crop. Seeing the improvement on the old orchard, the grower, in many instances, abandons his original program and allows all the old trees except the very poorest to remain, possibly removing 10 percent of the old trees. Why the old trees revive after planting new seedlings is a question worthy of study. Growers generally conclude that digging holes for the new seedlings necessarily severs a portion of the roots, and the new growth of roots acts as a stimulus to the tree. The filling of the holes with the surface soil and humus may be another factor.

The advantages of this system of planting new seedlings among the old trees are: relatively little loss of crop and low weeding costs, due to the shade of the old trees. The disadvantage is that, unless unusual care is taken, the new trees are spindly from lack of sunlight.

Stumping the Old Trees

If the old tree is sufficiently vigorous, cutting off the trunk at 1 to 2 feet above the ground level forces out many new shoots. After these have reached a height of about 12 inches, they are thinned out to the desired number, which is from 1 to 4, depending on the pruning system to be used. With sufficient vitality in the old stump, the new growth is rapid and a complete new top is developed with the loss of about two crops. Instead of cutting the old top completely off, it is a common practice to saw about three-fourths through the trunk and then push the top over. Sufficient attachment with the stump remains for the top to remain alive several months. It is said that this greatly aids in the early development of the new shoots.

Stumping the tree is a drastic method and often results in very weak growth or death of the tree. It is an odd fact that completely digging up and replanting an old stump, with its root systems severely pruned back, often seems to effect stronger growth with less mortality than stumping alone. May and June seem to be the best period to stump the trees.

This method has the advantage over replanting with new seedlings in the loss of only two crops instead of four. However, it is an uncertain one. In some instances, a high percentage of good vigorous trees has resulted, but in others the slow, uncertain growth, together with appreciable mortality, has rendered the crop loss as great as in case of replanting with seedlings. The removal of all top-growth also means high weeding costs for a 2-year period. In addition, the crown and root system of the tree are still old and there is some evidence that the new top loses its vigor more quickly than would a complete new plant.

Drastic Pruning

Topping system. In this system the trunk and old thickened laterals are untouched, but a large proportion, probably four-fifths of the remaining growth, is cut back close to the old laterals. Sufficient of the old wood and leaf surface remains to enable the tree to set on good new laterals, with the loss of little more than one crop. Its chief disadvantage is the excessive labor required for the pruning and subsequent thinning.

The so-called parrot stick method is sometimes used in other countries. The pruner works completely around the tree, removing all growth to about 12 inches of the trunk. The new sub-laterals develop on these old 12-inch lateral stumps. This method is quite rapid, but it is considerably more drastic than the thinning method, just described, and entails much subsequent thinning. However, it is often the only practical method, if the tree has been allowed to go without pruning until its top has become a mass of tangled growth. This method causes the loss of about two crops.

MULTIPLE VERTICAL SYSTEM. The number of verticals is reduced to one-third or one-half that of the original tree, and the lower laterals on those remaining are cut off close to the stem. A heavy application of fertilizer is also made. This generally forces a strong growth at the top of the old verticals. The weight of the crop during the next season bends them far over, and this stimulates development of the new verticals. With good trees the crop loss is one or two seasons.

In case of an abandoned grove, it is regarded as the best practice to build up the vigor of the trees for one season by heavy fertilizing and clean culture before any pruning is done other than the removal of dead wood. As the new growth develops, the old verticals are gradually removed so that by the end of the second or third season, a complete new top system has developed. Groves abandoned for a few years and then brought back by proper methods of rejuvenation often bear heavily for many years. The rest given the tree and accumulation of humus may be contributing factors. A grove in the Kealakekua Section, abandoned for almost 10 years, and brought back into production by this method, yielded 30 bags (3,000 lbs.) of cherry an acre the second season, and 150 bags in the third and fourth.

SHADING

It is recognized that coffee requires shade when it is subjected to extremes of climate. The effects of high temperature, excessive sunlight, low rainfall, and strong winds are greatly tempered by adequate shade and often by supplemental windbreaks. In many localities, where coffee is planted at varying altitudes, the low levels are shaded. With increasing altitude the shade trees are spaced farther apart and at the highest levels are omitted altogether. In other places, shade is used even at high altitudes, sometimes to protect the tree against cold night temperatures, sometimes to conserve moisture and increase humidity.

There are many localities where the advantages of shading are just about balanced by the disadvantages. Often this is a matter of the season. In a cool, moist year the open plantings, and in hot, dry years, the shaded plantings are better. There is no doubt but that if the coffee tree produces normally without shade, it should be dispensed with. It is a sort of necessary evil.

In the Kona District, no shade whatever is used. (See Plate 1). The quiet air, daily cloud blanket, frequent showers, high humidity, and good soil texture provide all the advantages of shade without its disadvantages. Growers contend that shading stimulates excess vegetative growth at the expense of coffee production, particularly in the central and upper zone. But it is the opinion of many that below 1,000 to 1,100 feet altitude, the crop would be benefited by proper shading. Here the coffee often suffers from drought, excessive heat, and low humidity. Heavy yields under these conditions cause excessive dieback, and the trees become depleted and unproductive at an early age.

The following notes are taken from the experiences of other coffee-growing countries with shade: The advantages of shade are that it conserves moisture, increases the humidity, and reduces daily temperature fluctuations. Shading makes the soil more fertile. Plant food is brought up from the deep soil strata by the shade tree and deposited on the top soil layer by means of leaves and loppings which fall to the ground and gradually decay. Shading breaks the force of rain and prevents erosion of the soil. It prevents overbearing and thus reduces dieback. It reduces the costs of weeding. Its chief disadvantage is that it reduces the yields of coffee. Particularly is this true if the shade is not properly controlled, or if there already exists ample rainfall and high humidity. It increases the danger of various diseases and insect pests. Finally, the shade trees require considerable pruning, thus adding to the cost of operations.

The requirements of a good shade tree for coffee are rapid growth, deep-rooting habits, a wide spread with light foliage, and a non-deciduous type. Most writers recommend a leguminous tree because of its ability to assimilate nitrogen from the atmosphere, but in most countries the silver-oak (*Grevillea robusta*), a non-legume, is still the chief shade tree. This species is used in one locality in the Kealakekua Section and also in the Hamakua District. Constant attention must be given the shade tree. Whether it is beneficial or harmful is often a matter of proper or improper regulation. The shade must be kept high above the coffee trees and thinned out so that the overhead canopy at all times provides the proper balance of sunlight, humidity, and air-circulation.

CULTIVATION, WEED ERADICATION, GREEN MANURES

Cultivation. Throughout the world, cultivation of coffee is little practiced. In a few localities, where the soil is deep and the topography and slope permit, horse or power-driven cultivators are used. These operations are particularly useful where the soil is heavy and tends to pack and where extensive production requires the employment of rapid methods. There is a growing belief, however, that stirring of the soil about a coffee tree is a precarious procedure. A certain amount of root pruning may be desirable, but it is very easy to exceed the desirable amount, in which case the vigor and producing power of the tree is correspondingly reduced. Where the plants tend to suffer from drought, special measures to force the roots of the coffee tree down are advocated, such as deep holing at the time of planting, and placing of the manure in trenches or pits. Shallow cultivation can then be practiced, but even here, the grower is cautioned to cultivate only during the dormant period and not when the tree roots are actively developing. Especially is the grower warned not to hoe under the drip of the tree. Some sort of fork, which gives the maximum of stirring of the soil with a minimum of cutting of the roots, is generally considered preferable to a hoe.

In Kona, it is a well-established belief that cultivation of any sort, other than that incident to hoeing and fertilizing, is injurious to the coffee plant. In many fields, rocks and steep slopes would prevent cultivation. It is reported that attempts have been made in the past to cultivate in the deep soil areas. Poor yields and excessive washing away of the surface soil are said to have been reasons for abandonment of the practice.

In many fields, the frequent hoeings, necessary to keep the weeds down, effect considerable stirring of the soil. Contrary to general practice, one grower in Kona hoes under his trees once a year to a depth of 2 or 3 inches at the time of pruning, cutting loose the mass of small roots which permeate the top soil. He believes this is an effective method of stimulating new root development.

Weed eradication. In the estimation of most growers, eradication of weeds is, next to fertilizing, the most necessary factor in the production of coffee. Efforts of fertilizing and pruning are largely nullified if fields are not kept reasonably free from weeds and grass. During the harvesting season, which extends from September to February, everybody is so busy with picking and curing the crop that weeds are allowed to grow until they are usually "knee-deep" in January. The usual practice is to kill this heavy growth by spraying with sodium arsenite.

The spray is prepared by combining white arsenic with caustic soda so that a water-soluble sodium arsenite results. Two different methods of preparing the solution are used. With one method, the two ingredients are boiled with water until the milky solution becomes clear. In the so-called "self-boiling" method, the white arsenic powder is mixed with just enough water to form a paste. The flakes of caustic soda are then added to the paste. The caustic generates sufficient heat to dissolve the arsenic and a clear solution results without any need of further heating. The solution can be prepared in the field, requiring only a short time so that considerable time and labor is saved. There is no single or "best" formula for preparing the sodium arsenite spray. It is necessary to add a certain minimum amount of caustic soda to make the white arsenic dissolve readily. This is about one-fourth to one-half pound of caustic for each pound of white arsenic. In some formulae, especially where the self-boiling method is used, more caustic is added. This makes the arsenic dissolve more readily and is said to make the spray stick better to some grasses and weeds which have a waxy surface. A formula in use on some sugar plantations is as follows: 13 pounds of white arsenic are made into a paste with 1 gallon of water and 7 pounds of caustic soda are added. The solution is allowed to stand till clear and another gallon of water is added. One-half pint to 1 pint of this solution is diluted to 5 gallons for spraying.

In Kona, a common formula is 15 pounds of caustic soda and 15 pounds of arsenic. This, diluted to 75 gallons with water, is enough spray for each acre of coffee land. If the weather is unusually dry, this solution is diluted with another 10 gallons of water. The higher concentration during the dry season is said to be detrimental to the coffee plants. At the Kona Substation, the following method is used: Into an ordinary 5-gallon kerosene tin are put 3 gallons of water and 4 pounds of caustic soda. This is brought to a boil and 11 pounds of white arsenic are gradually added and the solution boiled gently for about an hour. Enough water is then added to make 5 gallons of solution. This forms the stock solution. For spraying, this is diluted to 125 gallons for easily killed weeds. For heavier weed growth or for more resistant weeds and grass, a higher concentration is used. For panicum, the solution is diluted to only about 60 gallons. From 60 to 90 gallons per acre of spray are used, depending on the weed growth.

The common 5-gallon knapsack sprayer is used. It requires about 1½ man-days per acre for a heavy growth of weeds. With a lighter growth, the amount of spray and time per acre can be reduced about one-third.

The average planter sprays only two or three times a year; once after the harvesting, and again during the rainy season when, in spite of all his efforts, weeds grow faster than he can eradicate them. Almost a universal belief prevails that, if the field is sprayed too often, the soil becomes hard and lumpy and is detrimental to coffee. Only those individuals who have large areas to cover spray oftener than two or three times a year.

To avoid excessive spraying, the fields are cleared during most of the season by hand-hoeing. This is an expensive method. It requires between 5 and 10 man-days per acre, depending on the size of the weeds, and 5 to 6 hoeings per year are necessary if the field is to be kept in good condition. Groves in the central belt require more hoeing than the high-altitude groves, due to the more open types of pruning. Heavy weed growth is usually a good indication of low yield, as the plentiful sunlight which induces the growth of weeds is due to poor growth of the coffee trees.

Green Manures. In most coffee-producing countries, various green manuring crops are grown among the coffee. Some authorities advocate a quick-growing legume. Others recommend perennial bushes which can be lopped off several times a year. In 1932,[1] cooperative experiments were conducted with several growers to test the adaptability of different types of legumes. None of them were adapted to fields with mature trees and close spacing because of insufficient light. The growth became very puny and died out altogether in most instances. In the young fields, where the trees had not yet closed in, nearly all of the 10 species tried grew vigorously. The tall upright types, such as sun hemp (*Crotalaria juncea*) and pigeon pea (*Cajanus indicus*) grew too tall, and in some instances, overshadowed the young coffee trees. The climbing types, like Black Mauritius velvet bean (*Stizolobium ateirimum*) and lablab (*Dolichos lablab*) were objectionable because of the constant attention required to keep them from climbing over the coffee. The most promising were Birdsfoot trefoil (*Lotus corniculatus*) and Sarawak bean (*Dolichos hoseii*). These are creeping but non-climbing and form a dense matted growth close to the ground. They are perennial and sufficiently sturdy to choke out most of the weeds and grasses. They are also said to grow well under moderate shade, especially the Sarawak bean.

Kona growers are generally skeptical of the feasibility of a green manuring crop among coffee. They contend that growth of

[1] Thanks are due Dr. C. P. Wilsie, Agronomist of the Hawaii Experiment Station, for furnishing the seed and installing these experiments.

any kind among coffee is undesirable since it enters into direct competition with the surface-feeding roots of the tree. To be of any appreciable value to the Kona coffee industry, the green manuring crop would have to grow in the comparatively dense shade of the old fields.

FERTILIZERS

In other coffee-producing countries, the use of commercial fertilizers is almost nil. In the vast area planted to coffee in Brazil, only about 15,000 tons per year are imported. More than 90 percent of the entire area receives no fertilizer at all. Practically no commercial fertilizer is used in East Africa, Malay, Puerto Rico, Colombia, and Central America. The Agricultural Departments of these countries recognize the need for such fertilizers but their recommendations are usually of this order: 100 pounds ammonium sulphate, 200 pounds superphosphate, and 75 pounds potassium sulphate per acre. In contrast to this is the Kona practice of applying as much as 3,000 pounds of high-grade commercial fertilizer per acre per year, with an average of 1,200 to 1,500 pounds on the better tilled areas.

This difference in fertilizer practice is due to a number of factors. The coffee producing areas of most countries are located far up in the hills, relatively inaccessible and far removed from intensive cultivation of other crops. Commercial fertilizers shipped for long distances and transported up steep slopes are quite costly by the time they are applied to the soil. Animal manures and vegetation from nearby forests and waste land, as well as wood ashes from new clearings, are generally available at low cost. Then, too, the need of fertilizer is generally not so great where the coffee is grown under shade. The deep-rooted trees are continually bringing up plant food from the lower depths and depositing it on the surface of the soil in the form of leaves and loppings. In Brazil it has been the practice to move on to new virgin lands further into the interior as soon as yields of coffee decreased to too low a level.

These conditions are reversed in Kona. The District is comparatively accessible. Ready-mixed fertilizers used in large quantities by the local sugar and pineapple industries are available at relatively low cost. High labor costs make the commercial fertilizer actually cheaper, in terms of units of actual plant-food furnished, than forest litter and organic composts. High rentals and the ofttimes high prices of coffee have resulted in the development of an intensive system, the greatest net return generally resulting from high yields and heavy applications of fertilizer.

In all other countries, particular stress is laid upon the need of plentiful organic matter in the soil for successful coffee culture. Coffee is said to require the leaf mold of the virgin forest soil, and when this disappears, the coffee tree suffers. Under Kona conditions, coffee has been grown continuously for several decades without any direct measures being taken to increase the organic matter in the soil. That this has been possible is due to a very considerable extent to the remarkable properties of Kona soils, which retain their fine permeability and moisture-holding properties in spite of loss of organic matter. On most soils, continued application of inorganic

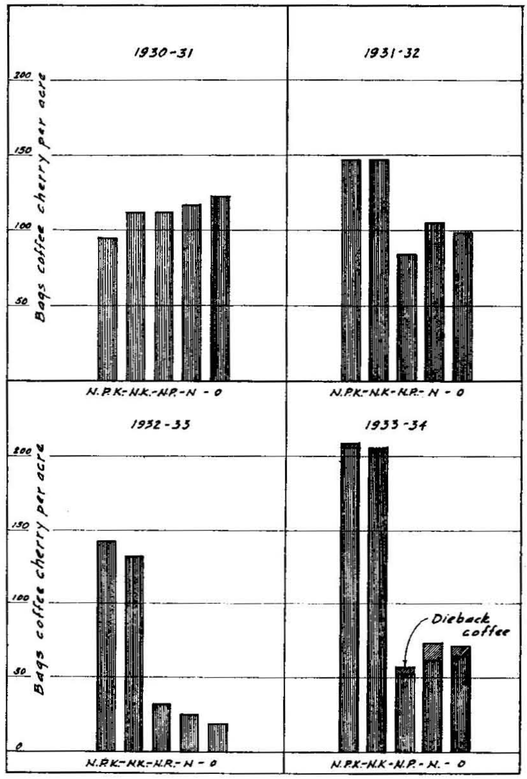

FIGURE 5—Coffee fertilizer experiment—Kainaliu, Kona, Hawaii.

Fertilization:—2000 lbs. of an 8-8-8 fertilizer.
N — 160 lbs. nitrogen—half as ammonium sulphate, half soda nitrate.
P — 160 lbs. phosphoric acid as superphosphate.
K — 160 lbs. potash as potassium sulphate.

NOTE:—The dieback coffee was weighed separately in the 1933-34 crop. This is shown in the cross-hatched blocks.

EXPLANATION OF FIG. 5—COFFEE FERTILIZER EXPERIMENT

This experiment is made up of five different fertilizer treatments. Each treatment is repeated five times, making twenty-five plots in all. The yields given in the diagram are the average of the five plots of each treatment.

Fertilization consists of 2000 lbs. of an 8-8-8 fertilizer per year, put on in equal applications in January and June of each year. The nitrogen—160 lbs. of N—is half as ammonium sulphate and half as soda nitrate. The P—160 lbs. of phosphoric acid (P2O5) is superphosphate. The K—160 lbs. of potash (K2O)—is potassium sulphate.

Results. The field had been given regular fertilizations of complete fertilizer up to September of 1929. In July, 1930, the first fertilizer of the new treatments had applied. Hence, the 1930-31 crop was not appreciably affected. This crop shows that all fertilizer treatments had approximately the same start, the complete fertilizer N-P-K being somewhat poorer.

The effect of the different fertilizers is plainly evident in the 1931-32 crop and in 1932-33 the N1P, N and O (i.e., no fertilizer) plots were nearly a failure. The trees were nearly bare at the end of the crop with excessive dieback. In vivid contrast to these were the N-P-K and N-K plots, with dark green full-leaved new growth, and almost no dieback in evidence.

In 1933-34, it was evident that the N-P-K and N-K plots would bear heavily. The others had developed new verticals which appeared fairly vigorous and gave promise of much better yields. As the fruit developed, all plots without potash (i.e., NP, N, and O) suffered excessively from dieback. The dieback cherry was picked and weighed separately. This is shown in the diagram in the cross-hatched blocks.

This experiment proves very conclusively that the field on which this experiment is located needs potash and nitrogen to produce good yields of coffee. The soil has thus far been able to supply the trees with all the phosphate they need. Continuation of the experiment may eventually show the need of phosphate in the N-K plots.

fertilizer has resulted in great increases in yield; nor is it difficult to prove that the high yields of 200 to 300 bags of cherry per acre are due to use of fertilizer. Withholding the fertilizer for two years generally causes a sharp and permanent drop to one-third or one-fourth of the former yields. (See Fig. 5). In certain areas, however, yields diminish in spite of high applications of inorganic fertilizer and the impression is gaining ground that such soils would be greatly benefited by organic matter.

Commercial Fertilizers

NITROGEN is needed in unusually large amounts by the coffee tree. Not only is it necessary for the production of bearing wood for the next crop, but also for the development of the coffee cherry. A careful balance of nitrogen and the other fertilizer elements, chiefly phosphates and potash, is required. Just as a deficiency limits its growth, an excess produces undesirable growth, weak, unproductive, and subject to infestation by pests and diseases. Fertilizing with nitrogen alone (either as ammonium sulphate or as sodium nitrate) has been tried in Kona and elsewhere. In Puerto Rico, experiments conducted over a period of 8 years showed that the trees fertilized with nitrogen only were tall, spindly, and weak with very low yields, compared with adjacent trees receiving supplementary phosphates and potash. Although nitrogen alone, as ammonium sulphate, is still used in Kona, most of the growers are agreed that such use is not good practice. The tree makes a fine vegetative growth, but during the development of the cherry dieback is unusually severe. Moreover, the cherry which does mature is not of as good quality as the complete fertilizer coffee. Recently some samples of green coffee were prepared from the variously fertilized plots in the Station's experiment at Kainaliu. Planters were able, without exception, to single out the sample from the plots receiving nitrogen only by its undesirable "pinkish" cast.

Opinion differs as to whether ammonium sulphate or sodium nitrate (Chile Saltpeter) is the best form of nitrogen to use. The Puerto Rico experiments showed the former to be superior in most instances. In Kona, good response can be had from either. Until recently, the local coffee fertilizer formulas contained chiefly the nitrate form. With the current low prices of ammonium sulphate, this form has been substituted for the nitrate to a considerable extent with little apparent difference in its effect on coffee. Some of the Kona growers prefer ammonium sulphate, stating that it lasts longer than the nitrate form and has less tendency to burn the coffee leaves.

PHOSPHORUS (phosphoric acid) is especially needed by young coffee plants for root development. It is also needed by the mature trees in the production of fruit but apparently in not very large quantities. Recommendations elsewhere include phosphates as an important part of the fertilizer, although there have been few experiments to show that the soil supply was not adequate. The Puerto Rico experiments showed no benefit from phosphate fertilizer over the 8-year period. The Hawaii Station's Kainaliu experiment has failed thus far to show any benefit to be derived from the use of phosphates after 4 years, as far as tree vigor and yields of coffee are concerned, although there are some indications that

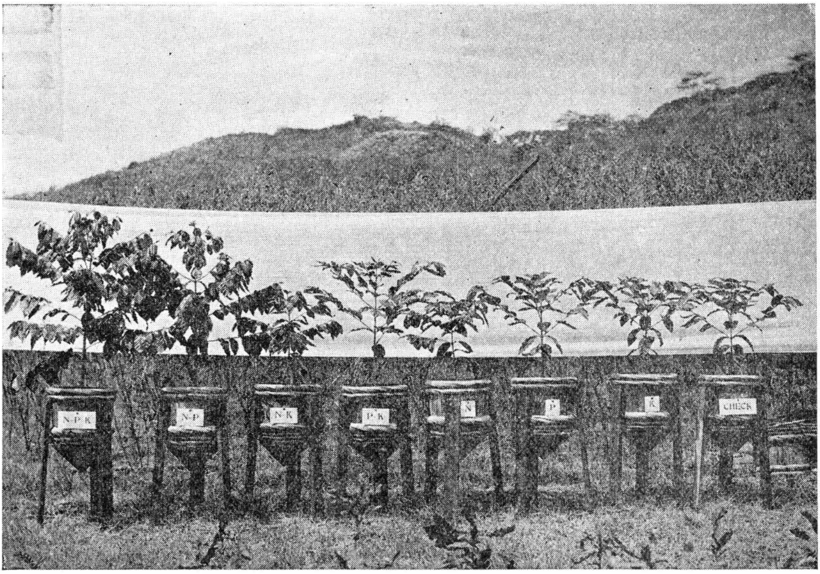

Plate 10. Pot test on a Kona Soil, Using Coffee Seedlings. The N-P-K (nitrogen-phosphoric acid-potash) and N-P trees show a strong response while the N-K and P-K trees are much smaller. Upon bearing their first crop the N-P tree dropped most of its leaves and set no fruit, while the N-P-K and N-K trees did not shed their leaves and bore fruit, thus confirming the results of the field experiment that potash is necessary for development of coffee cherry. For early development of seedlings, phosphates appear to be necessary in considerable amounts. Single element fertilizers gave no increased growth over check (no fertilizer).

the quality of the roast is affected by complete deletion of this element from the fertilizer formula. The beneficial effect of phosphates on young coffee seedlings is strikingly shown in a series of pot experiments being conducted at the Hawaii Station in Honolulu, in which the coffee seedlings are grown in a Kona soil. Those plants receiving ample nitrogen and potash, but no phosphate, are far smaller than those receiving all three. (See Plate 10). The form of phosphates most used in the local formulas is superphosphate. In East Africa, it has been found that on the very poor, heavy soils, steamed bone meal is superior to superphosphate but that on good soils with plenty of organic matter superphosphate was quite effective. Bone meal has the advantage that it is not changed into insoluble forms by the soil and its gradual decomposition makes it available to the plant over a longer period of time than superphosphate.

Potash is of especial importance in the development of the coffee cherry. With an inadequate supply, there is excessive dieback and the tree so exhausts itself that it is unable to develop new wood the following year. This is very strikingly shown in the Hawaii Station's field experiment at Kainaliu where the nitrogen-potash plots, as well as the complete fertilizer plots, are green and vigorous in spite of heavy crops, and the nitrogen-only and nitrogen-phosphorus plots (i.e., those receiving no potash) are badly depleted, poor yielding, and full of dieback. Record was kept during the past year of the amount of dieback in the various treatments. The results are shown in Figure 5. It is quite apparent from this diagram that potash is not only essential to high yields, but also to the

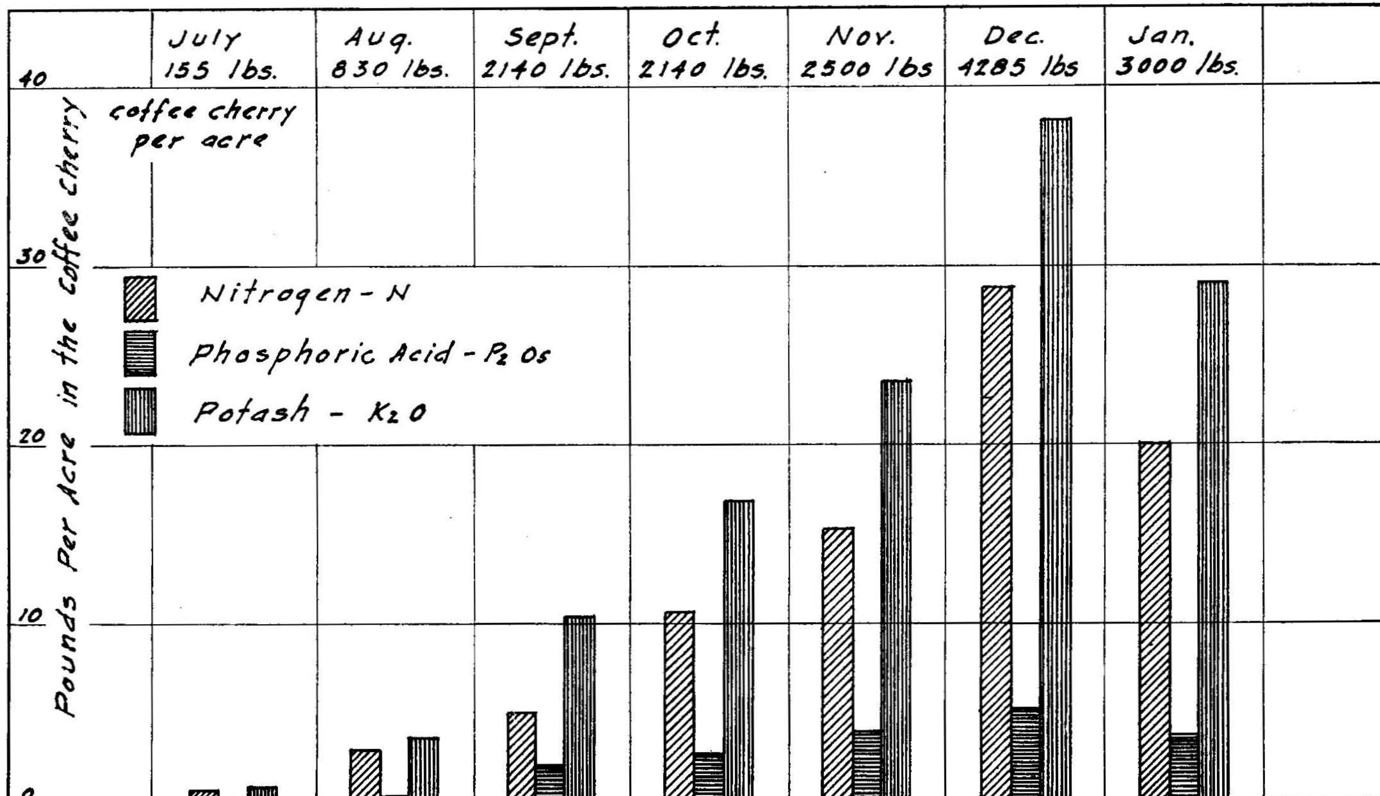

FIGURE 6—Amounts of plant food in coffee cherries per acre during successive months of their development. (Bearing at the rate of 3000 lbs. per acre of fresh coffee cherry when mature). (Data from Anstead and Pittock, **Planters' Chronicle**, VIII, No. 36, 1913).

prevention of dieback. The extra demand for this element during fruiting was well illustrated in the station's pot experiments. The seedlings in nitrogen-phosphate pots (with no potash) grew as well as those in the complete fertilizer pots, until the trees blossomed for the first time. The pots without potash set only a small amount of fruit compared with those with the complete fertilizer and the trees in the former lost most of their leaves. The foregoing results are borne out by similar experiments in Puerto Rico and Costa Rica. In the Puerto Rico experiments, the 12 best yielding plots all received potash.

Potash has the further advantage that it counterbalances the effect of too much nitrogen. With an ample supply of this element, large applications of nitrogen show none of the harmful effects which would result if the same amount of nitrogen were applied alone.

Fertilizer Formulas

Where experimental data is not available as to the fertilizer needs of a crop, it is common practice to use a general formula containing all three elements, nitrogen, phosphoric acid, and potash, in about equal proportions. This is undoubtedly the best procedure. But such a formula may be furnishing one element greatly in excess of needs, and another in insufficient amounts for maximum yields. When the requirements of the crop have been worked out, and what the soil can supply is known, it is possible to construct a more exact formula in which each element is furnished in the proportions needed.

With this purpose in view, the Station is now conducting a number of field fertilizer tests with coffee in Kona. (See Fig. 5). Results from the Kainaliu experiment are showing, year after year, the special need of nitrogen and potash. For a 4-year period, at least, the soil has been able to supply sufficient phosphates. When results from a series of such experiments are available, it will be possible to change the fertilizer formula to fit the needs of the crop more closely.

As a further step in studying the plant-food requirements of a crop, it is invaluable to ascertain how much of each of the different fertilizer constituents are taken up by the plant, how much is removed by the crop, and how much can be returned to the soil in the form of crop residues. Several investigators have analyzed coffee cherries to find the amounts of mineral plant food absorbed month by month by the growing fruit (See Fig. 6). The results show the large and increasing amounts of nitrogen and potash required as the cherry develops. The amount of phosphates required is very small.

Nitrogen, phosphate, and potash in samples of coffee pulp from various places in the Kona District show the same general relationship as was found by other investigators. (See Fig. 7). Another interesting feature is the difference in the percentages of the same element, especially potash, in the various samples. The lowest value for potash is 1.8 percent and the highest, over 4 percent. The effect of fertilizer on composition is shown in the much higher percentages of the three elements in the fertilized (nitrogen-phosphoric acid-potash plots) compared with the non-fertilized or check plots

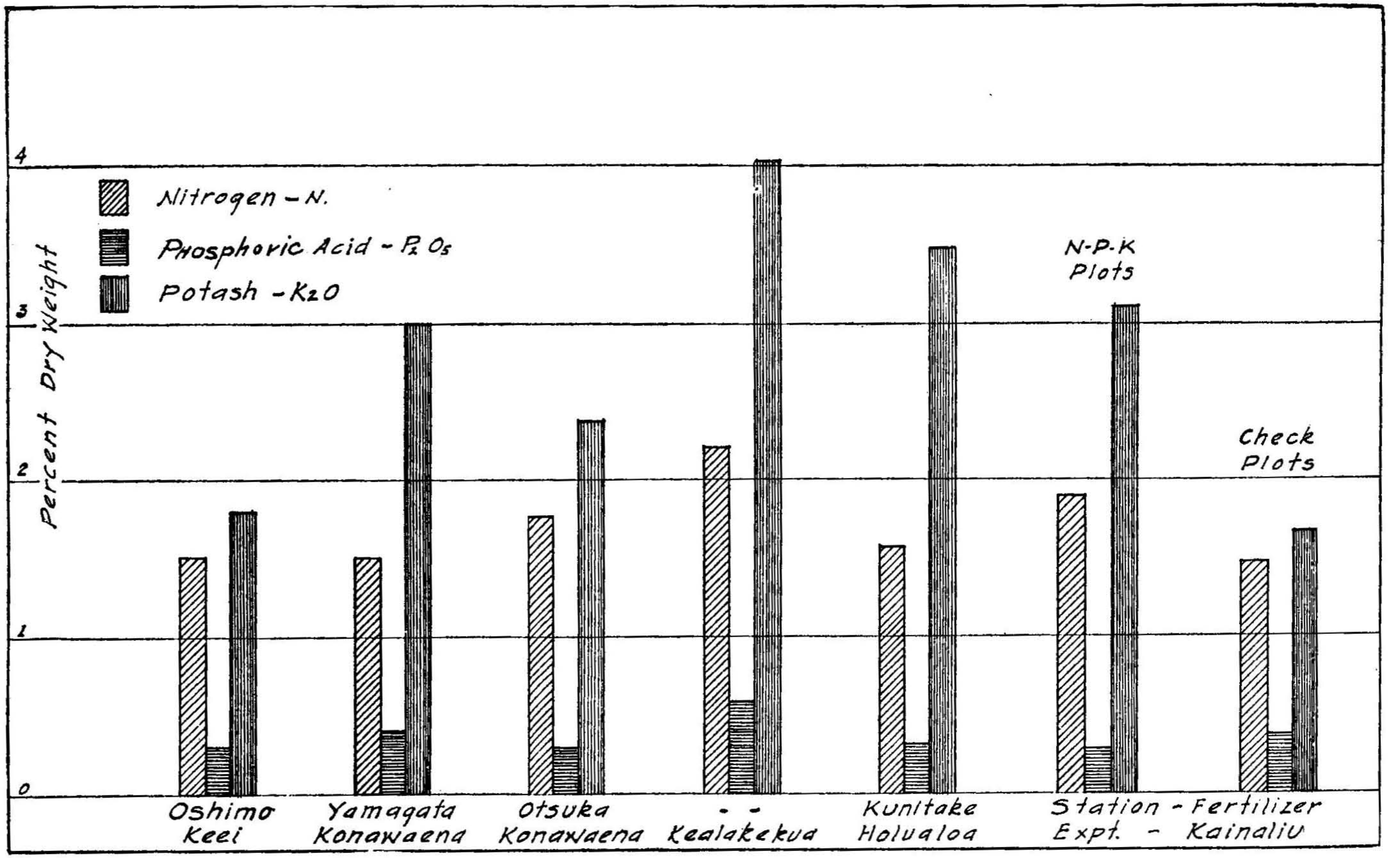

FIGURE 7—Composition of coffee pulp from different locations in Kona (Results expressed as percent of dry pulp).

of the Kainaliu experiment. Figure 8 gives the average composition of the different parts of the coffee cherry, namely the pulp, the parchment, and the bean. The same low phosphate content in proportion to nitrogen and potash persists throughout all three parts.

All of these facts fit very well into the general conclusion that nitrogen and potash are needed in largest amounts, potash in particular being necessary in ample amounts during fruiting. The demands for phosphates are more or less constant but relatively small compared with the others. These analyses do not of course take into account the amount of each element required for the production of vegetative growth.

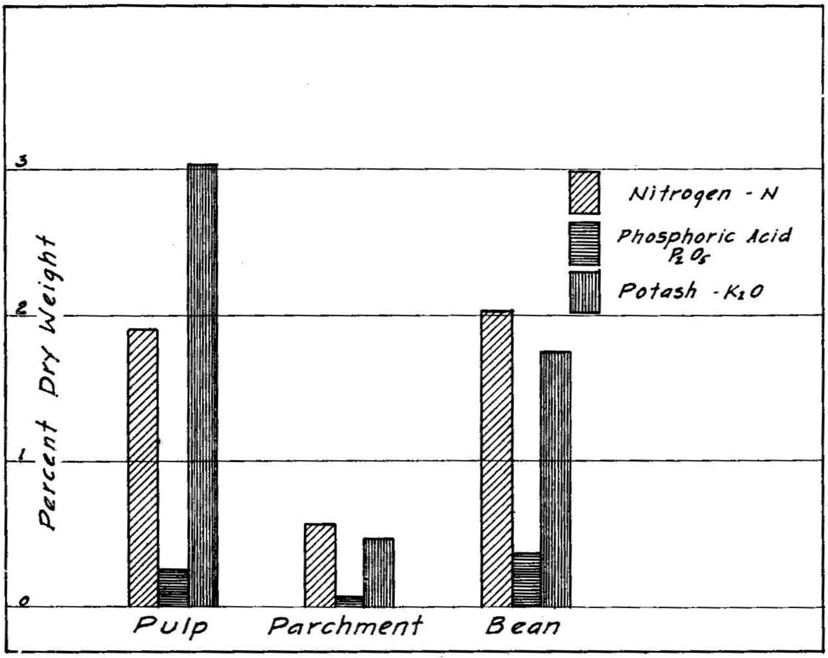

FIGURE 8—Composition of different parts of the coffee cherry (Results expressed as percent dry material).

Based on similar experiments, the Puerto Rico Experiment Station at Mayaguez recommends a 7-10½-14 formula—i.e., 7 percent nitrogen (N), 10½ percent phosphoric acid (P_2O_5), and 14 percent potash (K_2O) for coffee. During the past year, the local fertilizer dealers have reduced somewhat the phosphoric acid and increased the potash content, a typical formula being 9-5-13 as compared with the previous 8-7½-8. Further experiments in other sections in Kona will show how far this reduction of phosphate can safely proceed. It may also be found that several formulas are advisable, due to the widely different climatic conditions existing in the different zones of Kona.

Method of Application of Fertilizer

The present trend in the application of commercial fertilizer to many types of crops is to concentrate the fertilizer in holes, trenches, or narrow bands instead of broadcasting it. It has gener-

Plate 11. Applying Commercial Fertilizer to the Coffee Tree. The Kona District is famous for its large yields of coffee. These are due primarily to the heavy applications of high grade mineral fertilizer. The fertilizer is applied two or three times a year. The leaves and trash are raked out from under the tree and the fertilizer is applied in a narrow band just beneath the rip of the tree. No attempt is made to dig it into the soil. The leaves and trash are merely pushed back over the fertilizer. Efficient absorption of the fertilizer by the plant roots in the surface layer is due to the continuous high humidity which prevails.

ally been found that a given amount of fertilizer applied by the trench or band method will produce as much increase in yield as two or three times the amount broadcast. The reason for this is that in the former method the plant is fed rather than the soil. In the broadcast method, the soil locks up a part of the fertilizer in a form more or less unavailable to the plant. This, together with losses due to leaching, permits less chance for the plant to absorb the fertilizer.

Nearly all Kona growers follow the practice of distributing the fertilizer in a band underneath the drip of the tree. (See Plate 11). The trash is first hoed out from under the tree and the fertilizer applied. The trash and a light covering of soil are then put back over the fertilizer. Judged by the remarkable stimulation which results, this is an effective method. One result of the method, however, is that the fertilizer, particularly the phosphates and potash, remains concentrated in the surface layer. This causes an excessive development of roots close to the top of the ground, making the plant more susceptible to drought than if the fertilizer were placed several inches below the surface (See Plate 12). With the high humidity and frequent rains of the middle and upper belts in Kona, this is seldom a serious factor.

Organic Manures

Organic manures, broadly speaking, include animal manures and artificial manures, i.e., composts made from the rotting, in piles or pits, of all sorts of trash, coffee leaves, and pruned branches, as well as coffee pulp and parchment. Organic manures also include mulches carried in from the outside as well as plants grown among the coffee and turned under as so-called "green manure." Plentiful organic matter is the universal conditioner of soils. It lightens a heavy soil and cements together the coarse particles of a light soil. It increases the permeability of a soil with respect to water and, at the same time, enables it to hold more water. As the organic matter decays, it gradually makes available the mineral plant food the plant needs. Some plants require plentiful organic matter in the soil; others are more indifferent. Coffee is said to be of the former class.

Plate 12. The Root System of a Coffee Tree in the Kona District is concentrated in the upper layer of soil. Note the presence of permanent lateral roots close to the surface and the masses of smaller roots which develop even on the surface of the soil under the mulch of leaves. This extreme surface development is stimulated by surface application of heavy doses of fertilizer.

Sources of material. In most coffee producing countries, there is a plentiful supply of organic matter of one kind or another. Animal manures are often obtainable, and litter from nearby forests can be brought in. Where the coffee is grown under shade, the falling leaves and loppings are important sources of material. In some localities, it is possible to grow green manures between the coffee and to cultivate them into the soil.

In Kona practically no animal manure is available. The fact that no shade is used precludes this source of material. The carrying in of grass from nearby uncultivated areas is a possibility not to be overlooked in some sections. One grower in Waiaha has been carrying in honohono, panicum grass, and other weeds for the last 4 years. These grasses are laid on the field, forming a mulch of about 1 foot in thickness. Once a month, the grass is turned over with rakes and hoes to prevent it from taking root. This grove is now one of the best in this section of Kona. The production has increased by at least 5 bags of parchment coffee per acre, the quality has improved, and the trees are green and vigorous.

Within the coffee field itself, a considerable amount of vegetation is produced, namely, the leaves and prunings of the coffee tree and the weeds and grass which are periodically hoed out or poisoned. While the weeds and grass are produced at the expense of the tree, there are indications that a moderate amount of such growth which is not too close to the tree may be better than bare culture. A source of organic material available to every farmer is coffee pulp and parchment. It is universally agreed that this is valuable fertilizing material and should be returned to the soil.

COMPOST VERSUS FRESH MATERIAL. In utilizing available sources of vegetation, the grower has two courses open, one to apply the fresh material direct to the fields and the other to first compost it. By composting is meant the storing of the fresh material in piles or pits until it has rotted. Applying the fresh material has the advantage that, if it is close by the field, less labor is required than to make a compost. It has certain disadvantages, however. If the material is grass, it contains seed or tends to sprout and must be turned or sprayed frequently. As a mulch on top of the soil, there is a material reduction in evaporation of moisture, but rotting on the surface is wasteful. Most of the organic matter is dissipated in the air rather than incorporated as an organic reserve in the soil. If the fresh material is worked in or covered, much of it rots and remains in the soil, but such a procedure must be followed with care lest the growing crops be injured by the active rotting of the fresh material. This is especially true of materials like fresh coffee pulp containing readily decomposable carbohydrates which ferment and rot rapidly. This energy food greatly stimulates bacterial growth, which in turn robs the tree roots of available plant food. Kona growers are aware of this effect but some state that no harm is done to the coffee trees if the fresh pulp is placed in the interspaces rather than under the drip of the tree. If sufficient help is available during the busy picking time to carry the pulp back to the field, this is probably the cheapest method. The tendency, however, is to distribute it on those fields or parts of fields close to the mill, with the result that they get an oversupply and the more distant fields get none. Composting has the advantage that the rotted material can be carried to the fields during the slack season, with no danger of affecting the growing crop.

METHODS OF INCORPORATING ORGANIC MATTER IN THE SOIL. In other countries, growers are strongly urged to get the organic matter deep into the soil. Where plowing between the rows is possible, the problem is simple. But since in a considerable number of countries no cultivation is practiced, this can be done only with hand labor. Several methods are advocated. If the soil is very poor and heavy, the pit method is recommended. The pits are dug in the interspaces between the trees and filled with the organic material. The next year, the locations of the pits are changed somewhat so that eventually the entire area has received a treatment of organic matter to a depth of 12 to 18 inches. It is stated that in a short time the rotted material in the pit is filled with vigorous new roots of the coffee tree. Instead of pits, trenches can be used. One writer advocates digging a trench in every fourth line, a different line each year. In 4 years, the whole area would have been treated. It is believed that some one of these methods of incorporating the organic matter into the soil is worth trying in Kona, particularly where the soils are obviously run down and the coffee does not respond to mineral fertilizer.

MAKING A COMPOST. Composting differs from simply making a pile of organic materials and allowing it to rot, in that the rotting process is more carefully controlled. In the ordinary rotting of a pile of trash, much of the bulk disappears, and the nitrogen largely dissipates in the air. If the pile is in the open, most of the valuable plant food is leached out and the material which is left is a relatively valueless residue. Methods of composting differ greatly, depending on conditions and the nature of the materials to be used. Often a pit or trench is dug. Sometimes it is cement-lined and covered. In case of very bulky materials, like straw, a pile or stack is made. One of the essentials of all composts is that the material be moist at all times. Another is that the organisms (bacteria, fungi, etc.) which cause the rotting must have a sufficient supply of available nitrogen, phosphorus, potassium, as well as energy food like sugar or starch, to develop rapidly. In materials like straw, many of these requisites must be added at the time of making the compost. In composting coffee pulp or succulent grass, it is necessary to add only phosphates and some limestone, the latter to neutralize the acids that are formed. Many materials also need a starter, that is, something added which contains rot-producing organisms. Animal manure or top soil is often used for this purpose.

If the compost is piled loosely, or if it is mixed or turned at intervals, it rots rapidly and the bulk is greatly reduced due to excessive loss of organic matter which goes off as a gas into the air. If the material is tightly packed and kept moist, rotting is much slower, but the yield of final rotted manure is higher. The fertilizer constituents remain in the residue with little loss if the compost has been protected from the rain and becomes more and more concentrated as the bulk of material decreases.

A number of writers have described the composting of coffee pulp and parchment. The fresh pulp is high in nitrogen and energy food, and it is generally recommended that grass or trash be mixed with the pulp in the ratio of 2 parts of the former to 1 of the latter. A pit is dug and a layer of grass, say 1 foot deep, placed in the bottom. On top of this is scattered a layer of pulp 6 inches thick, then alternate layers of grass and pulp to the top of the pit. Over each layer of pulp is sprinkled a mixture of superphosphate and finely-ground limestone at the rate of 30 to 40 pounds of the former and 60 to 80 pounds of the latter per ton of straw and pulp. Some of the water from the fermentation tank is run over the compost and acts as a starter. Coffee parchment skin may also be added as layers in the compost. It is recommended that the coffee pulp coming from the pulping machine be run over a grating to drain off the excess water before being conveyed to the pit. One ton of pulp plus 2 tons of grass is said to rot down to 1 ton of final compost.

Experiments in composting of coffee pulp by the Kona farmers have met with varying degrees of success. In no case was grass or trash used with the coffee pulp. Pits were dug and the pulp was run directly into them from the pulper. Superphosphate and limestone were added in some instances. The composts were allowed to stand undisturbed for about 6 months. In nearly every case, the top layer, 1 foot deep, had rotted to a mealy black mass, but the interior showed little evidence of rotting while the bulk of the pile had decreased but little. Where relatively shallow composts had been made, or where the material had been turned, the rotting was rapid and the bulk had decreased to about one-fourth that of the original.

Figure 9 shows the analysis of composts made from coffee pulp by various Kona farmers in 1932-33. The great differences in the final composition of the composts are apparent. In case of phosphates, the abnormally high percentages in some cases are due to the addition of phosphates at the time of composting. Some difference is due to variations in composition of the original pulp used. The cause for greatest variation, however, is in the amount of rotting. Where the mass had completely rotted down with a large loss of organic matter (as in Samples 2 and 5), the increase in plant-food elements is considerable. Where the bulk did not materially decrease, as in the center of the compost (as in Sample 1), the percentages of plant food did not materially increase over the original pulp. The fact that nitrogen did not exceed 3 percent, regardless of the increase in potash, indicates a loss of this constituent during rotting.

If composting of coffee pulp is to be feasible in Kona, it is desirable that rotting of the pulp be complete by about June or July of the following year (an average time of about 6 months). The grower would then be able to apply the compost to the fields and get the pit ready for the fall harvest. This requires quicker rotting than can be secured in a large pit without turning. Incorporating coarse grass and trash in the compost would no doubt help but would entail much extra labor. More experiments are needed to find a practicable method of composting coffee pulp in Kona.

Whether composting is used or not, there can be no doubt of the desirability of getting this valuable source of organic matter back to the soil. Even though the pulp is simply allowed to pile up outside the mill, it should be protected from the rain and carried back to the fields as soon as picking and pruning are complete.

Fertilizer Constituents Removed by One Crop of Coffee Cherry

Any part of a growing plant, whether it be the leaves, branches, fruits, or roots, requires mineral plant food. With coffee, the vegetative growth, leaves, branches, and the like, are left on the soil, where they rot and their fertilizer constituents are thus used again and again by the plant. The coffee cherry, on the other hand, is taken from the field. The bean is of course sold. The pulp and parchment may be returned to the soil, but in the past, none has been returned to a large percentage of the total acreage.

FIGURE 9—Composition of composts made by Kona farmers from coffee pulp and various amendments.

The following table, based on the values shown in Figure 8, gives the amount of nitrogen, phosphoric acid, and potash in a 150 bag per acre crop of coffee cherry:

	Pounds of fertilizer constituents per acre		
	Nitrogen (N)	Phosphoric Acid (P_2O_5)	Potash (K_2O)
Entire coffee cherry	94.7	17.4	100.7
Pulp only	23.0	5.5	41.1
Parchment skin	3.4	.4	2.8
Bean only	68.3	11.5	56.8

TABLE 1. Amount of nitrogen, phosphoric acid, and potash in a 150 bag per acre crop of coffee cherry.

If none of the pulp and parchment is returned to the soil, there is taken from the field about 95 pounds of nitrogen (equavalent to 475 pounds of ammonium sulphate), 18 pounds of phosphoric acid (equivalent to 90 pounds of superphosphate), and 101 pounds of potash (equivalent to 203 pounds of potash sulphate), or a total of 665 pounds. If the pulp and parchment are returned to the field, the per acre loss from removal of the bean is 68 pounds of nitrogen, 12 pounds of phosphoric acid, and 57 pounds of potash. This represents nearly half of the potash, and about one-third of the nitrogen and phosphoric acid.

The very small amounts of plant food in the parchment skin raises the question as to whether this material is worth carrying back to the field. Measured only in terms of the value of the mineral plant food, it probably is not worth hauling any great distance. As a surface mulch, it has a value far in excess of the plant food value, especially on bare lava flows and in the drier sections. Parchment skin rots down readily and soon becomes a part of the soil. The pulp is obviously of far greater value as a source of fertilizer elements.

THE SOILS OF KONA

ORIGIN. The soils of the Kona district have resulted from a series of lava flows of comparatively recent origin interspersed with volcanic ash eruptions. In cuts or gullies, there can often be found two or three distinct layers of ash, with layers of hard, stony lava in between. Where a lava flow lies on top of the last of the ash eruptions, there is no soil other than a light accumulation of organic material on the hard undecomposed lava rock. Where the ash lies on top, a fine-textured soil results. The reason for this difference in rate of decomposition of volcanic ash and lava rock is that the ash is blown into the air during a volcanic eruption and falls as black pumicy glass which decomposes quickly into fine-textured, yellow soil, which gradually darkens in color with the accumulation of organic matter. The lava flow, on the other hand, consists of dense crystalline rock which breaks down very slowly. Even the fragments of scoria or clinkers show little decomposition. The depth of the ash soil varies from a few inches to several feet. Across the slope the depth depends on how many eruptions deposited their blanket of ash without any intervening lava flow. The changes from a rough flow barren of soil except in pockets, to a deep layer of soil are sudden. Up and down the slope the transitions are gradual. The thickness of the ash mantle increases from sea level, where the deposit is very thin, up to a maximum in the rain belt (2,200 to 2,400 feet altitude) and decreases again above the rain belt.

The entire district lies on a decided slope which, in some places, becomes so steep that coffee raising is difficult. The surface has been little affected by erosion and has the same general hummocky topography as a lava flow smoothed out somewhat by the ash mantle. There is no well established drainage system, aside from a few gullies, which are dry except during the heaviest rains. The profuse cracking of this lava flow and permeability of the ash soil make possible a high rate of absorption of rainfall.

The Hawaii station has made a map of the lava flows and soils of Kona. The soils were grouped into types depending on which of the two sources of material predominated, namely, the ash mantle or the underlying lava flow. Where the ash deposit is sufficiently deep, it masks, to a great extent, the type of lava flow beneath and becomes a fine-textured soil—soil in the true sense of the word. As the ash becomes thinner, the characteristics of the underlying lava become increasingly important until finally they become dominant with the ash occurring only in pockets or absent altogether.

The two kinds of lava flows are the well-known pahoehoe and aa. The former has a relatively smooth, unbroken surface, and the aa has a rough, hummocky surface made up of huge boulders and lenses of solid rock interspersed with masses of clinkers and fine rock powder. Within each of these two kinds of flows there is a great variation. Some aa flows contain a large amount of scoria or clinkers, while others contain very little, the flow consisting mostly of a dense bed of unbroken, stony lava. Within the pahoehoe type, some flows are relatively thin, and upon cooling, tend to produce numerous cracks throughout the mass. Others are thick, solid, and relatively unbroken. These differences in the amount of scoria or clinkers, and in the extent of cracking of the under part of the flow, undoubtedly play an important part in drainage and root-penetration.

Based on the two soil-building materials, volcanic ash and lava, the soils[1] of Kona may be divided into the following types:

No ash mantle
- Soil type— Bare flow rock

Thin ash mantle (less than 3 inches)
- Soil types— { over aa—ashy scoria; over pahoehoe—pockety ash }

Medium ash mantle (3 to 18 inches)
- Soil types— { over aa—scoriaceous ash; over pahoehoe—pure ash }

Deep ash mantle (more than 18 inches)
- Soil types— { over pahoehoe; over aa }—pure ash

PHYSICAL AND CHEMICAL PROPERTIES. Kona soils are remarkable in many ways. Not particularly fertile in most respects, they are capable of producing coffee yields far larger than other soils of greater inherent fertility. This is because of their fine physical qualities. From nearly every standpoint they are ideally adapted to coffee. They are open and porous and at the same time do not dry out readily. All writers on the subject stress the importance of this. In Puerto Rico coffee sickens and finally dies out on the poorly drained heavy soils of the lowlands and flourishes on the slopes of the adjacent hillsides. In East Africa much of the coffee is planted in sandy areas where the soils have little water-holding power and the surface roots are easily killed by drought. Almost universally, coffee soils are deep and porous and situated on a slope to ensure good drainage.

Kona growers regard a gravelly texture as the perfect coffee soil. They state that it provides better drainage than the fine textured soil. Moreover, the latter is inclined to produce too much vegetative growth at the expense of fruiting, particularly in the upper levels, where rainfall is copious.

There is a well established belief among the coffee growers of Kona that the kind of stone mixed in the soil is important. That preferred is locally known as "bluestone." Growers will pay a premium price for such a location. These "bluestones" appear to be the dense, blue-gray clinkers found on the surface of aa flows. The soil intermixed with such clinkers is usually black in color and is said to be more moist during dry weather than nearby fields of the yellowish soil overlying a pahoehoe flow. There would seem to be a sound basis for this belief. An aa flow usually produces a tumbled mass of solid boulders intermixed with large quantities of clinkers and finer particles ground down to the size of sand. This material, together with the decomposed volcanic ash, would produce a deep, porous subsoil, much more conducive to deep rooting than the denser pahoehoe. In actual practice, it is often difficult to tell which of the two lava types underlies a given field. Many flows are mixtures of the two. Under an appreciable thickness of ash, it becomes still more difficult to identify the underlying strata.

Since much of the coffee in Kona is grown on lava rock with little or no ash mantle, it is evident that the plant receives a large part of its mineral plant food from the slowly decomposing lava rock. To determine the value of lava rock as a source of phosphates and potash, samples of clinkers from a recent lava flow, as well as some finely ground lava rock, were brought to the Hawaii Station. These materials were placed in pots and planted to Sudan grass to see to what extent the pure rock and clinker would support plant growth. These experiments showed that plants can extract enough phosphates and potash from the lava rock to support a good growth. There is, of course, no nitrogen in pure rock.

Judged by the ordinary standards of fertility, Kona soils are only moderately fertile. They are not nearly so fertile as the soils

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1 A soil being taken to mean any material in which plants can be made to grow.

of the Hamakua coffee district, where shade trees are used. However, with the aid of the fertilizer, the Kona soils, with their ideal physical properties, are able to produce crops that rival the world's best in both quality and quantity.

Very little is known regarding differences in fertility among different soil types. Undoubtedly such differences exist but they are largely masked by many factors, such as the very heavy applications of commercial fertilizer, the great differences in rainfall, humidity, and amount of sunshine, which occur in short distances, as well as the differences in cultural methods used by the various farmers. Uncertain though these fertility differences may be, the growers do recognize the textural differences in soils and their relationship to coffee culture: the deep, pure ash soils, which tend to produce excessive vegetative growth; the black, rocky bluestone soils with frequent massive outcrops, which retain their moisture to an unusual degree; the thin yellow soils, which tend to become powdery and dry out quickly; the gravelly (or scoriaceous) soils, and the bare flow rock. Studies of these various soil types are now being made by the Hawaii station.

BARE FLOW COFFEE CULTURE

In considering the culture of coffee on bare flows, it should be borne in mind that in Kona there is every gradation from deep pure ash soils on the one hand to the bare flow on the other, so that the bare flow represents the one extreme of this soil transition, rather than a separate class.

It is a well established fact in Kona that it is entirely feasible to grow coffee on bare lava flows devoid of all yellow ash or any fine-textured material other than organic matter. Coffee plantings in such a medium continue to bear year after year among the huge rocks and coarse boulders in a truly remarkable manner. While there is no doubt that a soil with some fine-textured material is more desirable than a bare flow, soil is not so important a factor in coffee growing as climate. It may truthfully be said that, given the proper climate, coffee will produce good yields on any soil in Kona, regardless of type. Often it is the physical difficulty of tending and harvesting the coffee on the roughest flows which deters the grower rather than its lack of growth. As already stated, the lava type becomes of increasing importance as the soil layer decreases. Other conditions being the same, the aa type, or pahoehoe with profuse cracking, are the more desirable.

In preparing a bare flow for coffee, a certain amount of leveling of the loose rock is done, then holes are made, sometimes by blasting or opening up with a crowbar, and occasionally by terracing to maintain regularity of spacing. Soil is oftentimes carried in to fill the hole in which the seedling is planted. The young tree generally grows vigorously up to the setting of the first good size crop (the third year). The excessive drain this imposes on the tree often causes disastrous dieback and necessitates replanting. If the tree weathers this critical period it generally continues to be prolific for some years, although it is usually smaller in size than corresponding trees planted in true soil. Generally, the period of profitable production of bare-flow trees is appreciably less than of those grown in fine-textured soil. By replacing a tree whenever it loses its productivity, it is generally possible to maintain the field in excellent vigor. It is noticeable that in most bare flow fields, the trees are of varying ages due to frequent replantings.

One of the mysterious properties of these bare flows is their ability to supply water to the crop. In protracted periods of drought, the trees stand up surprisingly well. However, there can be no doubt but that they suffer more than those in corresponding locations with a good, deep soil. A procedure which appears to be effective in increasing the water-holding capacity, as well as the general fertility of bare flows, is that of mulching with coffee parchment skins. This material serves as an excellent mulch. It gradually rots down and accumulates in the cracks of the lava rock. This rotted material retains moisture and causes more rapid decomposition of the rock, thus producing a greater supply of plant food. One bare-flow field in the Keei section, at an altitude of 1,100 feet, and a none too favorable location, has received an average annual application of parchment skins 4 inches thick for the past 4 years.

The gradual accumulation of organic matter has kept the trees in excellent condition even through periods of rather severe drought. The yields have been consistent with no more than normal dieback for this altitude. The same fertilizer formulas are used for bare flow coffee as for deep soil coffee. The general feeling is that more frequent applications are needed.

DIEBACK OF COFFEE

The dying back of coffee during the later stages of the maturing of the fruit is a common occurrence in many coffee producing countries. In some places, it is believed to be due to a fungus disease which enters the plant through the leaves and sometimes the stems. It is nearly always found on the parts of the tree in heavy bearing so that it is concluded that the excessive drain on the branch weakens its resistance to disease organisms. In other places it is regarded as a purely nutritional phenomenon, the result of overbearing. In Kona, dieback is often a serious factor in the middle and lower rainfall belts. It results in a poor grade of coffee, cuts short the bearing period of the vertical, and if severe enough causes complete exhaustion of the tree. Under such conditions as much as 3 years are required to bring the tree back into vigor. (See Plate 14).

The first symptom of dieback is the yellowing of the leaves in the regions of heavy bearing and often over the entire plant. This is followed by the *abscission* of the leaves. As the dieback becomes acute, the lateral stem begins to shrivel from the terminus in toward the vertical. As the lateral dies, the coffee cherries blacken and shrivel, sticking tenaciously to the stem. (See Plate 13).

There is no doubt that dieback is associated with heavy bearing. In the same field, bearing trees will have vivid yellow leaves, while on the non-bearing trees the leaves will be dark green. In a single tree with several verticals, the bearing verticals will have yellow leaves and the non-bearing, green leaves.

Dieback is further localized to that part of the vertical which is in heavy bearing. The central portion of a vertical may be leafless with shriveled laterals and dead cherries, while the new vegetative growths at the top and bottom are green and vigorous. Apparently each lateral is restricted to a certain maximum of plant food and water and any demands in excess of this result in dieback.

There is not yet sufficient experimental data to prove which of the many possible causes are chiefly responsible for dieback in Kona. Preliminary observations, as well as the practical experience of the growers, give a general idea of the problem and how to minimize the effects. It is probable that overbearing is the primary cause. Excessive set of fruit is common among many types of trees, and to avoid this thinning of the fruit is often practiced. The alternate heavy and light bearing years of most trees is due largely to the tendency of the trees to overbear one year, exhaust themselves, and

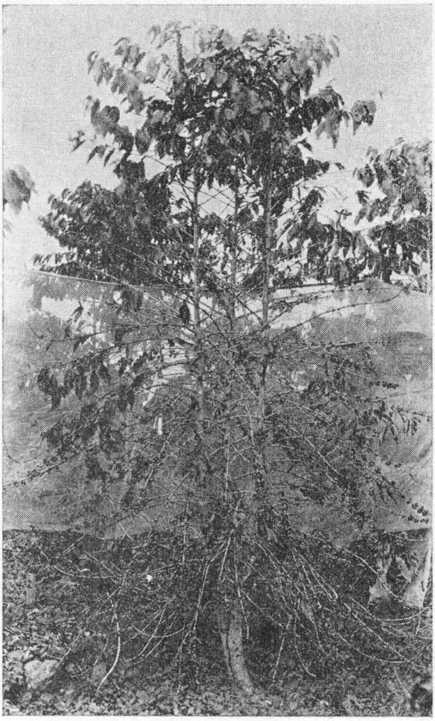

Plate 13. Dieback on a coffee tree. The coffee cherry on the tree is dried, shriveled, and worthless. Complete defoliation of the bearing laterals is followed by shriveling of the cherry and partial or complete death of the lateral. Even when the lateral is not completely killed it requires at least two years for sublaterals to develop and bear. Often the whole tree is thus weakened.

hence produce a light crop the ensuing year. Every tree has a limit to its capacity to bear, based not only on the amount of mineral nutrients and moisture available, but also on the capacity of the plant to absorb and transport and synthesize them into plant food for the development of fruit and vegetative growth. Dieback may be severe even with a light crop if some growth factor, such as moisture or one of the essential plant-food elements, is deficient.

In Kona the most important factors concerned with dieback are climate, soil, fertilizing, pruning, and shade.

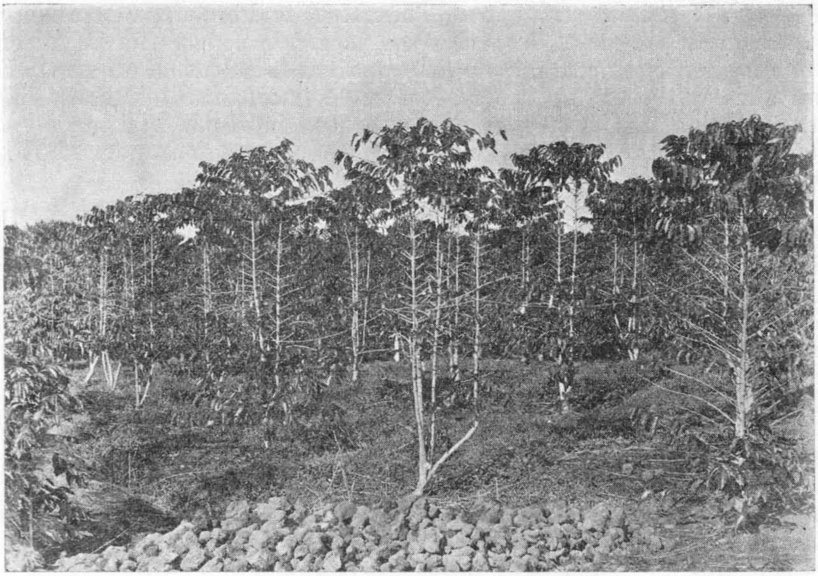

Plate 14. Showing Disastrous Dieback in a Young Coffee Orchard. The laterals of the entire middle and lower section died back due to overhanging. It will require from two to three years for these trees to recover their vigor. The tips of the laterals have been pruned back to within two or three nodes of the vertical to stimulate sublateral development. This is effective if dieback has not killed the entire lateral.

CLIMATE. Kona coffee growers agree that dieback is always worse during a dry summer, all the more so if the previous winter and spring have been wet so that the growth is unusually vigorous and succulent. With moisture a limiting factor, no amount of supplemental fertilizing will forestall the inevitable dieback.

The more pronounced the seasons of alternate wet and dry, the more severe is the dieback. The upper coffee areas in Kona are less seasonal than the lower. The blossoming is stretched out over a period of months, some occurring throughout the entire year. Under such conditions, the drain on the coffee plant at any given period is not excessive. In addition, there is usually ample moisture so that this climatic belt is seldom affected by dieback. In the central and lower zones, the sudden change of season from dry to wet brings about a quick succession of heavy blossoms, and a large portion of the crop, as well as the main portion of the vegetative growth, develops simultaneously. This produces a peak load on the reserves stored up in the plant roots, on the moisture supply and mineral plant food in the soil so that even in the normal years there is appreciable dieback.

An effective means of conserving moisture and at the same time of increasing the water holding capacity of the soil is by covering the entire surface of the soil with a layer of grass or trash several inches deep. Although this requires much hand labor it undoubtedly reduces dieback in the low, dry areas.

SOIL. Bare flow soils, pockety ash soils (i.e., thin ash over pahoehoe), which have a small water-holding capacity and limit the depth of root penetration, are more inclined to dieback than the deep ash or gravelly ash types. The nature and amount of cracking of the underlying lava, as well as the uncertain penetration of water from higher levels, are factors not apparent from casual observation but which have an important effect on the moisture available to the tree. With the heavy fertilizing practiced in Kona, differences in fertility of the various soil types are probably not an important factor in this regard.

FERTILIZING. Forcing the coffee tree into heavy bearing by the use of excessive amounts of fertilizer tends to increase dieback. With the sudden appearance of some other limiting factor, such as moisture, the heavy-bearing tree is more likely to collapse than one with a moderate crop. Most farmers agree that once the crop has set, an adequate application of fertilizer will help to reduce dieback. Often a grower attempts to stave off impending dieback, as the crop matures, by supplemental applications of fertilizer. Such a treatment usually does little good. The leaves turn yellow and the fruit and stems wither even though the roots are in contact with ample plant food. The effect of the kind of fertilizer on dieback has already been referred to. (See Fig. 5). The danger of using nitrogen alone was pointed out as well as the special value of potash when used in connection with nitrogen.

The use of organic manures is recommended in some places as a means of reducing dieback. The increased capacity of the soils to hold water and the slow but continuous liberation of plant food from the manure is said to extend the process of ripening over a longer period and hence to reduce the peak drain on the plant. Some Kona growers state that those fields which have received applications of coffee pulp are less susceptible to dieback.

PRUNING. Since pruning is intimately related to the production of new growth, it is evident that any pruning system which results in too much bearing wood in any given season would induce dieback. There is a tendency in the non-topped systems for growers to prune a tree very heavily one year and during the following year or two to prune lightly. This has certain advantages with close spacing in that it gives the new growth more light, but when carried to an extreme it produces excessive bearing. Insofar as it can be accomplished without reducing yields, a moderate amount of pruning each year should reduce dieback. The pruning system used is also a factor. Theoretically, those systems in which a considerable portion of the tree is permanent should result in less dieback than the systems in which most of the tree is young wood. For the same reason, recovery from severe dieback should be more rapid in the former. The station is conducting an experiment in Kona to determine the feasibility of controlling dieback in a young orchard by reducing the bearing surface on the new verticals. Among the methods being tried are: pruning out every third or fourth lateral in the growth, pruning the primary laterals back to 7 bearing nodes, stripping off the cherries soon after they set to 7 bearing nodes and reducing the amount of upward growth of a new vertical by capping. It is too early to report any results from the experiment. Several growers reduce the bearing surface of a tree by removing a whole vertical or by pruning off part of the laterals, if it becomes evident early in the season that dieback will be severe.

SHADE. Shade is generally recommended as a means of reducing dieback under conditions of excessive heat and sunlight. Shade causes higher humidity, less evaporation, a greater water-holding capacity of the soil, and a smaller set of cherry.

SUMMARY. Dieback is caused by numerous factors of climate and soil which are largely beyond the control of the farmer. It can be increased or minimized by the grower, however, according to his cultural methods. Moisture can be conserved through the use of mulches and organic manures. Pruning should be so regulated that the plant does not produce an excess of bearing wood in any one year. Fertilizer constituents should be balanced so that there is an ample potash supply and no excess of nitrogen. Finally, shade trees can be used in the hot, dry locations to reduce dieback.

TABLE 2. Summary comparison of production costs and returns for 1932 among 25 coffee producers in Kona, Hawaii[1].

Item	Highest Farm	Lowest Farm	Average All Farms	YOUR FARM
Capital Investments:	10-A.	8-A	6.87A.	
Land	—	—	$ 9.11	
Trees	$245.00	$195.00	245.05	
Improvements	92.94	—	41.75	
Machinery & Equipment	16.71	5.39	19.68	
Supplies & Miscellaneous	—	—	—	
Total Investment	$354.65	$300.39	$315.59	
Expenses:				
Hired Labor, Man	$ 16.57	$ 6.47	$ 19.73	
Family Labor, Man	175.96	45.89	102.56	
Animal Labor	1.03	1.36	.76	
Material Cost	29.08	23.56	33.18	
Cash Overhead:				
General Expenses	13.36	4.64	9.69	
Rent	16.00	18.50	11.77	
Taxes	6.15	5.00	3.03	
Investment Overhead:				
Interest on av. invest. @ 6%	21.28	18.02	18.18	
Depreciation on av. invest.	19.21	11.70	18.17	
Total Expenses	$298.64	$135.14	$217.81	
Receipts:				
Cash from sale of coffee	$243.00	$ 53.83	$147.89	
Increase in inventory values	—	—	—	
Miscellaneous	—	—	—	
Total Receipts	$243.00	$ 53.83	$147.89	
Total Expense	$298.64	$135.14	$217.81	
Net Profit or Loss (Income Minus Expense)	—55.64	—81.31	—69.92	
Labor Income (Net Profit Plus Value of Family Labor)	120.37	—35.42	32.64	
Farm Income (Labor Income Plus Interest on Invest.)	141.60	—17.40	51.52	

[1] Tables 3 and Fig. 10 were reprinted from A. S. T. Lund, Extension Economist; W. Maneki, Assistant Economist, and Y. B. Goto, County Extension Agent, West Hawaii County, "First annual summary of costs and farm efficiency in coffee production." **Extension Circular No. 14,** 1933.

TABLE 3. Segregation of labor costs for 1932, among 25 coffee producers in Kona, Hawaii.

Item	Highest Farm	Lowest Farm	Average All Farms
Total Acres	10 A.	8 A.	6.87 A.
Man Labor:			
Hoeing	$ 26.81	$ 14.75	$ 29.34
Poisoning Weeds	2.29	2.80	2.59
Pruning	18.13	6.80	9.35
Fertilizing	9.09	2.63	2.27
Insect Spraying	—	.28	.01
Rat Poisoning	.01	.02	.03
Rat Trapping	—	.47	.02
Picking	130.48	20.86	73.67
Pulping	.84	—	.60
Washing & Drying	.66	—	1.26
Bagging	.66	—	.42
Transportation	.19	.64	.30
Miscellaneous	3.50	3.13	2.49
Total Man Labor	$192.66	$ 52.37	$122.35
Animal Labor	1.04	1.31	.76
TOTAL LABOR EXPENSE	$193.70	$ 53.68	$123.11

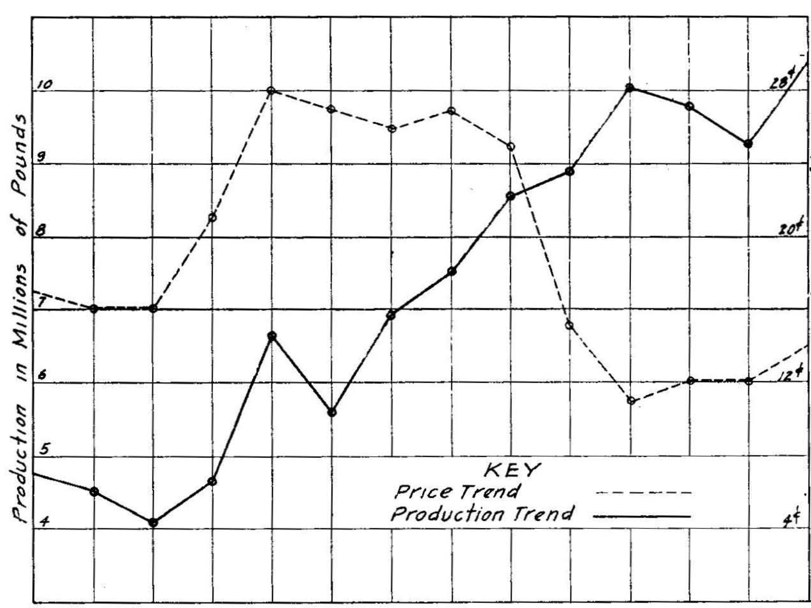

FIGURE 10—Production and price relationship of coffee in Hawaii (1920-1934)