GROWING COFFEE IN HAWAII

REVISED EDITION

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University of Hawai'i at Mānoa

Published by the College of Tropical Agriculture and Human Resources (CTAHR) and issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Andrew G. Hashimoto, Director/Dean, Cooperative Extension Service/CTAHR, University of Hawai'i at Mānoa, Honolulu, Hawai'i 96822. An equal opportunity/affirmative action institution providing programs and services to the people of Hawai'i without regard to race, sex, age, religion, color, national origin, ancestry, disability, marital status, arrest and court record, sexual orientation, or status as a covered veteran. CTAHR publications can be found on the Web site <http://www.ctahr.hawaii.edu/freepubs>.

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ISBN 1-929325-06-1
January 2004 edition revised slightly, March 2008.

Contents

Sources

The following commercial sources for various products mentioned in the text are provided for the convenience of readers. Other suitable sources may also be available.

Sudax (variety Dekalb-Pfizer Genetics SX-17+): Hikiloa Co-op, PO Box 231, Hoolehua, HI 96729; 808-567-6774; fax 808-567-6660.

ZipSets (paper planting containers for raising seedlings): Monarch Manufacturing, Inc., 13154 County Road 140, Salida, CO 81201; <www.monarchmfginc.com>.

Spin Out® (root growth regulator for plastic or paper planting containers for raising seedlings): United Horticultural Supply/UAP Pacific, Hilo, HI; 808-935-7191; <www.nurserysupplies.com>.

Vegetable grafting clips: Fukuda Seed Store, 528 Kaaahi St., Honolulu, HI 96817; 808-841-6719.

Tractor-mounted rotary saw for stumping trees in mechanical pruning systems: TOL® pruner (TOL Inc., Tulare, CA).

Coffee harvester currently in most frequent use in mechanically harvested coffee in Hawaii: Korvan Inc., 270 Birch Bay Lynden Road, Lynden, WA 98264; 360-354-1500; <www.korvan.com>.

Hand-held air-powered harvest aid: The Spidy®. The New Farmer, 17655 Panama Ave. S, Prior Lake, MN 55372; fax 612-440-6624; <kumamn@aol.com>.

Growing Coffee in Hawaii

Hawaii's coffee industry today

Hawaii's coffee industry is one of the most diverse and dynamic in the world. The current technologies and production practices span a range of producers from 1-acre, certified organic, rainfed farms to 4000-acre, totally mechanized, irrigated plantations. Even the forests, and long-abandoned coffee farms on most of the inhabited Hawaiian islands, yield harvests of feral coffee sown in the droppings of birds and pigs. Hawaii's coffee production grew in recent years from under 2 million pounds of green coffee bean in 1992 to 7 million pounds in 2003, with a farm-gate value of $23.5 million. Hawaii's coffee roasting industry also ranges widely, from home roasters to "boutique" labels to full-scale industrial roast-and-grind marketers. The retail value of the blended portion of our roasting industry (roasted beans plus beverage sales) was valued at $117 million in 2002. The coffees grown include a hybrid of 'Mokka', one of the most primitive landraces from Africa; 'Guatemalan' (also called "Kona typica"), an early 19th century Central American land race of *Coffea arabica* "typica"; and some of the most modern semidwarf cultivars from Brazil, including both 'Red Catuai' and 'Yellow Catuai'.

This guide to cultural practices for coffee in Hawaii builds on CTAHR's earlier publications by Y. Baron Goto and Edward T. Fukunaga, written in the 1950s and cited with the references (p. 40). New developments and changes in coffee production technology have occurred both in the traditional "coffee belt" in Kona on the island of Hawaii and in the new coffee-growing sites elsewhere in the state. This manual is designed both to serve the many new coffee farmers who need information and to provide a "sounding board" for discussion of its contents and recommendations, which will aid development of a subsequent edition.

Where and how to start a coffee orchard

The choice of a location to grow coffee in Hawaii is simple if one lives in the Kona region of the island of Hawaii, where soil and climatic conditions are ideal for coffee. But the question of where coffee can be grown is often asked by people whose interests extend across the state from northwest Kauai to the southern tip of Hawaii. Conditions differ widely over this range, and many factors need to be evaluated in consideration of the coffee plant's growth requirements.

Coffee has been grown commercially for more than 170 years in Kona, despite periods of adverse economic conditions. While coffee was grown earlier in other locations in Hawaii, it was not continuously cultivated, and coffee grown in areas other than Kona never attained great importance until the 1990s.

Many factors have contributed to the development of the Kona coffee industry. A historical one was that large-scale agriculture, such as sugarcane or pineapple plantations and ranching, was more profitable elsewhere in the islands. But the principal factor is that the climate of the Kona region is ideal for coffee. Its spring and summer rainfall pattern is more favorable for coffee growth than the winter rainfall normally received by much of the state. When rainfall coincides with warm temperatures, the conditions are optimum for plant growth and fruit development in coffee and many other fruit crops. Furthermore, Kona's cool, dry winter is conducive to maturing the coffee fruits ("cherries") and forming flower buds for the next crop.

In locations in Hawaii other than Kona where coffee has been grown in the past, experience to guide the prospective grower is either scant or forgotten. Accordingly, the prospective coffee grower outside Kona should proceed with care and caution.

Temperature

Temperature is a key factor in coffee production, and the strongest influences on temperature are latitude and elevation. Coffee is grown around the world at latitudes from 24°N to 25°S and elevations ranging from sea level to as high as 7000 ft. In general, high-elevation coffee regions are found in countries at or near the equator, such as Kenya, the New Guinea highlands, and Colombia, while low-elevation coffee regions, such as Hawaii and São Paulo, Brazil, are usually at subtropical latitudes (22–25°). At any given latitude, coffee is often grown over a wide range of elevations. In Hawaii, it seems that most elevations between sea level and 2500 ft should be suitable for coffee, provided that rainfall and soil factors are favorable.

Coffee tolerates wide annual variations in temperature. In parts of Brazil's São Paulo and Paraná states, coffee trees are injured by frost almost every year, and freezes occasionally kill them. In the summer, however, coffee in these regions experiences very hot and humid conditions. A more moderate climate for coffee is found in one of the most important coffee-growing districts of Colombia, Chinchina, where the mean minimum temperature is 60°F, the mean maximum is about 80°F, and the mean monthly temperatures seldom vary more than 2–3°F throughout the year.

High temperatures (> 90°F) before and during flowering may result in abnormal coffee flowering and poor fruit set. In Kona (as in Brazil), the low winter temperature and rainfall seem conducive to regular annual flowering. In Colombia, on the other hand, where temperatures are neither too high nor too low and extremes are not encountered, dry periods seem to be of greater significance in affecting flowering.

Cloudless, dry, high-temperature areas such as Kekaha on Kauai or Waianae on Oahu are not favorable to coffee. However, successful coffee production is found in low-rainfall areas at elevations as low as 200 ft, such as Eleele on Kauai and Kapalua on Maui. In windward areas of Hawaii, Maui, Kauai, and Oahu, where rainfall is abundant and temperatures are relatively constant, coffee flowering and harvesting seasons may be more irregular and unpredictable than in Kona, with its more pronounced seasonal conditions. In such windward areas, special crop management practices may be necessary for coffee production to be commercially feasible.

Shade

Shading with one or more layers of trees is practiced in some tropical coffee-growing areas, but in the subtropics of Hawaii and Brazil it has been found to be unnecessary. If an area is too warm for coffee, shade might help. In the countries where shade is traditionally used, fertilizers are often in short supply, and the soil fertility is often inadequate to support a large crop. Under these conditions, restricting light with shade reduces the number of flowers per node, limiting production and helping prevent dieback due to overbearing. With adequate fertilizer and good management in Hawaii, however, high yields can be supported under full sun without dieback. Thus from the standpoint of coffee management, there is little use for shade in Hawaii. From the environmentalists' point of view, there is some interest in having shade trees in Central American coffee orchards to support bird populations—particularly migratory birds from the U.S. mainland.

Wind

Coffee should not be planted in sites exposed to tradewinds or severe "kona" storms without a well established windbreak. Wind bends young coffee trees, causing more vertical stems than desired to be produced, and this may reduce yield. Severe winds cause "cupping," tearing, and removal of leaves—and sometimes removal of ripe cherries.

Temporary windbreaks are essential for newly transplanted trees in windy areas; a single row of densely sown Sudax, a sterile hybrid of sorghum and sudan grass, in the middle of the alley between coffee rows, is recommended (see Sources, p. 2). Sudax should be planted at least six weeks before the coffee is transplanted and sown at a minimum rate of 2 lb/acre (nine seeds per foot of row, assuming the coffee rows are 12 ft apart). If access by equipment during this establishment period is essential, plant the Sudax closer to the windward side of the coffee. Birds can be a problem during germination. The windbreak should receive fertilizer, and irrigation may be necessary. It should be 3–4 ft tall when the coffee is transplanted. After 18 months, when the coffee is 4–5 ft tall, the Sudax can be killed by plowing or spraying a grass herbicide (this method was described by Osgood and Chang 1994; see References, p. 40).

Coffee hedgerows can serve to break wind velocity for the orchard, although severe wind-pruning will likely occur in the rows exposed to wind intensity. A system of taller, permanent windbreak plants is preferred. A windbreak protects a downwind distance as much as 10 times its height. Some farms combine two types of tree windbreak. When the coffee trees are young, protection is provided by the tall, narrow, fast growing 'Tropic Coral' wiliwili (*Erythrina variegata*) planted 3–4 ft apart in rows 100–150 ft apart. As the orchard matures, it is protected by taller trees such as Norfolk Island pine (*Araucaria excelsa*) or a non-spreading type of ironwood (*Casurina cunninghamiana*) planted 6–8 ft apart in rows 600–800 ft apart.

Rainfall

Some coffee-producing areas have annual rainfall of only 30 inches, while other areas receiving over 100 inches of rain also have good production. Optimum annual rainfall for coffee in Hawaii is considered to be 60–85 inches. However, the most important factor is the rainfall distribution pattern as it relates to the various phases in the coffee growth cycle: vegetative growth, flowering, maturing of coffee cherries, ripening, and harvesting. Excessive moisture stimulates vegetative growth at the expense of fruiting. If rainfall is uniformly distributed, flowering and fruiting will occur almost throughout the year. A short dry period, ideally occurring during the coldest part of the year, helps to synchronize the cropping cycle, inducing flower bud growth by satisfying coffee's requirement for dormancy prior to flowering.

Irrigation is essential in Hawaii's recently planted dry coffee-growing areas, such as Kaanapali on Maui, Eleele on Kauai, Kualapuu on Molokai, and Waialua on Oahu. These areas are characterized by dry summers and wet winters, although the winters are not as wet as a Kona summer. New orchards have also been planted in high-rainfall areas, along the Hamakua coast and in Puna on Hawaii and in Hana on Maui, where rainfall can exceed the optimum. So far, the coffee harvest in these areas appears to coincide with the August–December harvest season that is normal elsewhere in Hawaii.

Soil

Coffee grows best on deep, porous, well drained soils, especially those of volcanic origin. Soils with excessively leached topsoil, impervious subsoil layers, or solid rock close to the surface will not support healthy coffee trees. Coffee will not do well and can die on heavy soils if drainage is a problem or if the soil is kept continually waterlogged below the surface.

Some soils in Kona and elsewhere in Hawaii are of recent origin and appear to be almost pure lava. Coffee does surprisingly well in such soils where the rainfall is abundant and well distributed (or irrigation is available) and fertilizer is applied in proper amounts. Greater and more rapid leaching of fertilizers is expected in these locations, so applications must be lighter and more frequent.

During drought on rainfed *a'ā* lava land, particularly when the trees are bearing fruit, it may be impossible to maintain healthy trees. The trees will suffer leaf dieback, lose fruit, and possibly die. This damage in dry years will be less likely to occur if the trees are widely spaced and kept in optimum growing condition by light and frequent fertilizer applications, pruning to maintain only a few verticals, mulching, and controlling weeds.

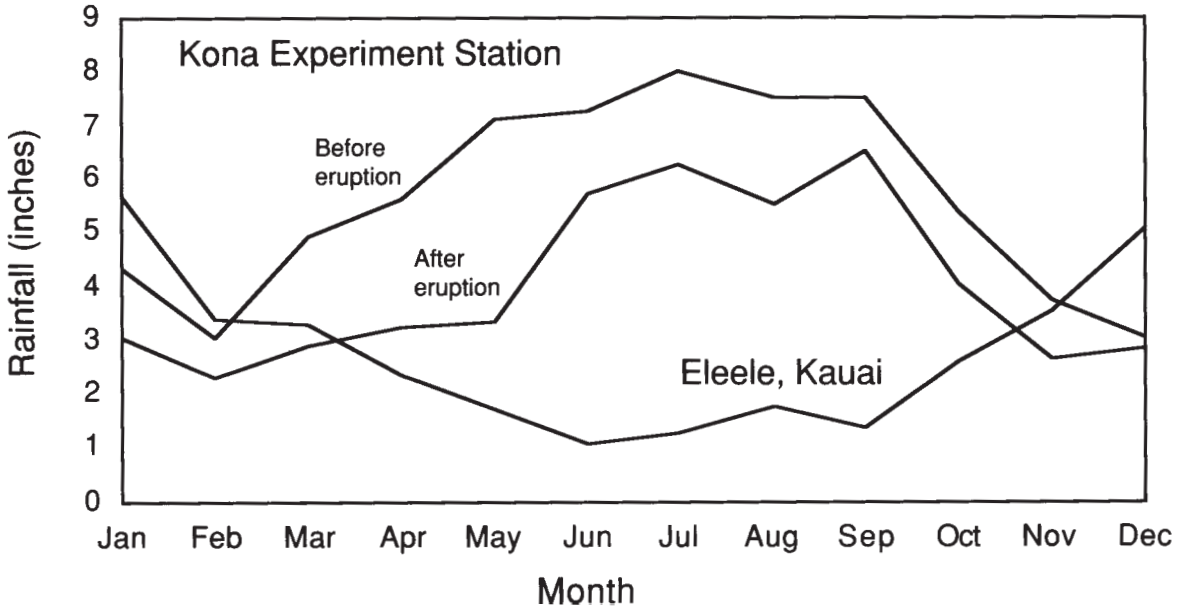
The Kona coffee belt

During the past 100 years, experience has shown that coffee production is ideal in a narrow zone in Kona approximately 20 miles long and 2 miles wide known as the "coffee belt." This "lower humid zone" runs almost parallel to the coast line. It begins in the north at Palani Junction and extends south to Puuhonua Road, and it lies between approximately 700 ft and 2000 ft elevation.

The temperature in this area is ideal. At CTAHR's Kona Research Station in Kainaliu (1460–1670 ft elevation) in the heart of the coffee belt, the annual average temperature is 69 °F, the average minimum is 60 °F, and the average maximum is 78 °F. The seasonal drop in temperature occurs simultaneously with drought, causing the coffee trees to slow their growth and develop flower buds. The temperature for December, January, and February at the Kona Research Station averages 67 °F (57 °F minimum, 77 °F maximum).

Another characteristic of the coffee belt is an ideal amount and distribution of rainfall, such that coffee in Kona usually has not been irrigated. The annual rainfall averaged 68 inches historically, but since the Kilauea volcano began erupting in 1983, it has been drier, averaging 49 inches. The seasonal rainfall distri-

Figure 1. Average monthly rainfall, before and after the 1983 Kilauea volcano eruption, at the Kona Research Station in the Kona coffee belt, compared with Eleele, Kauai, a major new coffee site.



bution provides a short, dry period during the winter months that forces the coffee trees into a state of semi-dormancy, which promotes a subsequent flowering. This dry period is followed by gradually increasing rainfall as the crop continues to maturity. As the harvest season approaches, rainfall decreases, and the winter dry period begins the fruiting cycle again.

During the low-rainfall period of December–February, the last of the crop is harvested and the annual pruning is done. At the lower elevations of the coffee belt, coffee trees appear to be on the verge of dying from lack of moisture. But a week or two after the first soaking rain, usually in late February or March, buds that have been forming during the dry, cool period will bloom. Three to four blossoming flushes take place in March–April, each following a heavy shower. As rainfall is intermittent and not too heavy during these months, blossoming usually takes place on dry days, which, when followed by several additional dry days, ensures good fruit set. CTAHR research has demonstrated that at a dry site on Oahu, coffee trees at the right stage of development can be forced to flower by applying drip irrigation following an irrigation-free "drought."

After mid-April in the coffee belt, rainfall increases rapidly. High humidity and temperature promote rapid development of the current crop and the accompanying vegetative growth that provides the foundation for the next year's crop. Around mid-September rainfall decreases, facilitating harvest of the ripe cherries and slowing vegetative growth until semi-dormancy is forced by the cool, dry winter months.

Evaluating areas for potential coffee production

Selection of a suitable site for coffee planting on Kauai, Oahu, Molokai, or Maui, or in areas of the island of Hawaii other than Kona, should be made after careful study of the particular location. The key questions to ask are

- Will coffee yield a sufficiently large crop to justify the financial outlay for planting?
- Will the crop be seasonal or be spread over the year?
- Can good quality coffee be produced in the area?
- Is any coffee being grown in the area, and will the grower share experiences?

Observing the condition of guava in the area is a simple way of determining whether or not coffee can be expected to grow well. If guava plants appear healthy and bear abundant, juicy fruit, it is very likely that coffee will do well. If the guava plants are sickly or stunted, it may be assumed that coffee will not grow well in the area due to poor soil conditions or insufficient moisture. If the guava plants are luxuriant with large green leaves and succulent limbs but few fruits, it is possible that the area is too wet and cloudy for profitable coffee production. If heavy rain continues for several days during the coffee flowering period, flowers will rot and the crop will be small (this was the experience of planters in Olaa, near Hilo, at the turn of the 19th century). Indeed, if temperature and rainfall are not ideal at the flowering season (are too cold or too wet), many difficulties may be encountered.

Maps showing the suitability of lands in Hawaii for coffee were generated by the CTAHR Hawaii Natural Resources Information System using a series of statements about the crop's environmental requirements. The particular environmental aspects were ranked according to how difficult the condition is to correct. For example, it is hard to change the temperature, but soil moisture can be modified by irrigation. The computer mapping program used the following statements, listed in order from the most difficult to correct to the least difficult:

A. Annual average temperature between 59° and 73°F.
B. Good soil drainage, plus meets A.
C. Land slope <28%, plus meets B.
D. Soil pH of 4.5–7.0, plus meets C.
E. Annual rainfall >59 inches, plus meets D.

From the maps (p. 8–9), one can see that most lands in Hawaii meet the temperature conditions. Every island has land that meets all five conditions—480,000 acres on the Big Island, 54,000 on Kauai, 70,000 on Maui, 39,000 on Oahu, and 2600 on Molokai. While the evaluation does not consider current use or zoning, one can see that coffee can grow in many areas of the state.

Land preparation

During land clearing for coffee, heavy vegetation and large rocks are removed. Where the land is not too rocky, clearing involves the removal of rocks, debris, and vegetation. After initial land preparation, collect a soil sample for analysis (follow the procedure in the CTAHR publication *Testing your soil: Why and how to take a soil sample*, available from CTAHR Cooperative Extension Service offices or from the web site http://www2.ctahr.hawaii.edu/oc/freepubs). The analysis will determine the need for soil amendments that must be incorporated before planting, as well as any fertilizer nutrients that should be applied before planting.

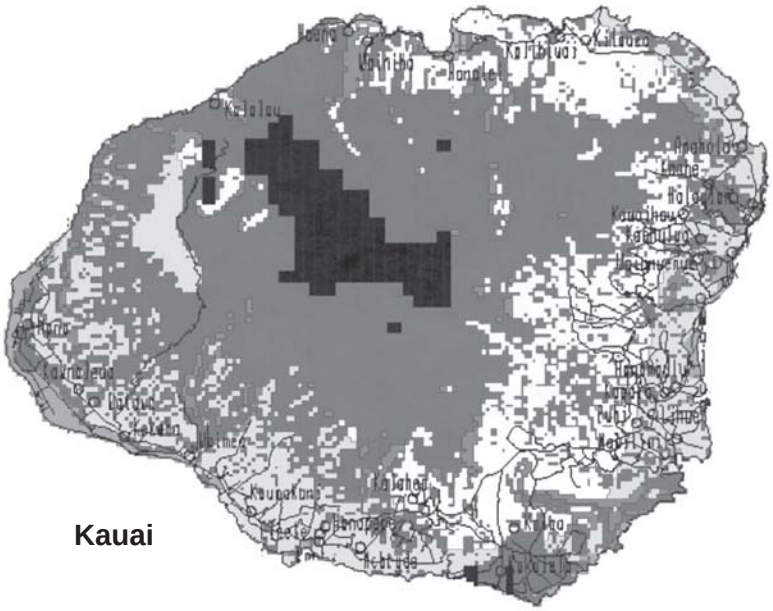
After the vegetation has been cleared, map the area. Assistance in developing a soil conservation plan is available from the USDA Natural Resources Conservation Service, 808-541-2600 ext. 101. Record the contours of the land and mark the tree spacing, windbreak locations, and approach roads to allow vehicles to enter and traverse the orchard. Roads within the orchard are essential in reducing costs of production. They facilitate delivery of fertilizer, transportation of harvested coffee cherry, and movement of sprayers for weed, insect, and disease control. Even where close coffee spacing is used, the installation of roads in the orchards between every fourth or fifth row of coffee trees to allow passage of vehicles is absolutely essential. Coffee planted in hedgerows for mechanical harvesting will require adequate roads at least 20 ft wide at both ends of each row for turning.

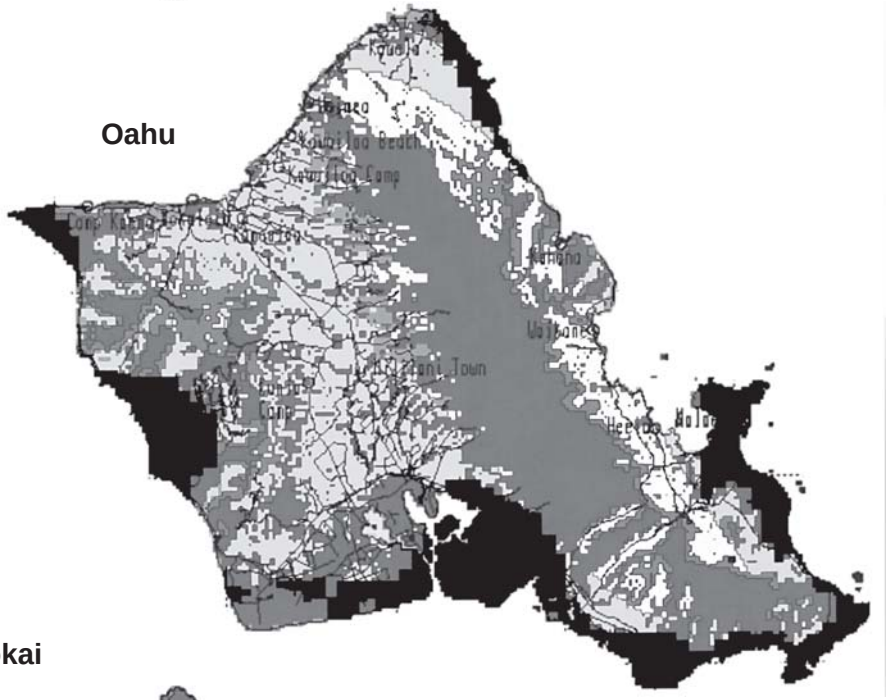
Where the land can be cultivated, fertilizer amendments such as phosphorus and lime should be thoroughly incorporated into the soil by plowing and disking several months before transplanting. If planting in former sugarcane or pineapple fields, rip any in-field roads to 20 inches depth, then rip the entire field. Apply lime and phosphorus in amounts recommended by the soil analysis laboratory; at planting, the soil pH should be 6. Then, cross-rip the field. Harrow the field to prepare for planting the windbreak rows. Rip again over the rows where coffee will be planted, then break clods and level the soil with a rail (Osgood and Chang 1994).

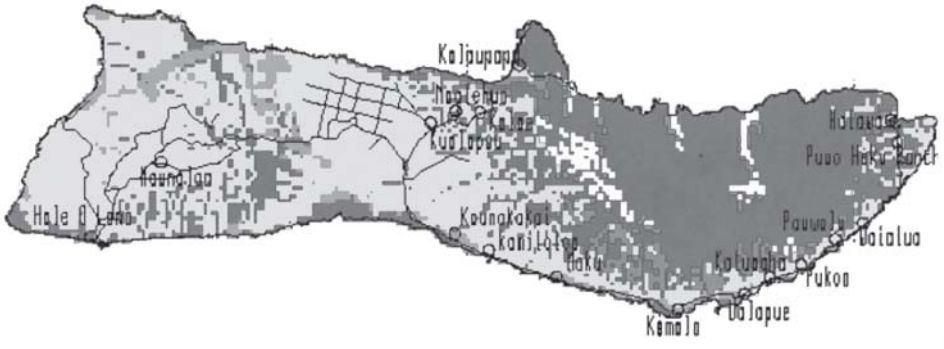
Where the land cannot be plowed, holes must be dug or a trench must be ripped with a bulldozer. The holes should be large and deep enough to allow plants to be

Growing enviromments for coffee on five Hawaiian islands

These maps were made with CTAHR's Hawaii Natural Resource Inventory System, a geographic information system developed by the Department of Biosystems Engineering; the islands are not shown to scale.







Not suitable, too hot or too cold

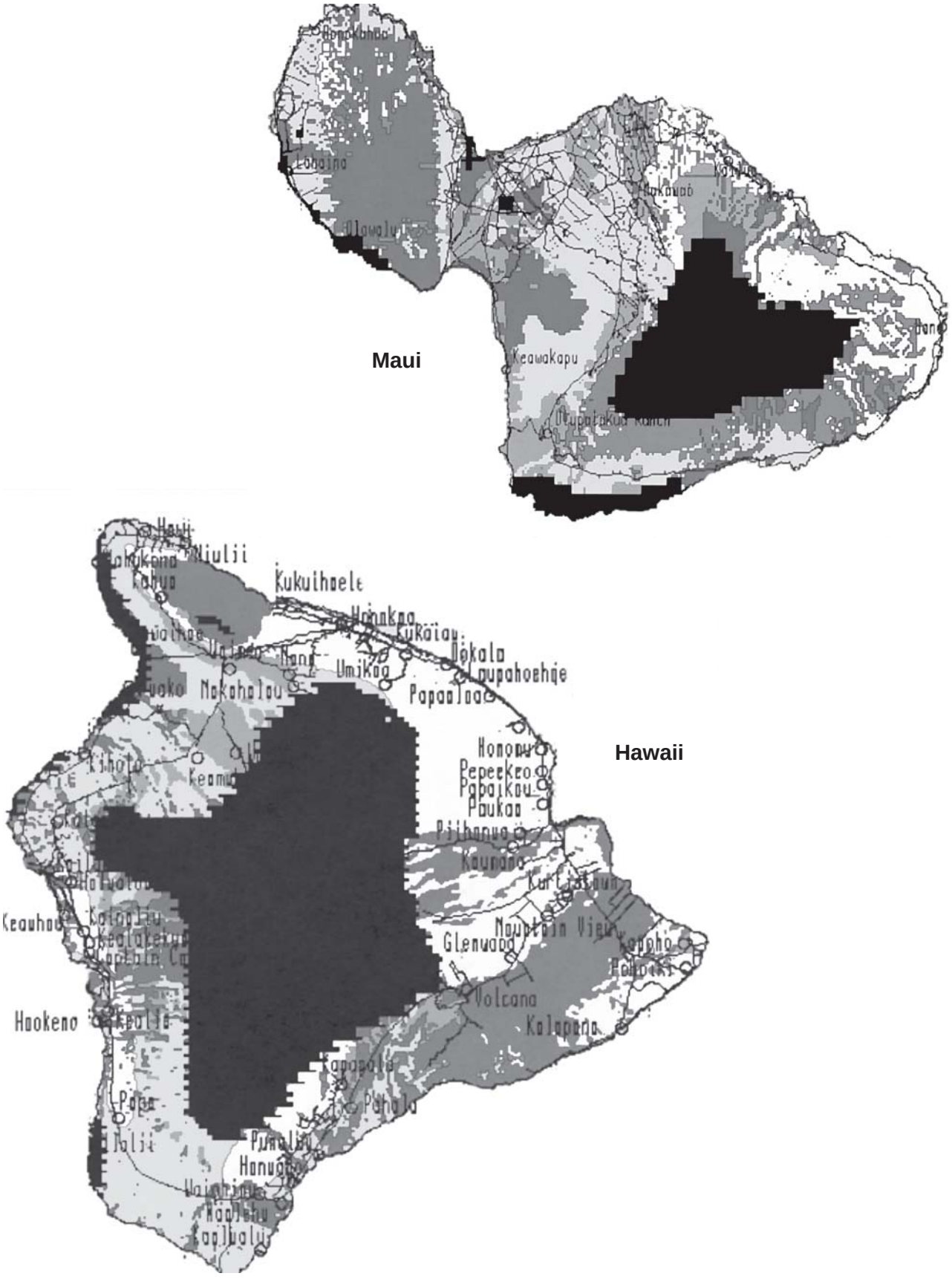
A = annual avg. temperature 59–73°F

B = A + good soil drainage

C = B + land slope <20%

D = C + soil pH 4.5–7

E = D + rainfall > 59 inches, meets all coffee growth requirements


Maui
Keawakapu
Hawaii
Kukuihaele
Honoka
Umikoa
Papaaloa
Honomu
Pepeekeo
Papaikou
Paukaa
Kaumana
Glenwood
Volcano
Kalapana
Hookena
Pahala

transplanted without bending the taproot. In former years, the practice was to place a handful of fertilizer high in phosphate (superphosphate or triple superphosphate) in the bottom of the hole, fill it completely with soil, and allow the soil to settle for a month or so before planting. Where little soil was available, a shovelfull of soil would be placed in the bottom of the hole before planting to prevent injury of the roots by contact with the fertilizer. Today, slow-release fertilizer tablets are often placed on the side of the hole with less danger to new transplants.

Planting distance

Traditionally, coffee trees were spaced at 8 x 8 ft or, in cloudy areas, 10 x 12 ft. These wide spacings allowed the trees to be kept low to facilitate picking and to expose a large surface of each tree to sunlight for increased bearing. Many farms in Kona are still planted in this manner, with spacing being determined by such factors as elevation (and its effect on sunlight and rainfall) and management practices.

Recently, planting coffee in hedgerows has become popular, with the trees close together in rows separated by wide alleys. This system increases the number of trees per acre. In Kona, 'Guatemalan' coffee trees pruned in the Beaumont-Fukunaga style (see p. 29) and hand-harvested may be spaced at 4–5 ft x 10–11 ft. This system also lends itself well to contour planting.

In other areas, spacing of high-density plantings of semidwarf cultivars ('Caturra', or 'Catuai') varies with the means of harvesting. Spacing for mechanical harvesting in Hawaii ranges from 2.5–3 x 12 ft; optimum in-row spacing has not been determined, but it may be 4–6 ft, to reduce the need for pruning.

An advantage of planting in hedgerows is lower fertilizer and herbicide application costs. Instead of applying fertilizer around each individual tree, application is made in a continuous band along either side of each row, 1 ft or so away from the trunks of the trees. Vehicle-mounted sprayers may be easily moved along the rows in an orchard planted in hedgerows. In irrigated orchards, soluble fertilizers can be applied with irrigation water.

Transplants

Coffee orchards are started from transplants. Coffee seeds are rarely planted directly into the orchard, primarily because they germinate slowly, and weeds become a problem. Growers have a number of options to obtain seedlings. For hand transplanting, these include growing plants in plastic bags or paper sleeves, growing plants in bed nurseries, and digging up volunteer seedlings (*pulapula*).

Mechanical transplanting requires plants in bottomless paper sleeves or plastic dibbles. Standard mechanical transplanters are used. Plastic containers must be removed before transplanting; bottomless paper sleeves can be left on, although removing them encourages roots to spread as soon as possible. Mechanical planting is usually done through plastic ground covers over drip irrigation tubes.

CTAHR researchers have found that tissue-cultured plantlets grow normally and are suitable for propagation. The Hawaii Agriculture Research Center is evaluating the use of rooted cuttings.

The recent appearance of the Kona coffee root-knot nematode (*Meloidogyne konaensis*; see p. 23–24) has created a need for caution in transplanting. Transporting volunteer coffee seedlings to new planting sites can also transport nematodes in their roots and should not be done unless the soil of the orchard they are taken from has been assayed and declared free of the nematode. When seedlings are grown in containers in media that includes soil, this also should be analyzed for the presence of nematodes.

For most situations, purchasing ready-to-plant seedlings is the most cost-effective alternative. Coffee trees can remain productive for 100 years provided they start as healthy, well grown seedlings. The money saved producing your own seedlings will not pay for the possible cost of replanting an orchard, replacing dead trees, or even starting a nursery over again. We recommend buying seedlings in paper sleeves or plastic bags, ready-to-plant, from a nursery.

Coffee intended for planting in an old or existing coffee orchard in Kona should be grafted onto rootstock of the species *Coffea dewevrei* if soil assay finds the Kona coffee root-knot nematode. Some nurseries may be selling such grafted plants.

Recommendation:
Buy transplants from a nursery and bypass producing seedlings.

Volunteer seedlings (*pulapula*)

Occasionally farmers use *pulapula* from abandoned orchards. We do not recommend this practice on the Big Island due to chance that the seedlings maybe infested with nematodes. If the site is nematode-free, then *pulapula* can be used, provided steps are taken to handle them appropriately. *Pulapula* are most often found growing in the shade. Transplant them into an open nursery and expose them to direct sunlight until they improve their root system, get accustomed to open sunlight, and develop new leaves. *Pulapula* are usually spindly and irregular in shape and size, ranging from 1–4 ft tall (trees 1–2 ft tall should be selected if possible). It is best, therefore, to plant them at an angle to force the development of several new verticals. Select three or four of the new verticals 18–24 inches above the ground, and cut off the original vertical.

Selection of the nursery site

Experienced coffee farmers in Kona prefer to grow seedlings near the proposed orchard site. Otherwise, it is preferable to grow them at a site below the main highway, where it is warmer, sunnier, and not as humid as above the highway. Seedlings grown ½ mile or more above the highway should not be planted in orchards below the highway. In areas other than Kona, coffee seedlings should not be raised in cool, cloudy, or rainy areas for planting in warmer, drier areas.

Nematode infestation of soil or potting media for plants is a concern if you are in areas where Kona coffee root-knot nematode is present. Roots of plants grown in containers should not come in contact with infested soil. Where this is a possibility, use raised planting benches (>18 inches above the ground) or beds of cinder or rock covered with plastic weed mat (woven or solid). If there is danger that water or soil from an infested area can wash into the nursery, prevent this by using benches or diversion berms.

Selection and preparation of seeds for planting into a nursery

When selecting seeds for growing seedlings for transplanting, pick ripe coffee cherries from consistently heavy-bearing trees. Do not use seeds picked up from the ground.

Remove the pulp by hand if only a few pounds are required. For larger amounts, it is safe to use seeds from cherries that were pulped and fermented. The seed (bean) at this stage is parchment coffee; do not mill to the green-bean stage, because milling injures the seed. Seeds from hydro-pulped cherry may be used, but it is advisable to check the germination to determine if the seeds were damaged by this preparation.

After pulping, dry the seeds in the shade for about 10 days if they are not to be planted immediately. The quantity of seeds needed to plant a given acreage depends on the spacing in the orchard, the germination rate, and the survival rate for plants both in the nursery and after transplanting into the orchard. In general, 4 pounds of 'Guatemalan' cherry produces 1 pound of seeds, which makes about 1000 seedlings.

Planting the seeds

Seeds can be started in a seed flat. Use sterilized topsoil (or at least soil without weed seeds and nematodes) or a 1:1:1 (volume) mixture of vermiculite, perlite, and peat moss. Spread the seeds evenly and cover them with ½ inch of soil or a 1:1 vermiculite-perlite mixture. Keep the flat moist (but not saturated) with regular misting and place it in direct sunlight. Coffee seeds take 50 or more days to germinate. As the seedlings emerge, 70–90 days after planting, gently pull out the entire plant by its matchstick-like stem before the cotyledons open. Transplant the seedling to a plastic bag or pot (3 inches diameter by 8 inches tall) using care not to bend the taproot.

Seeds can also be directly sown into pots or bags to avoid transplanting from a seedling flat. Plant two or three seeds per unit and thin to one after they emerge. Some growers favor direct seeding into bottomless paper sleeves (2 x 2 x 6–8 inches). Various types of planting containers are available (see Sources, p. 2), including "dibble" tubes designed for forestry trees, which are 1½ inches diameter by 8 inches tall and suspended in trays. One advantage of these planting systems is that the taproot is "air-pruned" and forced to branch.

The next seedling growth stage is when the cotyledons open. At first, cotyledon leaves are tender, but they gradually harden during the first 3–4 months after planting. After 6–8 months, several pairs of true leaves will have developed. If pots or bags are used, check the root systems of a sample of 10 plants chosen at random at least 4 weeks before transplanting into the orchard. Avoid seedlings with taproots bent in a J or Z shape. These bent roots will constrict sap and wa-

ter flow in the young, bearing trees, which may die back or fall over. Plants with severely bent tap roots should have the bend cut off and at least the top third of the leaves pruned away to compensate for root loss while the plant recovers. Cutting off the end of the taproot encourages branching. A new technique to avoid "J-root" seedlings is using a copper hydroxide compound, Spin Out® (see Sources, p. 2) painted or sprayed on the inner surface of pots, plastic bags, or paper containers. CTAHR research found that 12-month-old coffee seedlings treated with the compound were taller, 50 percent heavier, and had a better root system than untreated plants (Nagao and Ho-a 1999).

Seedlings from nursery beds

Raising seedlings in nursery beds is seldom done and should not be done in areas where nematodes are a problem. Coffee seedlings grown in nursery beds are normally 18–24 inches tall at 14–20 months, which is the ideal size for transplanting. After root pruning 2 months or so before transplanting, the seedlings are carefully dug up with a ball of soil to protect the root system. The root system should be covered with wet burlap to protect it from exposure to sun and air while the seedling is being taken to the field for planting.

Transplanting time

The best time to transplant in Kona is at the beginning of the rainy season, preferably early April through July, but it can be done as late as September. During this period there is usually afternoon rain, and planting conditions are ideal. In areas beyond Kona, plant at the start of the rainy season, selecting a day when the soil is moist. Avoid planting in the hottest, driest months unless transplants are well adapted to the sun. Irrigate before planting and as needed to prevent wilting. Do not keep the soil too wet after transplanting, as coffee is sensitive to waterlogging. Depending upon weed and water control, transplants may be only 6–8 inches tall with as few as 5–8 leaf pairs, or they may be up to 24 inches tall at planting. Larger plants can compete better, but a bigger plant means more time in the pot and an increased likelihood of "J-root" malformation. Large plants are more expensive, whether purchased or grown. Avoid planting too deep, which can kill the seedling by girdling or waterlogging. The soil line should not be more than ¼ inch higher on the transplanted seedling than it was in the nursery. The first small root should be close to the surface after transplanting.

Table 1. Varieties (cultivars) in the Hawaii State Coffee Trial, taken from the CTAHR coffee germplasm collection in Kainaliu, Kona.

Name	HAES #*	Comments
Blue Mountain	6433	Grown in Jamaica; our seed source did not produce uniform trees
Bourbon, Pink		
Bourbon, Red	6434	
Bourbon, Yellow	6618	Yellow cherry
Robusta	6621	*C. canephora*
Caturra, Red		Briefly popular in Kona in the 1960s; semidwarf parent of Red Catuai
Caturra, Yellow	6620	Yellow cherry; semidwarf parent of Yellow Catuai
Guadalupe	6436	
Guatemalan	6432	Standard cultivar in Kona; also known as "Kona typica"
Margogipe		Very large bean but low yield
Kents	6550	Indian cultivar
Mundo Novo	6592	High-yielding in Latin America; parent of the Catuais
Pacas	6789	
Preanger	6657	
Pretoria	6443	Large bean, low yield
Progeny 502	6843	A single-seed selection from "typica" collected in Central America; similar to Guatemalan, but cherry harder to pull off
San Ramon	6444	Very dwarf
S.L. 28	6552	Rust-resistant; from Africa
K–7	6549	Rust-resistant; from Africa
H–66	6661	Good yield in Kenya
Catuai, Red		High-yielding, semidwarf from Brazil
Catuai, Yellow		Yellow version of Red Catuai. Not tested in this experiment; the most widely planted cultivar on Kauai

*Hawaii Agricultural Experiment Station (CTAHR) accession number

Which variety to plant?

Hawaii State Coffee Trial

CTAHR's Hawaii State Coffee Trial (Tables 1–4) was a state-wide, on-farm variety trial, planted in 1986–1987 by cooperators, using varieties from the CTAHR coffee collection plus an early version of the Brazilian cultivar 'Red Catuai' ('Catuai Vermelho' in Portuguese) donated by John Hays. Several sites where results or

Table 2. Original Hawaii State Coffee Trial sites.

Island	Location	Comments
Hawaii	S.Kona	2700', unirrigated
	S. Kona	3200', unirrigated
	Kainaliu	1980', unirrigated, rain 80", avg. temp. 63/80°F
	Kealakekua	1500', unirrigated, 3 cvs.
	Peck Rd., Mtn. View	1925', unirrigated
	Pszyck, Mtn. View	1650', unirrigated
	Kukui Camp, Kurtistown	1350', unirrigated
	Puna Mill, Keaau	300', unirrigated
Kauai	Eleele	300', irrigated, avg. temp 66/83°F
	Honomalu, Lihue	450', unirrigated
	Makena, Kapaa	100' irrigated
	Kekaha mauka	650', irrigated
Lanai		above Lanai City, abandoned
Maui	Lahaina	1190' irrigated, rain 57", avg. temp. 61/76°F
	Waikapu	single plants
Molokai	Kualapuu	846', irrigated, rain 26", avg. temp. 68/77°F
Oahu	Maunawili	a few plants
	Kunia 1	irrigated
	Kunia 2	irrigated

Table 3. Summary of yields (pounds) of cherry, green bean, and Hawaii Extra Fancy size beans across locations and years where data are available; Hawaii State Coffee Trial, harvest years 1989–1991.

Cultivar	Cherry	Green bean		HEF*	
	yield (lb/tree)	Recovery (%)	Yield (lb/acre)	(%)	yield (lb/acre)
Blue Mountain	9	16.2	1850	22	410
Guadalupe	11	14.7	2000	23	460
Guatemalan ("Kona typica")	14	17.7	2910	23	670
HAES #6661	16	16.0	3020	20	600
Kent	15	16.7	3010	30	900
Mundo Novo	10	16.0	1850	29	540
Pink Bourbon	11	15.1	2080	15	310
Progeny 502	14	16.7	2810	48	1300
Red Bourbon	14	16.3	2730	8	220
Red Catuai	16	16.4	3230	22	710
Red Caturra	13	14.5	2310	12	280
SL 28	17	15.1	3170	35	1100
Yellow Caturra	14	15.1	2550	15	380
Cultivars not evaluated at most locations:					
6549	16.1	40			
Yellow Bourbon	16.3	10			
Margogipe	16.4	58			

*Percentages of beans that fell into the largest bean category (Hawaii Extra Fancy = >screen 18) were used as an indicator of bean size for a location.

other conditions were promising for coffee production became founding sites of the new coffee areas of Hawaii. Most of these areas were formerly planted to sugarcane or pineapple. These lands usually require irrigation due to dry summers and less dry winters and windbreaks against constant tradewinds—conditions virtually opposite those of the Kona coffee belt.

The varieties were grouped based on cherry yields in different environments. 'Yellow Caturra' and 'Red Caturra' were high-yielding, responsive to good environments, and also more stable in relatively poor environments (climate, management, and unexpected stresses). 'Kent', 'Red Bourbon', '6661', 'Guatemalan', 'Red Catuai', 'Progeny 502', and 'SL 28' were all

Recommendation:
Plant 'Guatemalan' (also known as "Kona typica"), unless the trees are mechanically harvested or are in a windy area without permanent windbreaks.

Table 4. Effect of location on pounds of cherry per tree and green bean recovery (percentage based on fresh cherry weights, bean weights were adjusted to 10.5% moisture) and percentage of Hawaii Extra Fancy green coffee (% beans > screen size 18).

Location or cultivar	Elevation (ft)	Rainfall (inches)	Cherry (lb/tree)	Recovery (%)	HEF (%)
Kukui	1330	157	11	13.2	38
S. Kona	2700	>60	5	13.3	39
'Pszyk'	1560	200	-	13.7	47
'Peck'	1925	wet	-	14.0	40
Keaau	300	150	13	14.1	21
Kainaliu*	1280	50	-	14.9	20
Eleele	290	30	23	15	19
Hanamalu	450	>80	11	15.3	30
Lihue	80	57	13	15.3	8
Kainaliu 2	1980	80	10	15.3	49
Lahaina	950		10	16.4	21
Kunia	230	20	17	16.6	14
Kekaha	650	< 40	12	16.8	4
Average			12.5	14.9	26.9

*CTAHR Kona Research Station

high yielding and responsive to favorable environments but lower yielding than expected (unstable) under relatively poor environments. 'Blue Mountain', 'Mundo Novo', 'Pink Bourbon', and 'Guadalupe' were low yielding but stable as assessed by a statistical procedure called stability (Bittenbender et al. 1991).

Cherry yield and green bean recovery were affected by both location and variety. Cherry yield and recovery of green bean for all varieties were averaged across years for each location (Table 4). Yield is very sensitive to management and the physical and biological environment. Highest yields are likely under the same environments favoring bean recovery. Good recovery environments are characterized by higher average annual temperatures, lower rainfall, and higher levels of sunshine. Bean size, however, was negatively affected by such site conditions favoring bean recovery. Sites at low elevation with warm temperatures, such as Lihue, Kekaha, and Kunia, had significantly lower percentages of Hawaii Extra Fancy green coffee beans (Table 4). Sites at higher elevations, with cool temperatures and fairly heavy rainfall, such as Pszyk, Peck, and Kainaliu (2300 ft elevation), had the highest percentage of Hawaii Extra Fancy green coffee beans.

The 'Guatemalan' or "Kona typica" variety is preferred

The coffee variety most generally preferred in Hawaii is 'Guatemalan', also known as "Kona typica." In the early days of the Hawaii coffee industry, beans from Kona-grown coffee trees were called "Melikan koppe" (American coffee). Today, in 1999, due to a large corporate planting on Kauai, the greatest acreage of coffee in the state is planted with the Brazilian cultivar 'Yellow Catuai' ('Catuai Amarelo' in Portugese).

Most established varieties (cultivars) of Arabica coffee (*Coffea arabica*) are self-fertile and breed true from seed.

Hermann Widemann introduced the 'Guatemalan' variety to Hawaii from Guatemala in 1892 (Goto 1982). He gave seeds to John Horner, who planted an orchard of 800 trees in Hamakua, comparing 400 trees of this new variety with 400 of the then-current variety known as "kanaka koppe," the so-called "Hawaiian coffee" believed to be the first coffee type introduced here, probably from 30 plants brought from Brazil in 1824 by John Wilkinson. By 1895, Horner was convinced that the variety from Guatemala was superior. Horner gave seeds to Charles Miller, who started a nursery on the Kona Tea and Coffee Company's farm in Kahaluu, North Kona. In 1897, Zentaro Inaba planted Miller's seedlings in Waiaha, North Kona. In 1899, Kunigoro Yokoyama planted 100 acres in Kamalumalu from seeds purchased from Horner. By 1910, Kona coffee growers were convinced of the superiority of the new variety. In the 1960s, some growers in Kona tried another variety from Latin America, 'Red Caturra', but few in Kona grow it today. The Kona coffee industry and reputation is based on 'Guatemalan', which some growers refer to as "Kona typica"; it is the recommended variety for Kona.

The young coffee orchard

The most crucial period in the life of a coffee orchard is the first five years. During this period the trees must be fertilized, protected from weeds and pests, and pruned for efficient growth and future production.

Fertilizer

Coffee requires nutrients to grow and produce a crop. The crop growth stage determines the types and amounts of fertilizers necessary, and they must be applied at correctly spaced intervals in order to produce optimal growth.

The main purpose of applying fertilizer to young trees is to supply the nutrients necessary to support vigorous and continuous growth of roots and leaves. Young trees in particular need a fertilizer with a high phosphorus (P) content to promote root production.

Bearing coffee trees have different nutrient requirements, as described below. A harvested crop of 10,000 pounds of cherry contains about 63 pounds of nitrogen (N), 13 pounds of phosphorus (P, but calculated as P_2O_5), and 68 pounds of potassium (K, but calculated as K_2O). The trees producing that much cherry contain 250 pounds of N, 60 pounds of P, and 200 pounds of K in their leaves, stems, and roots. Additional quantities of nutrients are utilized in the orchard system, including nutrients in coffee leaf litter, wood that is pruned,

windbreak trees, and weeds. In addition, nutrients are lost by leaching, erosion, and volatilization.

The suggested fertilizer schedule given at right was developed for farmers who broadcast fertilizer by hand, but the amounts can be adjusted for banded applications or "fertigation" (injection through an irrigation system). An example for fertigation is also given at right, below.

Year 1

As described in the section on planting, a liberal amount of fertilizer high in P is placed in the bottom of the planting hole before transplanting. The next fertilizer application is made approximately two months after transplanting. Traditionally, a 10-30-10 (percent N:P:K) formulation is used, but this should be modified according to recommendations based on soil analysis. A handful (2 oz, ¼ cup) per tree of this fertilizer should be evenly spread over a zone beginning a few inches from the trunk and extending to the tip of the lateral branches (leaf drip line). This application is repeated at intervals of about three months during the first year.

Year 2

During the second year the vertical branches will grow taller and the roots and side branches will extend laterally. The quantity of fertilizer should be increased to approximately two handfuls (4 oz, ½ cup) per tree at three-month intervals.

Leaf sampling for tissue analysis

The second year the trees have been in the ground is the time to begin sampling leaves for tissue analysis to correct any nutrient imbalances. Pick the most recently fully matured pair of leaves (usually the 3rd or 4th pair from the terminal) from lateral branches at mid-height of the tree. Sample leaves after flowering but before the cherries are full size. Take one or two pairs of leaves from 20 "average" trees per acre. If the farm is large and uniform, 20 pairs of leaves from 5 acres is sufficient. If parts of the orchard are managed differently, sample them separately. If in parts of the orchard trees are doing poorly, collect samples from both normal and poorly growing trees.

Soil and plant tissue analyses can be done by commercial laboratories or by the CTAHR Agricultural Diagnostic Service Center (ADSC). ADSC also ana-

Fertilizer schedule for coffee farms in Kona

All amounts are in pounds / acre / year and assume adequate rainfall or irrigation. Do not apply in two consecutive months unless there has been rain or the field is irrigated.

Farms above 1500 ft
minimum amount per year = 270 N, 100 P_2O_5, 400 K_2O

January	0
February	500 CC* or 360 CS
March	0
April	500 CC or 360 CS
May	0
June	500 CC or 360 CS
July	0
August	200 AP or AS or 100 urea
	(This is important to avoid overbearing dieback.)
September	0
November or December	500 CC or 360 CS
	(Apply once during this period to avoid overbearing dieback.)

Farms below 1500 ft (sunny areas)
minimum amount per year = 300 N, 100 P_2O_5, 400 K_2O

January	0
February	500 CC or 360 CS
March	0
April	500 CC or 360 CS
May	500 CC or 360 CS
June	300 AP or AS, or 150 urea
	(This is important to avoid overbearing dieback.)
July	0
August	300 AP or AS, or 150 urea
	(This is important to avoid overbearing dieback.)
September	0
October	0
November	0
December	500 CC or 360 CS

*Key to fertilizer types: CC = 10–5–20 fertilizer, sometimes called Coffee Cherry®, a product formulated for coffee; CS = 14–7–28 fertilizer, sometimes called Coffee Super®, a product formulated for coffee; AP = ammonium phosphate; AS = ammonium sulfate

One possible fertigation schedule for bearing coffee.

	Pounds per acre		
	N	P_2O_5	K_2O
January	0	0	0
February	25	10	40
March	25	10	40
April	25	10	40
May	0	0	0
June	25	10	40
July	25	10	40
August	25	10	30
September	25	10	0
October	0	0	30
November	0	0	0
December	25	5	40
Total	**200**	**75**	**300**

Nutrient concentrations in leaf tissue of adequately fertilized coffee trees.*

		Percent (%) of leaf dry weight	
Nutrient	Symbol	Deficient	Adequate
Nitrogen	N	1.45 – 1.90	2.6 – 3.0
Potassium	K	0.35 – 1.10	1.9 – 2.5
Phosphorus	P	0.05 – 0.08	0.14 – 0.17
Calcium	Ca	0.36 – 0.55	0.8 – 1.5
Magnesium	Mg	0.04 – 0.10	0.30 – 0.32
Sulfur	S	0.04 – 0.05	0.15 – 0.22

		Parts per million (ppm) of leaf dry weight	
		Deficient	Adequate
Iron	Fe	1 – 25	43 – 60
Boron	B	9	31 – 50
Zinc	Zn	10 – 15	18 – 25
Manganese	Mn	< 25	200

*data from Nagao et al. 1986b

lyzes insect and plant disease problems. Contact the nearest CTAHR Cooperative Extension Service office for information on analysis fees and the best time to bring in samples for shipment to ADSC at UH-Manoa.

The tissue analysis report will indicate the concentration of nutrients (elements) in the leaves. The table above is a guide, indicating the desired levels of nutrients in recently matured leaves of coffee plants.

A regular program of plant tissue analysis is a recommended part of an efficient coffee farm's operation. Tissue analyses can often pinpoint "hidden" deficiencies before they cause observable symptoms in the field. By the time visual symptoms become apparent, plant growth usually has been seriously affected. Signs of nutrient deficiencies in coffee are described in the key at right. Photos of these symptoms can be viewed at the CTAHR Web site at <http://agrss.sherman.hawaii.edu/bookshelf/coffee/coffee.htm>. The most frequently seen deficiency symptom in coffee is nitrogen deficiency, followed by, occasionally, zinc.

Year 3

The trees will be 4–6 ft tall in the third year. At this stage, the coffee plant needs less phosphorus and more potassium, which is needed for flowering and seed formation. Various fertilizer formulations have been tailored to the needs of the coffee industry. Coffee Cherry® (10-5-20) has been the traditional mix for many years.

Key to identifying nutrient deficiency symptoms

I. Problem seen on older leaves or generally on the entire plant. *If not, go to II.*

A. Uniform leaf chlorosis (yellowing) or light interveinal chlorosis (yellowing between green veins). *If not, go to B.*

Lower leaves exhibit slight chlorosis, young leaves remain darker green; faint interveinal chlorosis of older leaves at advanced stages; small necrotic (dead) spots (usually brown) may be present. **Phosphorus**

B. Localized necrosis or interveinal chlorosis evident on older leaves.

1. Marginal chlorosis followed by development of dark brown necrotic spots on the leaf margins; necrotic areas coalesce until entire margins are dark brown, while the areas along the midrib remain green. **Potassium**
2. Faint marginal chlorosis with sunken, yellow-brown to light brown necrotic spots developing in a wide band along leaf margins; interveinal chlorosis evident in affected leaves, particularly along the midrib. **Magnesium**

II. Problem seen on younger leaves near shoot tips.

A. Uniform chlorosis to faint interveinal chlorosis; plants have sparse vegetative growth.

1. Leaves rapidly becoming pale green; emerging leaves uniformly pale green with a dull green sheen. Entire plant becoming pale green, with sparse vegetative growth; leaves becoming yellow-green at advanced stages; whitish veins may be present in lower leaves. **Nitrogen**
2. Leaves light green to yellow-green, with faint interveinal chlorosis; deficient leaves retain shiny luster. **Sulfur**

B. Sharp interveinal chlorosis of youngest leaves; older leaves unaffected.

1. Leaves expanding normally, with vein network remaining green and clearly visible against the light green to yellow-green background; background becoming nearly creamy white at acute stages. **Iron**
2. Leaves not expanding normally; narrow, often strap-shaped; veins visible against a yellow-green background; failure of internodes to elongate properly, giving plants a rosetted appearance. **Zinc**

C. Bronzing, mottling, or necrosis of youngest leaves; dieback of terminal buds.

1. Leaves bronzed along margins, cupped downward; emerging leaves necrotic; eventual dieback of terminal buds. **Calcium**
2. Youngest leaves light green, mottled, with uneven margins and asymmetric shape; emerging leaves with necrotic spots or tips. **Boron**

Other fertilizers sold for coffee in Kona are Coffee Super® (14-7-28) and "plus" formulations containing N-P-K with zinc (Zn), magnesium (Mg), and iron (Fe). If a 10-5-20 formulation is used, a total application of 1000 pounds per acre per year is considered enough in year 3.

The fertilizer is applied by broadcasting by hand four times a year. The first application is made at the beginning of the growing season following the semidormant period. The second application is given immediately after the flowering period, and the third is given when the crop is making its most rapid development and vegetative growth is at its maximum. The fourth application is made just before harvest.

Year 4

As the trees grow larger, the amount of fertilizer applied per year is increased to approximately 1500 pounds per acre (based on 10-5-20), split into four or more applications. As the amount of fertilizer increases, care should be exercised to broadcast it evenly over the entire area under the branches and no closer to the trunk than 6 inches away.

If the orchard is located in a sunny, relatively unclouded area, as are coffee orchards in Kona below the Belt Road, additional N fertilizer is recommended, split into two applications. Up to 500 pounds per year of ammonium sulfate should be applied (or 230 pounds of urea, which would provide the same amount of N). These two applications are given between the first and second, and the third and forth applications of 10-5-20.

Where there is excessive rainfall and cloudiness, supplementary nitrogen fertilization is not necessary. The usual practice among experienced coffee growers whose orchards in Kona are located in areas that fall between the excessively cloudy section and the sunny section is to apply an additional 200–300 pounds of ammonium sulfate.

Year 5

Fertilizer is increased to 2000 pounds per acre per year as production increases in the fifth year. However, if the orchard is established on exceptionally rich soil, 1500 pounds or even less will probably be sufficient. By this time, the trees should be bearing a commercial yield, and a target of 10,000 pounds of cherry per acre is feasible.

Fertilizer application calendar

The fertilization calendar on p. 15 for bearing coffee grown in Kona is revised from an earlier CTAHR recommendation (Anon. 1961) and is meant to be used as a starting point and modified by the grower based on crop performance and tissue analysis. A target yield of 10,000 pounds of cherry per acre is assumed.

Farmers who are "fertigating" must use soluble formulations. Urea and potassium nitrate (KNO_3) are frequently used. Farmers who are fertilizing organically should start with overall nutrient targets similar to those suggested here and then adjust applications based on the products available and the condition of the crop.

Irrigation

Many farmers in the Kona coffee belt do not irrigate, nor likely will those in areas with rainfall over 60 inches a year, but where rainfall is less, irrigation is needed. Setting up an irrigation system can be expensive, and mistakes by do-it-yourselfers will increase the costs. Drip or micro-emitter systems are best for tradewind conditions.

The water requirement of a crop is often measured in terms of "crop coefficient," which describes the crop's water demand compared to the amount of evaporation from an open pan of water placed in the orchard. Research in Hawaii has shown that young, nonbearing coffee trees require 60 percent of the amount of water normally lost to evaporation from an open pan, whereas bearing trees over two years old demand 75–80% of pan evaporation. Overirrigating and leaks in the drip tube can lead to waterlogged conditions resulting in poor root development, root injury, poor yields, and—if uncorrected—death of the plants. Symptoms of extreme overirrigation may include some wilting; frequently, leaves may have dead margins; later, laterals and the top of the vertical die, with the dead leaves remaining on the tree. The symptoms may appear to be damage from black twig borer, but this cause can be eliminated if no entry holes are found. It is easier to

Recommendation: Hire an irrigation consultant to design and install your system.

overirrigate on heavy clay soils, which hold more water and drain slowly. However, overirrigation can occur on *a'ā* lava soils if there is a solid rock "pan" below the surface that allows water to stand. The presence of standing water under a tree half an hour after irrigation is shut off is a sure sign of overirrigation and a signal to take steps to correct the problem.

Applying irrigation based on calculated water demand is both cost-effective and important to crop health. Devices for monitoring crop water needs include soil tensiometers, open evaporation pans, and evaporation blocks; irrigation consultants usually know what works best in a given situation. Coffee is irrigated when the tensiometer reads 50 centibars, and water is generally applied for 1–48 hours to ensure deep wetting.

When using an evaporation pan, one needs to take rainfall into account. A simple though approximate system includes a ruler that measures 1/16- or 1/32-inch increments and a 12-inch deep by 24-inch diameter pan half filled with water and covered with wide-mesh screen to prevent animals from bathing in or drinking the water. The water level is checked once a week; only if there is less water than there was a week ago is irrigation needed. To determine the amount of water to apply, you need to know how much water your system can deliver, the age of the trees, and the percentage of land covered by trees.

For example, assume your orchard is planted 10 x 5 ft, your trees are bearing age (expect a 75 percent crop coefficient or water use compared to pan evaporation), and the lateral branches are touching in the row and have grown into the alley, which is now 4 ft wide; therefore, coverage is 60 percent (5 x 6 ft = 30 ft^2; 30 ft^2 / 50 ft^2 spacing = 60 percent). In the past week the water level dropped ½ inch. The amount of water needed is determined as [½ inch (due to evaporation) x 0.6 (60% coverage) x 0.75 (75% crop coefficient) = 0.22 acre inches], or about ¼ inch over each acre of orchard. An acre inch is 27,154 gallons. Given that there are 870 trees per acre and 0.22 acre inch of water is applied, each tree receives about 7 gallons of water to replace the water used in the previous week. This calculation assumes 100 percent efficiency of application. No irrigation system is 100 percent efficient, but each system has an expected efficiency. If the efficiency of the system is 80%, then the amount to be applied in this example is 0.275 acre inches (0.22 / 0.8), or 8.75 gallons per tree (7 / 0.8 = 8.75).

Growers who irrigate may also wish to fertigate (fertilize through the drip irrigation system). Only fertilizers that completely dissolve in water can be used, and these formulations are often more expensive. If you are using the municipal water system, backflow-prevention valves are required to prevent fertilizer contamination of the water. An example of a fertilizer schedule for bearing coffee, proposed by Osgood and Chang (1994), is given on p. 15.

Weed control

To obtain good coffee yields, weeds must be controlled, regardless of the pruning system, degree of mechanization, or fertilization program. If weeds are neglected, no amount of fertilizer will help. Among the important weeds affecting coffee are vines such as morning glory, ivy gourd, bittermelon, and *maile-pilau*, to mention a few. Volunteer coffee seedlings are a particular problem in mechanically harvested orchards.

Weed control costs are estimated to range from 3 to 10 percent of annual growing costs, assuming that weeds are managed well and extensive hand weeding does not become necessary (Fleming et al. 1998).

In the past, farmers have used mulch to protect the area under the tree from weed growth. Mulch materials used include coffee parchment skin, flat stones, macadamia nut husks, and dried grass. Mulches of organic materials are still used by organic farmers and others. Mulch should be kept at least 2 inches away from the trunk to avoid having any area on the trunk in continuous contact with moist material.

Most often today, artificial mulches are used as barriers to weed growth. Two common types are black plastic film (as used in pineapple fields) and black woven cloth ("weed cloth") that is permeable to water. Normally, weed cloth is laid before transplanting to keep weeds away from the area where the feeding roots are most numerous. During the dry season, mulch helps maintain soil moisture, particularly important at lower elevations. Hoeing or hand weeding is expensive, and mulches are a good way to minimize the expense of weed control during the first year. Although hoeing was the most common weeding practice in the past, chemical weed control is almost universally practiced in cof-

fee orchards in Hawaii, except in organic orchards, where string trimmers, hoeing, and even geese are used.

The advantages of chemical weed control (herbicides) over hoeing are that it is faster, it is less expensive because less labor is needed, it minimizes soil erosion on sloping land, and it has greater efficiency during rainy weather because the soil is not disturbed to bring buried weed seeds to the surface.

Mowing is feasible in coffee orchards provided the orchard floor is properly prepared by removing rocks and uneven sections. Planting a cover crop will produce a uniform groundcover that will be more efficient to mow than a mixed, volunteer groundcover. Allowing volunteer groundcovers and keeping them mowed is a common practice that works well provided there are no vines to tangle in the mower or climb the coffee trees. Undesirable weed species that occur in the volunteer groundcover should be mown or otherwise controlled before they produce seeds.

Some herbicides registered for use in coffee crops are described below, but the person applying the pesticide must read the pesticide's label to learn about application rates, limitations, and use precautions. The label also specifies the weeds that the herbicide is effective against. One way to find out which pesticides (herbicides, insecticides, and fungicides) are registered for coffee is to check CTAHR's Hawaii Pesticide Information Retrieval System (HPIRS) at our Web site, <http://www2.ctahr.hawaii.edu>, under Services.

Postemergence herbicides

Postemergence herbicides are applied to weeds after they have germinated. Gramoxone® (paraquat) is a contact herbicide effective against many annual weeds; it will damage coffee leaves and green stems. You must be a certified applicator to purchase this product. Roundup® (glyphosate) is a systemic herbicide effective against most annual and perennial weeds; it may kill the coffee plant if allowed to contact coffee leaves or green stems. Fusilade 2000® (fluazifop-butyl) is a systemic herbicide effective against certain annual and perennial grasses.

Orchards in dry areas rely heavily on two broad-spectrum, postemergence herbicides, paraquat and glyphosate. Their efficacy against a wide range of weed species and growth stages allows flexibility regarding the timing of application; this is especially important to growers who cannot keep ahead of weeds. The effect of Roundup can be enhanced by mixing it, according to label directions, with ammonium sulfate or a postemergence herbicide called Scythe®, which has the active ingredient pelargonic acid.

Pre-emergence herbicides

Pre-emergence herbicides are applied before weeds germinate, usually to bare soil. Goal 1.6E® (oxyfluorfen) controls certain annual broadleaf weeds, but its continual use encourages perennial broadleaf weeds. Surflan® (oryzalin) controls certain annual grasses and broadleaf weeds.

Preemergence herbicides prevent weed seeds from sprouting. In newly established coffee orchards, they are sprayed beneath trees in rows between mown groundcover alleys to minimize maintenance costs. Mowing and use of selective herbicides are both usually needed to maintain groundcovers.

Groundcovers and cover crops

A number of groundcover species can be used in coffee. In Kona, a dwarf "wandering Jew" (*Tradescantia bolivaensis*) is seen. It is a relative of honohono (*Commelina diffusa*). Orchard grass (*Dactylis* species) is also common in Kona orchards.

Several species have been evaluated by CTAHR for dry areas, although none are in wide use yet. A demonstration planting (Evensen 1997) identified species of perennial and annual cover crops that establish effective soil cover, minimize soil surface exposure, and thus provide protection against soil loss on highly erodible lands. The planting indicated that the drought-tolerant perennial cover crops 'Tropic Lalo' (*Paspalum hieronymii*), Rhodes grass (*Chloris gayana*), Kline grass (*Panicum coloratum*), buffelgrass (*Cenchrus ciliaris*), and possibly bermudagrass (*Cynodon dactylon*) are well adapted to low-rainfall areas. The planting suggested that narrowleaf carpetgrass (*Axonopus affinis*) and perennial peanut (*Arachis pintoi*) are not good for dry conditions because they grow slowly and do not rapidly protect the soil or suppress weeds in their early growth stages. Perennial peanut should do well if planted at the beginning of the rainy season or irrigated during establishment.

An important benefit of cover crops is the elimination or reduction of weed control measures, including herbicide applications. While several of the cover crops studied in the CTAHR dry-site demonstrations provided adequate soil erosion control, they were not all effec-

tive in controlling weed infestation. Vigorous, thick grasses with a low-lying canopy, such as Rhodes grass and Kline grass, were most effective in suppressing the proliferation of invading weeds. However, these tall grasses required frequent mowing (every 2–3 months) to control their height to the extent desired by the plantation (i.e., less than about 1 ft high). The somewhat less vigorous buffelgrass provided a good compromise, being lower growing and requiring little or no mowing. In addition, buffelgrass was the most drought tolerant of the cover crop species in the demonstration. 'Tropic Lalo' paspalum is lower growing and may not require mowing to remain at the desired height under dry conditions. But it must be propagated with sprigs and thus may be more expensive to plant than the other species, which can be established from seed.

Small grains, such as ryegrass (*Lolium multiflorum*), oat (*Avena sativa*), and rye grain (*Secale cereale*), were also evaluated as temporary cover crops for protecting the soil during the rainy season from November to April (in areas other than Kona), which is generally the most erosive and weedy period of the year, and then dying out during the summer months. This may be an attractive option for plantations that face summer water shortages and have concerns about competition for water between the coffee and the cover crop.

The Natural Resources Conservation Service is a source of information on cover crops suited to various areas.

Caution is advised in selecting a groundcover for coffee orchards, because research has yet to determine if any of the cover crops mentioned above hosts the Kona coffee root-knot nematode. Rhodes grass and buffelgrass are generally not hosts of other root-knot nematode species, while 'Tropic Lalo' is suspect because it is related to hilograss, a known host of the Kona coffee root-knot nematode.

Insect problems

Thus far, Hawaii is fortunate in having neither the most serious coffee diseases nor the insect pests found in other coffee-growing regions of the world. This is due to Hawaii's natural geographic isolation and the quarantine regulation that prohibits entry of coffee plants or seeds (except with a permit and a 1-year holding period in a certified quarantine greenhouse). For more information on insect pests of coffee and pesticides registered for coffee, visit the CTAHR Web site at <http://www2.ctahr.hawaii.edu> and consult "Knowledge Master" about insects and the Hawaii Pesticide Information Retrieval System (HPIRS) about pesticides.

Pesticide use is governed by state and federal regulations. The person applying the pesticide must read the pesticide's label to learn about application rates, limitations, and use precautions. The label also specifies the insects that the insecticide is effective against. Insecticides currently registered for coffee in Hawaii are Volck® Supreme Oil, Safer's® Insecticidal Soap Concentrate, and Clean Crop® Superior 70 Oil.

Green scale

Green scale, *Coccus viridis*, sucks sap from the coffee plant and excretes a sweet substance referred to as honeydew that covers the leaves and supports growth of a black sooty mold that reduces photosynthesis. Scale requires constant attention when the trees are young and growing, particularly in dry areas or dry seasons. Unless scale is controlled, coffee trees will become stunted and sometimes die. Control green scale by spraying either an oil or soap emulsion according to label directions. CTAHR has submitted data for registration of a new insecticide, Admire® (imidacloprid), which should be very effective against scale if its use is approved.

Ants "herd" and protect the scale insects and therefore are chiefly to blame for the spread and increase of green scale. If ants are prevented from getting to a coffee tree, the green scale frequently disappears, controlled by its natural predators. Eliminating the ants is not easy, because no pesticides for ants are approved for use in coffee orchards. Ant-control baits such as Logic® are for use only in young, nonbearing coffee orchards or in uncropped areas around the orchard. Amdro® is very effective against ants, but it is not registered for use in coffee crops and may be used only in uncropped areas around the orchard.

The adult scale is oval, bright pale green, and legless, with short, curved black markings on the back. They are found on coffee leaves, stems, and cherries but most commonly on the underside of leaves, along the veins. Sometimes as many as 500 can be found on one leaf. When infestation is severe, leaves and fruits drop, growth is stunted, and young plants can even be killed.

Green scale attacks more than 70 plant species, including guava, mango, plumeria, and gardenia. Females reproduce without males. Eggs hatch within minutes after being laid. Scale has three growth stages (instars). The first, called a crawler, has two long tail-like structures; it wanders over the plant before settling to feed. The second and third instars are slightly larger. The life span from egg to adult is two months in Hawaii.

The scale and black sooty mold problem in Hawaii was first observed in 1905. Green scale was accidentally introduced to Hawaii on lemon seedlings imported from Fiji and caused the "coffee blights" that occurred in Kona during the early 20th century.

The first and most successful biological control agent against the scale is the white halo fungus (*Verticillium lecanii*) introduced from Florida around 1910. It destroys millions of scales in Kona during the more humid periods of the year. It also attacks other scales, aphids, and occasionally beetles, flies, and mites. When no insect host is available, it lives in the soil on dead plant material. It invades and destroys scales within two days. After 10 days, it grows out of the scale to produce the characteristic white halo around the scale that can be seen before the scale disappears.

The white halo fungus requires high humidity to germinate and rain to spread its spores. Even at 96 percent relative humidity, germination falls by two-thirds, hence the lack of fungus activity during dry weather. Temperatures above 77°F reduce effectiveness, and at 85°F germination and growth stop. It is likely that this fungus will control scale in other locations that have cool, wet conditions.

Five introduced ladybird beetle (ladybug) species feed on the green scale. The most common is *Azya orbigera*. The adult has a black back, except for two circular spots and short hairs. The legs and abdomen are orange-brown. The young resemble large mealybugs.

Seven wasps parasitize the green scale, but they are not effective in hot, dry, windy areas.

Growers may use two forms of imidacloprid, Admire® for soil application and Provado® for foliar application, for control of green scale. Organic growers can spray an organic insecticide such as Safer's® Insecticidal Soap or neem oil. If trees are grown as individuals, not in hedgerows, and no other plants touch the leaves, then an ant barrier can be used on the trunk. A band of woven polyester fiber about 3 inches wide is wrapped tightly around the trunk about 12–18 inches above the ground. A smooth plastic strip is wrapped around this, and sticky material such as Tanglefoot® is applied to coat the plastic strip. Provided blowing dirt and debris are kept off the barrier, ants become trapped in the sticky material as they attempt to cross. Thus other natural enemies of the scale can attack without the ants attacking them. The sticky material is toxic to coffee bark, which is why it is put on the plastic. The

Scouting for scale: how to monitor a coffee orchard

In dry areas, we recommend a regular monitoring program to determine when to spray for scale before infestation becomes too severe. Orchards are monitored in the dry months by collecting leaves from selected areas in the orchard, called sampling stations. Normally there is one sampling station for every 5 acres. On farms less than 5 acres, randomly sample 10 trees throughout the orchard if a scale problem already exists. Collect 20 leaves, 1 each from the top and bottom parts of 10 trees in the orchard. Check the upper and undersides of each leaf, and record the "scale score" for the number of live adult scales (green colored, not brown) for each leaf. Leaves are scored as 0 = no scale, 1 = light infestation with 1–10 adult scales per leaf, 2 = medium infestation with 11–50 adult scales per leaf, or 3 = heavy infestation of over 50 adult scales per leaf. Determine the percentage of leaves that have any scale. Add up the number of leaves in each category (none, light, medium, and heavy) and multiply the number of leaves in each category by its score. Total the products of these multiplications. Divide this total by the number of leaves with scales to obtain the average density of scale infestation on the leaves. Multiply the average density of scale infestation by the percentage of leaves with scale and divide by 3. This number is the "infestation index." Here is an example:

From 20 leaves collected from 5 acres, 10 leaves (50%) had some scale; they were grouped as:

10 had no scale, 10 x 0 = 0
5 were scored light, 5 x 1 = 5
3 were scored medium, 3 x 2 = 6
2 were scored heavy, 2 x 3 = 6
The total is 0 + 5 + 6 + 6 = 17.

17 divided by 10 (the number of leaves with scale) = 1.7, the average density of scale infestation.
Multiply 1.7 by 0.5 (50% of the leaves had scale):
1.7 x 0.5 = 0.85 (= 85%).
Divide by 3: 85 / 3 = 28.3, the infestation index.

Based on research at the Hawaii Agriculture Research Center (Osgood and Chang 1994), we recommend treating for scale when the infestation index reaches 6. In the example above, it is clear that the orchard has a scale problem that may lead to yield losses, and a spray program should be started.

gauze beneath the plastic is to wick away water that might injure the bark; it also serves as a barrier to ants going beneath the sticky strip. It is essential that the sticky trap block the *only* route for ants to get into the tree, because they will find and cross the smallest blade of grass that touches the tree and circumvents the barrier (Reimer 1991).

Black twig borer

The black twig borer (coffee twig borer) (*Xylosandrus compactus*) is not usually a serious pest, although infestations on individual farms can be severe. The tiny, brownish-black, cylindrical beetle was first found in Hawaii in 1961. It is a type of ambrosia beetle, and it attacks both the lateral and vertical branches. Besides coffee, it infests over 110 hosts including avocado, cacao, mango, macadamia, hibiscus, tea, orchids, anthuriums, and other ornamental and forest trees and shrubs.

Typical symptoms of black twig borer are wilting and death of leaves and wood beyond the beetle's entry hole. The wilted leaves frequently stay on the tree but turn dry, and the bark beyond the affected area turns black. The circular entry hole, less than 1/16 inch in diameter, is usually between the last healthy leaf and the first wilted leaf on the dying lateral. Although a single beetle hole may kill a twig, often several burrows are required before the lateral is killed. On the thicker verticals, even heavy infestations do not always kill the branch.

Pregnant females bore into the twig to make a tunnel for eggs and to grow food for the larvae. The female carries a fungus, *Fusarium solani*, which she cultivates within the tunnel to feed her larvae. This fungus produces a toxin that kills the twig and leaves beyond the entrance hole. This beetle generally attacks trees weakened by drought, girdling, heavy pruning, standing water, or lack of fertilizer. Some coffee cultivars are more susceptible than others.

The best control is maintaining healthy trees. Infested laterals should be pruned behind the last entrance hole as soon as wilting is observed, because new adults will emerge in a few weeks. Pruned laterals should immediately (the same day, if possible) be chipped, burned, or buried to kill the beetles and young. Simply cutting off the wilted lateral and leaving it in the orchard will not kill the adult or young—they will leave the lateral and move to another tree (Jones and Johnson 1996). Imidacloprid as Admire® or Provado® may provide control.

Minor insect pests

The Mediterranean fruit fly, or medfly (*Ceratitis capitata*), is not a serious pest of coffee. As late as 1913, medfly caused serious damage to coffee in Kona, but a parasitic wasp was introduced to attack the medfly's larvae. Cherry loss to medfly is not a problem today, although coffee is a preferred host of the insect. Many cherries will have medfly larvae or maggots in them, but the few maggots in the cherry do not negatively affect tree productivity or the taste of the bean. Medfly eggs are not laid until the cherry has attained its maximum size and its seeds, the beans inside the parchment, are already mature; thus only the pulp is affected.

A new species of crab spider, *Gasteracantha* sp., with webs that are a nuisance and a bite that is slightly painful, was discovered in Hilo in 1986. It spread to Kona and became a nuisance in coffee orchards by 1988. CTAHR and Hawaii Department of Agriculture entomologists found that populations of this pest fluctuate drastically. Solutions of a household soap such as Wisk® sprayed on the spider helped control it; however, Wisk is not labeled for this use. Crushing the spider's green-to-yellow, quarter-sized egg masses also helps. A parasitic wasp reduces the population.

The Fuller rose beetle (*Pantomorus cervinus*) is not a serious coffee pest in Hawaii. The beetle first reached Maui in 1894 and spread to all islands to inhabit elevations from sea level to 5000 ft. Its hosts are avocado, coffee, citrus, koa, rose, corn, sugarcane, gardenia, and hilograss. The beetle feeds at night by eating large pieces from around the edges of leaves. The damage is different from that of the Chinese rose beetle, *Adoretus sinicus*, which eats small holes within the leaf margin. Sometimes adults attack young shoots and flower buds. The larvae live in the soil and eat small roots. The adults, all females, cannot fly, and they live in crevices and under dead leaves on the ground during the day. They lay pale yellow eggs covered with a spongy white material in bark crevices. When the eggs hatch, the larvae drop to the ground and bury themselves. The life cycle from egg to adult takes less than a year.

The West Indian flatid (*Melormenis antillarum*) is also not a serious coffee pest. First found in Hilo in 1967, it is now found throughout the state, although it is more commonly seen on coffee in dry areas. The adult is powdery gray and has square wings with one large dark spot on each wing. It feeds on a wide range of hosts, including castor bean, hibiscus, eggplant, mulberry, and tangerine.

Diseases and nematodes

The major coffee-growing regions throughout the world have serious diseases such as coffee rust (*Hemileia vastatrix*) and coffee berry disease (*Colletotrichum coffeanum*) that require costly control measures, but these diseases are not present in Hawaii. They are described at the end of this section (see also Trujillo et al. 1995).

State regulations require a permit and fumigation to import green coffee for roasting, and afterward the coffee bags or other containers must be destroyed. Our one-year quarantine on viable coffee propagation materials and Hawaii's isolated location have prevented the introduction of most diseases and pests of coffee. People traveling from coffee areas anywhere in the world to Hawaii need to take precautions if they have been at a coffee farm or mill. Washing your clothes and hair *before* arriving in Hawaii is recommended.

Coffee nematode decline caused by the Kona coffee root-knot nematode

A serious disease of coffee has occurred in the Kona region in recent years, characterized by the occurrence of individual or clustered, poorly growing or stunted coffee trees. Initially, it was referred to as "transplanting decline," "replant problem," "nutritional stress," and "Kona wilt." CTAHR plant pathologists have determined that it is caused by a new species of root-knot nematode, named *Meloidogyne konaensis*. Nematode entry and feeding within roots disrupts plant growth processes and causes growth decline, so infection by them is considered a plant disease (see Schmitt 1996, Serracin et al. 1999). Root-knot nematodes are the most harmful of the extremely small, parasitic roundworms known as nematodes, although the burrowing nematode, which is also found in Kona, is also a pest of coffee.

Root-knot nematodes have been a misunderstood problem on coffee in Kona for many years. Coffee trees have died at CTAHR's Kona Research Station and on some farms. At the station, in the infested area, CTAHR researchers assessed four rootstocks and two cultivars of coffee for performance in the presence of root-knot nematodes. It was determined in 1991 that the nematode on the station was a new species. Subsequent surveys revealed that at least four farms in the Kona area were infested with this new species. The nematode was described and named in 1994.

Experimental evidence proved that the Kona coffee root-knot nematode is damaging to the 'Guatemalan' variety. It was calculated that the damage threshold is about 1.5 nematode eggs per 250 cm^3 (approximately 1 cup) soil. At the level of 150 eggs, 20–40 percent of the roots were galled and up to 44 percent of the roots were rotted.

Tolerant rootstocks are a promising means of nematode control. In a field infested with the Kona coffee root-knot nematode at the Kona Research Station, most rootstocks tested (including *C. arabica* var. *purpurascens*, *C. congensis*, *C. liberica* var. *dewevrei*, and *C. kaffe*) suppressed populations of the nematode better than the susceptible 'Guatemalan' cultivar. The *dewevrei* selection was especially effective in reducing the nematode population and has been named Fukunaga and released by UH-CTAHR (see Bittenbender et al. 2001). The grafted trees grew vigorously, and the rootstock had no detectable effect on cupping quality. In a subsequent experiment in which yields were collected, the grafted treatment yielded about 10 times more than seedling 'Guatemalan' in the nematode-infested orchard.

Limited amounts of Fukunaga seeds are available to growers or nurseries for growing mother trees to produce seeds for rootstocks, although buying grafted plants is recommended. The grafting procedure is fairly simple but tedious because the plants are grafted at a very young age. The rootstock seeds are planted 2–3 weeks before the scion seeds. The best time to graft is after the rootstock seedlings and scion seedlings have germinated and before or just after the cotyledon leaves emerge from the parchment coat. A Fukunaga seedling is cut in half with a razor blade, and the stem is split less than ¼ inch (5 mm) to make a cleft to receive the scion. A 'Guatemalan' seedling is the scion, which becomes the top of the new grafted plant. It is cut in half, and the razor blade is used to make two angled cuts to form a wedge at the bottom of the stem. This wedge is then gently pushed into the cleft in the top of the Fukunaga seedling, so they fit together. The two parts of the new plant are held in place with vegetable grafting clips (see Sources, p. 2) for a few weeks until the graft union has formed. After grafting, the seedling flat should be covered with clear plastic to prevent drying and kept out of direct sun. Once the grafted plants begin to grow, they can be planted in plastic or paper sleeves like any other seedling to grow until they are ready for transplanting into the field. More informa-

tion on this topic is available from CTAHR as a video (Bittenbender 2002) and a document (Nelson et al. 2002).

Commercially available nematicides do not significantly help recovery of nematode-infected or declining coffee trees, they are expensive, and they are not registered for use on coffee in Hawaii. Nemacur®, a nematicide, was evaluated by CTAHR nematologists. It was applied bimonthly at 0.5 pounds a.i./acre for two years on trees damaged by the Kona coffee root-knot nematode. The nematicide treatments gave little or no improvement in yield. Other nematicides based on organic products such as fungi or plant products (e.g., sesame) are becoming available. These products have not been tested on coffee and probably require a lengthy period of use before good nematode control is realized, if at all.

CTAHR's Agricultural Diagnostic Service Center assays soil for nematodes and identifies them, for a fee. If nematodes are present, consider the full range of management options. These options include the use of grafted plants on Fukunaga rootstock, which is tolerant of nematodes; weed control; nutrition and water management; organic soil amendments; growing coffee under shade; etc. (see Serracin et al. 1999).

Cercospora leaf spot (brown eyespot), *Cercospora coffeicola*

Cercospora fungus is found in coffee-growing areas worldwide. It is common in Hawaii but not economically important. Good growing conditions, sufficient air circulation, adequate fertilization, and irrigation if necessary to prevent drought will normally prevent the problem. Copper fungicides registered in Hawaii are necessary only in a serious outbreak. Symptoms appear as small chlorotic spots that expand to 3⁄16–5⁄8 inch in diameter on leaves. The outer portion of the leafspot becomes brown; the center becomes gray-white. The spot's eye-like appearance distinguishes it from other leafspot diseases. Spots can occur on the cherries, appearing as sunburn, a black, dried, elliptical scar on the skin. These make the cherry difficult to pulp and may reduce the green bean quality. The disease is favored by high humidity, rain, warm temperature, and drought stress after flowering. Exposed, unshaded trees and nursery seedlings are most susceptible.

Recommendation:
Buy plants from a nursery that produces seedlings on raised benches in a soilless media, or one using sterile soil. Do not use *pulapula* (volunteer seedlings). If you want to grow your own plants, do not use field soil to start new seedlings. If planting into an old coffee orchard, have a soil assay done for nematodes.

Diseases not found in Hawaii that could be accidentally introduced

Coffee leaf rust, Hemileia vastatrix

This fungus is the most widespread, serious coffee disease everywhere except Hawaii and Australia. Symptoms are yellow-orange lesions under the leaves; the lesions may grow together. Tiny spores (seeds) produced by the lesions give a dusty appearance to leaves. Spores are spread by wind, rain, coffee bags, and clothing and hair of people in the area. Control is by quarantine, copper fungicides, and resistant varieties. Hawaii already has a quarantine. Kocide® (copper hydroxide) is already registered in Hawaii to control coffee rust. Resistant varieties have been imported by CTAHR and the Hawaii Agriculture Research Center. If this disease should reach Hawaii, prompt destruction of infected plants may stop it from spreading. If you suspect that you have observed this disease, it is important to report the symptoms to the Hawaii Department of Agriculture or your CTAHR Cooperative Extension Service agent immediately.

Coffee berry disease, Colletotrichum kahawae

The aggressive strain of this fungus is found only in Africa. Other less dangerous strains, such as *C. gloeosporioides*, known as anthracnose, are widespread, even in Hawaii. The initial symptom is brown, sunken lesions on green cherries. Spore-producing bodies appear as very small black dots in the lesions. The lesions grow, covering the green cherry and causing it to shrivel and blacken, destroying the bean. The dried, shriveled cherries may drop or hang on the tree. These are not the dried cherries that occur with overbearing

dieback. Flowers can also be infected. The ability of the fungus to remain dormant for a long time in healthy plants and shriveled cherries makes detection and destruction of all infested plants impossible. Quarantine remains the best control. Hawaii does not allow the import of any green bean or coffee plant parts from African-grown coffee for roasting or production. If you suspect this disease, which is not known to be in Hawaii, it is important to report the symptoms to the Hawaii Department of Agriculture or your CTAHR Cooperative Extension Service agent immediately.

Growth and fruiting habit of the coffee tree

The coffee tree has two distinct types of branches: vertical (orthotropic) and lateral (plagiotropic). The first shoot emerging from a seed becomes a vertical. As the vertical grows, lateral branches grow from buds produced at leaf axils (the node or base of each leaf) on the vertical. Normally, two laterals (rarely, three) are produced at each node on the vertical. Below each lateral branch are other buds that may develop into vertical branches under certain conditions. The basic difference between vertical and lateral branches is growth habit. Verticals always grow upward, producing laterals once at the nodes and thereafter only new verticals at those nodes, if the conditions are favorable. The trunk is an old vertical. Laterals grow horizontally and produce leaves, flowers, and new laterals.

As the vertical elongates, two laterals are produced at each new node. The elongation of the vertical and lateral branches is most rapid during the summer months. During cool or dry months without irrigation, growth stops. When new growth resumes, the vertical will grow taller, while the laterals, in addition to growing longer, will produce new laterals on the previous season's growth. These lateral branches that grow from the main or first side-branches are called *secondary laterals,* while the main side-branches that grow at the nodes of the verticals are called *primary laterals*.

As the cycle is continued, the primary laterals produce more secondary laterals, and the secondary laterals themselves produce additional branch laterals: *tertiary laterals*. These will in turn produce further side-branches if the tree is left unpruned. For the sake of convenience, all laterals with the exception of the primary laterals are usually called *sublaterals*. Thus, as the coffee tree gets older, the main vertical becomes surrounded by a mass of intertwined and crossed sublateral branches.

Flowering and fruiting occur at the nodes of the laterals and rarely on the verticals. Under normal conditions, flowers are produced only once at each node. Fruits (cherry) on the verticals are few and inconsequential, while good fruits are produced at every node on the bearing wood of the laterals if sunlight is adequate; heavy shade results in a node with few or no flowers.

Coffee trees grow taller and wider by the growth of both the verticals (taller) and the laterals (wider) (see Fig. 2, p. 26). The new growth on laterals is called *growing wood*. Fruit clusters appear at the nodes of this new growth during its second year, when it becomes known as *bearing wood.* While fruit is maturing on the bearing wood, new growing wood for the next crop is being produced at the end of the lateral. The size of the next crop will depend upon how much growing wood is produced during any given year, or, more exactly, on the number of new nodes on laterals.

Because the growing wood is being produced while the fruit is maturing, the tree is taxed for nutrition simultaneously by the growing wood and the developing fruit. As a result, when the tree is overloaded with fruit, very little growing wood is produced. Because the next year's crop is produced on this year's growing wood, overbearing during one year results in a small crop the next year.

On the other hand, if the crop is small this year and the tree is able to produce more growing wood, the result will be a larger crop next year. This tendency of bearing a heavy crop one year and a light crop the following year is commonly called *biennial bearing.*

Recommendation:
The number of verticals considered to be most effectively productive is four to six.

Pruning

Careful pruning of coffee trees is one of the most important cultural practices. Improper pruning can reduce yield and subject trees to biennial bearing, often resulting in *dieback,* when leaves, fruit, laterals, and sometimes verticals die before harvest due to exhaustion of nutrients, particularly N, and depletion of carbohydrates in the tree due to overproduction of fruit. The farmer must prune correctly for efficient annual production and healthy trees.

The principle objectives of pruning are (1) to control biennial bearing through control of flowering and fruit setting; (2) to regulate the age of the bearing portion of the tree by training and shaping it into a predetermined form or pattern, and (3) thereafter to maintain the tree in a young and productive condition.

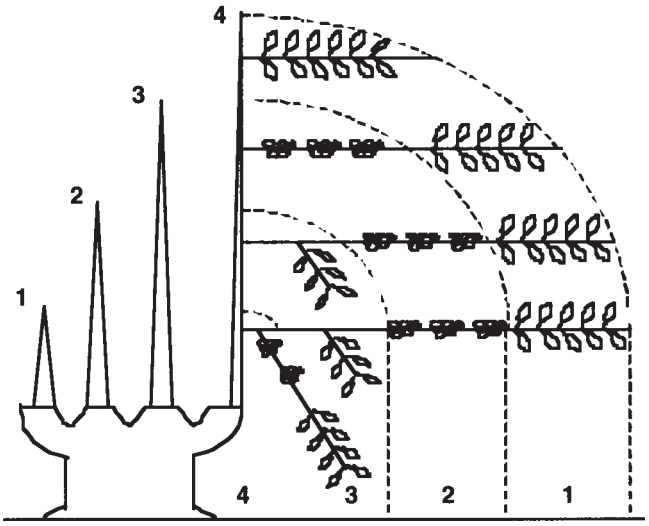
Three pruning systems are currently practiced in Hawaii: (1) "Kona style," (2) the Beaumont-Fukunaga (BF) method, which is the standard in much of Latin America and is becoming popular in Kona, and (3) the mechanically hedged and topped system (HAT) used on large coffee farms on Molokai, Kauai, and Maui.

"Kona style" pruning

"Kona style" pruning, the most popular pruning style in Kona (Fig. 2), is a multiple-age vertical system. If done properly, it accomplishes the objectives of pruning mentioned above in addition to admitting light to various parts of the tree, encouraging the type of growth and fruiting that will permit easiest hand harvest with the least reduction of yield, encouraging the production of uniform, high-grade coffee cherry, and facilitating the effective control of insects. On the negative side, annual hand pruning is required, and a good understanding of the system is essential to select the appropriate verticals for removal. This system cannot be mechanized except to use chain saws and power loppers instead of hand tools.

The number of verticals to be maintained on each tree depends on several factors, including the inclination of the farmer, soil fertility, planting distance, sunlight, rainfall, and other factors affecting the growth and fruiting habits of the trees. There may be as many as 10 or as few as four verticals on each stump, as determined by these conditions.

Figure 2. Diagram of a coffee tree pruned in the "Kona style" with four verticals, ages 1 to 4 years old, on an old trunk. Dotted lines show different ages of growth on primary laterals on the 4-year-old vertical: 1 is first-year growing wood, 2 is second-year or bearing wood (note the cherries), 3 is third-year wood that is producing sublaterals, 4 is the 4-year-old portion of the oldest lateral that has a sublateral with bearing and growing wood.



Two variations of the "Kona style" system described below are known as the "four-vertical 1-2-3-4 type" and the "six-vertical 1-2-3-4 type."

Training for the "Kona style" system

Two methods of transplanting can be used. In the first method the upper half or third of the seedling is removed when transplanting into the orchard. A second method is to transplant the seedling at an angle of 10–30 degrees. Both methods force the production of new verticals.

First year: During the first year the objective of training consists of selecting and developing two to four strong and vigorous verticals and removing all others. The number of verticals allowed to grow depends on the vigor of the plant.

Second and third year: Remove any suckers (new verticals) developing on the trunk or on the selected verticals.

Fourth year: The tallest vertical, or the one which appears to be the oldest, should be removed at the trunk

during the winter or spring. Allow one or two new verticals to develop during the year.

Fifth year: Remove one of the remaining old verticals to make room for one or two new verticals.

Sixth year: Remove one or two of the remaining old verticals and allow new verticals to develop. This will just about start a new cycle of pruning.

No vertical should be allowed to remain on the stump longer than five years under the multiple-age vertical system, with four years generally considered the best time for removal.

Four-vertical 1-2-3-4 "Kona style"

This is the simplest variation of a multiple-age vertical system (Fig. 2). The trunk of the tree may be of any age (some in Kona are 100 years old). *Four verticals only* are allowed on the stump at one time. The system is maintained by cutting the oldest vertical each year about 3 inches from the trunk and allowing a new one to replace it, thus completely renewing the verticals every four years. Any suckers that grow on the trunk or selected verticals are removed as well.

This system enables the farmer to keep approximately the same bearing surface on the tree year after year, and it will produce about the same size crop annually. The trees are relatively certain not to suffer from the problem of biennial bearing and possible dieback.

Calendar for a four-vertical "Kona style" example.

Vertical number	Removed after the harvest in year	Removed again after the harvest in year
1	1998	2002
2	1997	2001
3	1996	2000
4	1995	1999

Vertical 1, which replaced a four-year-old vertical after the last crop was harvested in the fall of 1998, will be left on the stump until 2002 when, after harvest, it will itself be replaced. Vertical 2, which replaced a four-year-old vertical in 1997, would be two years old in 1999. It will be replaced at the age of four years in 2001. Vertical 3, which replaced an older vertical in 1996 and would be three years old in 1999, will be replaced after harvest in 2000. Vertical 4 is four years old this year, 1999, and will be replaced after harvest of the current 1999 crop.

Six-vertical 1-2-3-4 "Kona style"

Six verticals are maintained in this system. These are replaced on a systematic basis in the manner of those in the 4-vertical system, however, two verticals are replaced every other year, and one in each alternate year. The system is recommended for trees planted at distances of 9 x 9 ft or wider in sunny areas that have adequate rainfall and high fertilization.

Calendar for a six-vertical "Kona style" example.

Vertical number	Removed after the harvest in year	Removed again after the harvest in year
1 and 2	1998	2002
3	1997	2001
4 and 5	1996	2000
6	1995	1999

Time of pruning

Pruning is most profitably and effectively done from just after harvesting through the semidormant period, January through March. This holds for all of Hawaii's coffee areas, as the tree is semidormant due the cooler temperature and shorter daylength of our winter months.

When the harvesting season continues throughout the year, as in upper elevation (cooler), rainy areas where seasonal changes do not affect regular seasonal characteristics in flowering and fruiting, it may be necessary to prune at various times. Under these conditions, old verticals may be removed by sawing through them partially and bending them over without completely severing them. The sawing should be done just before a given round of harvesting. This will allow the cherries on the partially severed verticals to mature while new verticals develop just below the point of sawing. After the cherries on the cut verticals have matured and been harvested, the verticals may be completely severed and removed from the tree.

Removal of suckers

It is important to remove unwanted young verticals, called "suckers," which the farmer does not wish to

develop into bearing verticals. This can be done when the suckers are 3–6 inches in length, at which time they can easily be pulled off. If smaller, they can simply be rubbed off with the palm of the hand. In Kona, these unwanted branches grow most prolifically during the rainy months of April to August. The usual practice is to remove them every other month during this period. This is a *must* for the "Kona style" pruning, but it is usually not necessary in hand-pruned Beaumont-Fukunaga systems after the first year. Removal by hand is not feasible in mechanical pruning systems. Suckers low on the trunk are killed by postemergent, contact herbicide applications (e.g., Gramoxone®) when controlling volunteer coffee and weed seedlings.

Relationship of rainfall, fertilization, and pruning practices

The following discussion of factors affecting yield applies to the "Kona style" system (Goto and Fukunaga 1956); the application of this information to mechanized pruning systems is still being studied.

Rainfall, irrigation, fertilizer application, and pruning practices are all closely related to coffee yield. A major goal is to have regular annual bearing, avoid overproduction and the resulting biennial bearing pattern, and discourage conditions that result in overbearing dieback. The amount of fertilizer and the degree of pruning to be done are determined to a large extent on the basis of rainfall during the preceding and current crop years, as well as last year's yield and the current crop load.

If the previous crop was small and rainfall was heavy, in the current year the tree can be expected to have a lot of bearing wood. To prevent overproduction, both the amount of fertilizer applied *and* pruning should be heavy. By fertilizing heavily and pruning off an adequate amount of bearing wood, the tree is provided a food supply to develop the current crop and a reserve supply to support a moderate yield in the following year. If, on the other hand, the tree was allowed to fully utilize all its bearing wood during the current season, there is danger of overproduction, severe dieback, and an unprofitably light crop the following season. Dieback will reduce the crop for several years and in severe cases may even kill the trees.

If the orchard has suffered from low rainfall during the current year, resulting in light growth of bearing wood and exhaustion of stored plant food, pruning for the following year should be light. The bearing wood that developed during the preceding year is light, and therefore the crop will be light.

If rainfall is normal, the trees tend to develop new wood excessively. The amount of fertilizer should be reduced accordingly, thus limiting vegetative growth, preventing overproduction in the following year, and providing against the occurrence of overbearing dieback.

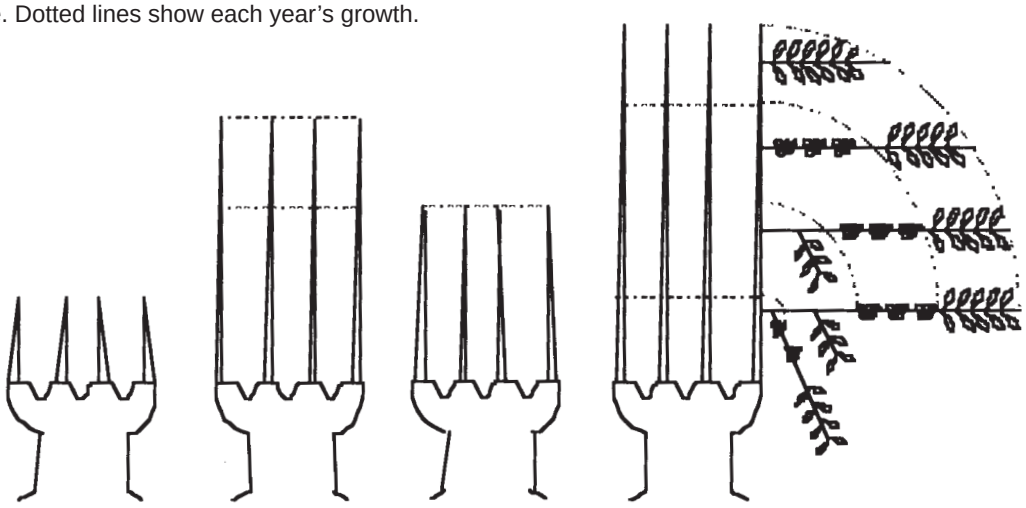
The avoidance of overbearing dieback—resulting in biennial production, lower production, and even tree death—is the chief aim of pruning. The farmer must carefully appraise the size of the crop and the amount of vegetative growth during any given year in order to determine the degree of pruning and amount of fertilizer to be applied the following year. The schedule shown below is a guide for regulating fertilizer and pruning programs to attain consistently moderate yields, which are in fact the *best annual efficient crop yield.*

Each coffee tree in an orchard has individual characteristics that must be taken into consideration. This diversity demands flexibility in the application of the pruning method. Very rarely is this style of pruning applied uniformly to every tree in an orchard. Each tree is managed according to its characteristics. The good farmer knows each of his trees well.

Pruning schedule to prevent biennial bearing

If last year . . . wood growth was	and the crop was	This year . . . Prune	Fertilize	Growth will be	Crop will be
Heavy	Light	Heavily	Heavily	Moderate	Moderate
Light	Heavy	Lightly	Moderately	Moderate	Moderate
Moderate	Moderate	Moderately	Moderately	Moderate	Moderate

Figure 3. The Beaumont-Fukunaga (BF) system, a multiple-same-age vertical pruning system, is a four-year system at harvest. The diagram below shows the arrangement of rows in a planting in a nonmechanized, nonirrigated situation (in a mechanized, irrigated system, the stages would be applied to blocks rather than rows). The tree at far left was pruned in early spring, new verticals were set. The tree at far right will be pruned to the trunk in the spring after harvest. All verticals on each trunk are the same age. Dotted lines show each year's growth.



Beaumont-Fukunaga (BF), a multiple-same-age vertical pruning system

This system was developed at the Kona Research Station by John Beaumont and Edward T. Fukunaga in the 1940s and 50s. Its initial popularity in Kona diminished, but it became widely used in Central and South America. In the 1990s, the Beaumont-Fukunaga system is being tried again in Kona. Instead of renewing one or two verticals in each successive year as in the "Kona style," all the verticals on the tree are renewed in the same year every 3–5 years (Fukunaga 1959).

The BF pruning system has three variations: the four-year/four-row 1-3-2-4 (Fig. 3), the three-year/three-row 1-2-3, and the five-year/five-row 1-3-5-2-4. All verticals on the trunk are removed at one time; in other words, the tree is cut (stumped) 18–24 inches above the ground, usually with a chain saw. This height is for ease of desuckering and harvesting by hand. If the trees are mechanically harvested, we currently recommend the cut should be above the height of the catching pans to reduce dropped fruit. The number of verticals allowed to develop on each trunk may vary from three to six, depending upon the spacing of the trees in the row (usually 2½–6 ft). In Kona, where the distance between rows is 7–10 ft, this row-pruning sequence is 1-3-2-4 and is repeated across the orchard. Because the rows are usually spaced less than 10 ft apart, pruning is done in alternate rows, which results in more efficient interception of sunlight. Shading is reduced because with the 1-3-2-4 pattern the rows with the tallest verticals (the 3- and 4-year-old verticals) are not side by side.

Usually, the trees produce many suckers in response to stumping. The number of suckers allowed to become verticals must be limited to three to six, depending on the tree spacing. If this is not done and there are too many verticals, the first harvest after pruning will be small because there will be few flowers per node due to shading within the tree. Yields in subsequent seasons in the remaining cycle of those trees may also be smaller.

When the suckers are about 12 inches tall, reduce their number to about 1½–2 times the final number desired on each trunk. This can be by hand (gloves are recommended) or with a hand pruning tool. Remove suckers that are weak, deformed, or low on the trunk. The suckers selected should be spaced evenly around the trunk to reduce shading.

When these verticals are 18–24 inches tall, which is usually by May–June, remove any new suckers and thin the verticals to the desired number—plus one extra—per trunk. The extra one is to replace any lost due wind or other damage. This is important in windy areas or if the final number verticals per trunk is low (three or four). This second round of desuckering and thinning should be done with hand pruners to avoid ripping the bark. If this operation is delayed (for example, until November or December), shading may have caused new laterals to die or a low number of flower buds to form.

Remove the extra vertical left as a safeguard against wind in August–October. Remove any new suckers. After this stage, there should be sufficient shade to prevent or retard the growth of new suckers.

In the 3-year cycle system, the pruning sequence is 1-2-3. In the 5-year cycle, the sequence is 1-3-5-2-4. Row 1 is stumped in the first year, row 3 is stumped in the second year, row 5 is stumped in the third year, row 2 is stumped in the fourth year, and row 4 is stumped in the fifth year. The 4-year cycle is recommended for higher elevations, and the 3-year cycle is most suitable for lower elevations. Orchards planted to dwarf cultivars such 'Red Caturra' or red or yellow 'Catuai', or located in cloudy areas, may perform better with the 5-year cycle.

Calendar for a 1-3-2-4 BF pruning system example.

Row number	Prune after the harvest in year	Prune again after the harvest in year
1	1995	1999
2	1997	2001
3	1996	2000
4	1998	2002

BF system for mechanized farms

The Beaumont-Fukunaga system for mechanically pruned and harvested orchards is modified compared to orchards pruned and harvested by hand. The trees can be stumped with rotary saws on a rotating arm mounted on a tractor (see Sources, p. 2). Or, a mechanical harvester can be rebuilt with fixed rotary blades. Several passes are generally required, plus passes with a tractor-mounted chipper to mulch the prunings in place.

Suckers can be controlled by "burning" them with a spray of a highly concentrated foliar nitrogen fertilizer, such as urea ammonium nitrate (UAN, 32-0-0) or a 25–50 percent urea solution. Another method is to use a postemergence, contact herbicide such as Gramoxone® during the standard weed control program. Do *not* use a systemic herbicide, such as Roundup®, for sucker control—it will seriously damage or even kill the tree.

The objective in pruning with contact herbicide is to spray weeds (including volunteer coffee seedlings) in the row as well as suckers on the trunk. On one side of the row, direct the spray from the ground to close to the top of the trunk; on the other side, spray lower, from 6 inches below the top of the trunk to the ground. This results in an area where the suckers are allowed to develop, and elsewhere the suckers are killed. Several sprays will be necessary, and they should be started when the suckers are 3–6 inches tall, particularly when using the concentrated fertilizer solution, which will not kill larger suckers. Do not spray in windy conditions, unless using a shielded sprayer with fan or herbicide nozzles. Practice on a row to see how it works before spraying all the trees.

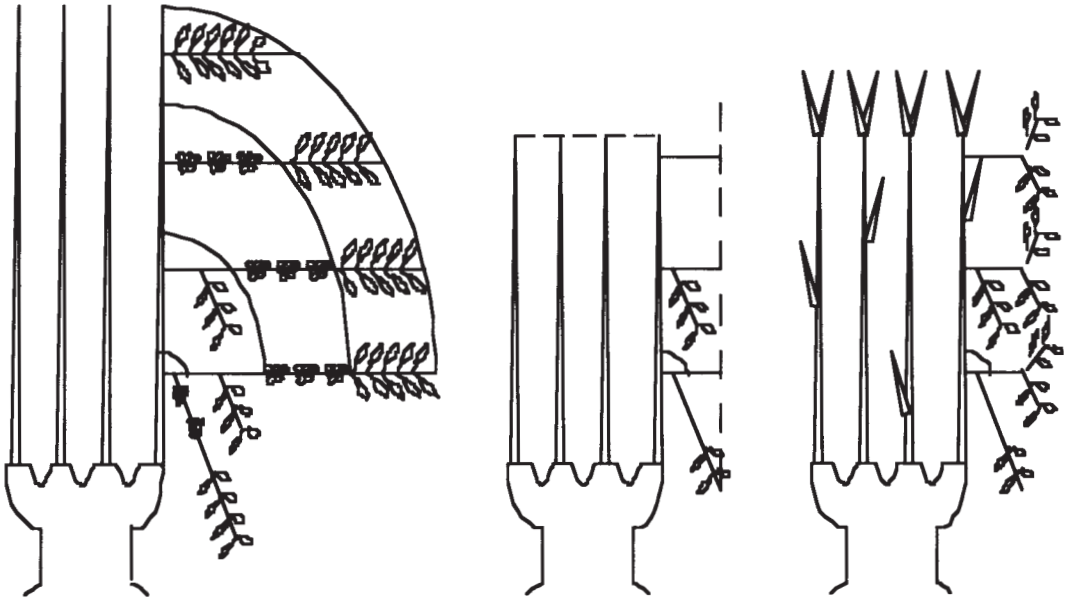
Pruning should be done by block instead of by row. An orchard is divided into three blocks for a 3-year cycle, four blocks for a 4-year cycle, and five blocks for a 5-year cycle. The advantage of blocks over rows is that irrigation, fertilizer application, weed control, harvesting, and other cultural practices can be managed more efficiently in blocks of rows rather than in alternating rows within a block. Also, unnecessary travel in the alleys between rows is avoided.

Advantages of the BF system

Some of the advantages of the BF system are

- Simplicity of pruning. All that is necessary is to completely remove all verticals on the trunk in the prescribed rows each year. After the cycle is established, rows with the oldest verticals are stumped each year. Verticals can be removed with large hand loppers, pneumatic or hydraulic loppers, light-weight chain saws, or tractor-mounted circular saws. Laterals can easily be cut from the verticals and left under the trees, or the debris can be chipped with a chipper or flail mower and used for mulch to add organic matter to the soil and possibly reduce weeds and soil compaction.
- No annual desuckering. Because the verticals are upright, few suckers are produced on them. After the new verticals are set in the first year, no desuckering is necessary, even if suckers grow.
- Ease of starting an orchard. In the "Kona style" system, the trees must be started with more than one vertical, but in the BF system it does not matter if the trees have one or more verticals before the first stumping.
- No propping of the verticals during the harvest season. Because the new verticals develop in the open without shading by older verticals, the verticals are thicker and stronger, provided the number of suckers allowed to grow into new verticals is not excessive.
- Ease of harvest. Fewer rows are harvested, as trees

Figure 4. Mechanically hedged and topped system (HAT). The tree at left, before spring pruning, was originally stumped (BF style). The middle tree, after pruning, has dashed lines showing where hedging (5 ft wide) and topping (5 ft tall) cuts were made. The tree at right shows regrowth; note excess growth of new verticals at the topping cut; these will be cut again in the summer.



in the first year of the cycle have no crop. Trees are shorter, and fruit is on primary laterals.

- Yields may be higher. A 1-3-2-4 cycle over a five-year period in the mid-1950s averaged 15,000 pounds of cherry per acre—well above today's average for Kona.

Mechanically hedged and topped system (HAT)

Tall and dwarf varieties can be hedge-pruned. Hedging can be done for hand-harvested coffee, but the long-term yield and ease of harvesting may be less than with the "Kona style" pruning, although in a three-year comparison it was superior (Bittenbender 1996). For mechanically harvested orchards, or when sufficient labor is either lacking or too expensive, the HAT system performs well (Fig. 4).

A sickle-bar type hedge pruner that is hand-held or mounted on a tractor can be used. Special rotary saw blades mounted on a frame or on a rotating arm can be used (e.g., the TOL pruner; see Sources, p. 2). The appearance of the hedge after pruning with rotary blades is not as "tidy" with a sickle bar, as some branches will be left uncut. Saws are more robust than sickle bars, as leaning verticals can jam a 2-inch sickle bar. The tree is cut horizontally (topped flat) at 5 ft in height. This can be done with the same equipment, unless the verticals are too thick for a sickle bar. Pruning can be done after harvest, up to May. Which year to prune in is based on the tree size and expected yield; if too tall or wide to easily harvest and the crop will be small, then prune.

The hedging will stimulate the regrowth of sublaterals. The topping will bring light into the center of the tree, resulting in the production of new verticals on remaining old verticals but particularly at the top near the cut. New primary laterals will be produced on these new verticals. In summer, the tree should be topped again near the first topping to further encourage production of new sublaterals. Yield in this year will be small in most cases.

In years 2, 3, and 4, the trees are topped after flowering just below the highest fruit set, or limited to 12–18 inches of new top growth. It may also be advantageous to lightly hedge (tip) the sides to further encourage the production of sublaterals or if the crop load is very heavy, particularly in year 2.

When the trees need pruning again, probably in three to fours years, hedge again at 5 x 5 ft. Trees pruned with this system have produced good yields for 10 years (three cycles). The BF (stumping) system is a more

radical approach to tree rejuvenation and may be necessary after several cycles. Research to further refine mechanical pruning is in progress.

Advantages of the HAT system

- This is fastest method to prune a large acreage.
- Once a tractor-mounted sickle bar is purchased, the labor cost is fairly low.
- Training is minimal; the operator is given a target height and width and cuts a straight line.
- Prunings are mulched where they fall and can be chipped with a rotary or flail mulching mower because they are of smaller diameter than with the BF system.

A Kona coffee field managed in a Beaumont-Fukunaga style pruning system, ca. 1956.

Harvesting

Quality is of key importance in the specialty coffee trade. If Hawaii is to hold its place in the coffee market, it is imperative that we be competitive and provide a top-quality product. The paramount consideration in maintaining coffee bean quality is that, when picked, the beans in fully ripe coffee cherries are as good as they will ever be. There is nothing that can be done to improve the quality of a cherry or its beans after harvesting. The farmer must grow the best quality. Only carefully applied cultural practices can achieve this end.

When hand-harvesting, only ripe coffee should be picked. Immature, overripe, and raisin (dried-on-the-tree) cherries are of inferior quality. Overripe cherries are soft and brown, and when they are squeezed, the individual seeds can be felt inside the fruit because the pulp and mucilage is gone. The "black bean defect" results from a cherry that rotted because it was repeatedly dried and rewet while on the tree. This is something that is more likely to happen in Kona or wet areas than in dryer areas.

In the lower part of the Kona coffee belt, coffee ripens from late August to December. The period from late September to early November is the busiest. By contrast, in the extreme upper (cooler), wet and cloudy section of Kona, the harvesting period can stretch throughout the year. The new coffee areas on Kauai, Molokai, Maui, and Oahu ripen from August to January. Any area being considered for coffee planting should have climatic conditions (a definite dry period) that will permit seasonal harvesting, rather than a long 8–10-month harvesting period, which requires labor throughout the year and costs proportionately more to manage. A long harvest period is the least efficient use of harvest labor, but it can be a useful strategy if the orchard is small and low-paid labor (family) is available in regular, short periods.

When the cherry has matured and is ready for picking, it usually turns from green to slightly red and then to glossy red when fully ripe. However, fruits of yellow-fruited varieties such as 'Yellow Caturra' or 'Yellow Catuai' remain yellow and do not turn red when fully ripe or even overripe. Another test for maturity for harvesting is if the seeds (the parchment coffee with bean inside) can be squeezed out by hand. If the fruit is hard and the seed cannot be squeezed out, the fruit is too immature to pulp. Under conditions of overbearing dieback, the fruit may turn from green to reddish brown. These fruits are usually smaller than normal and probably contain immature, low-quality beans; these fruits generally float and are removed during processing.

Coffee fruit on a tree does not mature all at once—several stages of cherry development will be found on a tree. Therefore, coffee harvesting practices differ in various parts of the world. Cherries are sometimes picked individually when ripe, as is done in Kona. Else-

Recommendation:
Harvest only ripe cherries, and maintain quality by processing as soon as possible using proper processing methods.

where, fruits of all stages of development are stripped at one time. Another strategy is that all cherries are allowed to become raisins and are stripped from the tree or gathered from the ground after they have fallen or been shaken down. In the machine-harvested areas of Hawaii, cherries of all stages, from green cherry to raisin, are harvested in single or multiple-pass harvests. Mechanical harvesters remove immature, ripe, and raisin cherries. These three products must be separated to ensure a highly uniform, quality product at roasting. Raisins are floated away, while the mature cherries sink in water. Immature or green cherries are separated from the ripe ones by a device called a classifier. Thus harvested cherries can be separated into three different parchment coffee products of differing quality.

In Kona, picking in four to eight rounds in any one season is common, with a month's interval between each picking. The number of rounds depends to a large extent on the elevation. In upper areas of Kona, the coffee is ripening almost the year around, while in lower areas, ripening occurs over a period of four months. Sometimes pickers are permitted to harvest three types of cherry: green-ripe, or mature green, which is mature coffee although not fully ripe and has a yellowish-green skin; hard-ripe, which is firm and red (or yellow); and soft-ripe, which is overripe, red to dark red, soft, and juicy. These three types, or what might be called ripeness stages, were noted as early as 1937 to have similar cupping qualities in tests conducted at the CTAHR Kona Research Station. However, a danger in picking the green-ripe cherries must be noted: at this stage, the beans are not sufficiently covered with mucilaginous coating to allow them to slide between pulping surfaces during the pulping process. Injury to the bean can thus occur, which will lower the quality of the pulped beans. This also applies to overripe and raisin fruits.

At the peak of the harvest season in Kona, experienced pickers gather between 200 and 400 pounds of coffee per day. To ensure quality, pickers must be instructed not to harvest immature cherry. There is a tendency for pickers to harvest immature cherry as the amount of coffee increases and the number of pickers available per harvest acre decreases.

Hand-harvesting equipment

The equipment needed for hand-harvesting coffee is simple and inexpensive: baskets for the individual picker, holding hooks for bringing branches into position for picking, and burlap bags for transporting cherries from the orchard to the processing area.

Coffee pickers in Hawaii in the past used baskets locally made from pandanus leaves; today, woven baskets are imported from Central America, and plastic baskets are also used. The capacity of these baskets is generally about 20–25 pounds of berries. The baskets may be suspended from the shoulder or fastened with a belt around the picker's waist.

The holding hooks are usually made of 3–4-foot long sticks of coffee or guava wood to which a cord is attached. The length of the cord is adjusted to the picker's height, in relation to the average height of the trees. The sticks are usually about 1½ inches in diameter at the thickest end. A loop of wire tied onto the cord affords a place for the picker's foot, which can be inserted to hold the hooked branch in place while the picker removes coffee with both hands free. The hook-end may be simply the stump of a branch or a metal hook screwed into the stick. The picker must be instructed not to bend branches to the breaking point.

Mechanical harvesting

The coffee harvesters used in Hawaii in the late 1990s are manufactured by Korvan Inc. (see Sources, p. 2). Harvesters can be leased or purchased (cost is about $100,000). Harvesters from other manufacturers were tested in the late 1980s and early 1990s. The Korvan is a three-wheeled, self-propelled machine that straddles the row with finger-thick rods attached to 6½-ft high spindles. Two multi-rowed spindles with fiberglass or nylon rods are carried on the harvester so that about half of each spindle's rods contact and enter the alley side of the coffee hedgerow. The rods vibrate, and the entire spindle turns as the harvester passes along the row. The vibrating rods knock off cherries directly and shake the laterals and verticals, which shakes off more cherries.

The cherries are collected at the base of the harvester on spring-loaded pans that form a "false floor" beneath the tree as the harvester moves over the tree. Cherries are diverted to conveyor belts that move them past fans, which blow off leaves and sticks, and deposit the cherries into a bin. The bin is emptied at the end of the row, and the cherries are taken for processing.

If all stages of cherry maturity—green, ripe, overripe, and raisin—are on the tree, the harvest will re-

move a certain percentage of each. These percentages vary with the cultivar and the tree's moisture status, as well as harvesting factors (type of harvester rod, harvester speed, and frequency of rod vibration; see Gautz 1999). In general, mechanically harvested cherry has percentages of the various maturity stages in the order raisin > overripe > red > green.

Ethephon®, which breaks down to ethylene, a natural plant hormone, is being registered for use on coffee. When sprayed on coffee trees at the appropriate time and concentration, it will increase the percentage of ripe cherries on the tree and reduce the force necessary to knock off ripe cherries. The Hawaii Agriculture Research Center is developing recommendations for using Ethephon. CTAHR has submitted the residue data required for registration with the EPA; final approval is expected in 2001.

A hand-held, air-powered, six-fingered harvest aid with fingers that open and close like a hand is being evaluated by some growers. The Spidy® knocks off cherries, and the fruit is collected from mats spread beneath the trees. All maturity stages of cherry are removed, and they must be separated to maintain quality.

Yields

In the second year after transplanting, a few hundred pounds per acre of cherry coffee will be produced in well managed orchards. When the price is low, farmers do not harvest this first crop, but at high prices, farmers may harvest and sell this small crop profitably.

In the third year**,** with optimum rainfall and good management of fertilizer and weeds, production may be in the neighborhood of 80 bags per acre (8000 pounds) of coffee cherry.

In the fourth year**,** 100 bags of cherry coffee can be produced under typical Kona conditions. The authors have observed similar yields on mechanized farms in dry areas, but we cannot predict such yields in wetter, cooler, cloudier areas elsewhere in Hawaii. The record at the CTAHR Kona Research Station is 196 bags (19,600 pounds) of coffee cherry per acre.

Processing

Structure of the coffee fruit

There are two distinct processing methods, dry and wet, and both methods are used in Hawaii. The dry method is used at a few of the small farms in Kona, and at the more recently established large coffee operations, on raisins or fresh cherries, which are dried whole without pulping. They are milled when thoroughly dried to remove the dehydrated pulp, parchment skin, and silver skin in one operation. The product is green coffee, ready for grading and bagging, and is often called "natural coffee."

The wet method is used throughout the state, and particularly in Kona. It involves the removal of the pulp, fermentation of the mucilaginous material covering the parchment skin, rinsing, and then drying. Most countries producing mild coffee use the wet method. A variation of the wet method is mechanical demucilization. The Fukunaga (CTAHR) hydro-pulper is an example of a machine for this purpose (see Fukunaga 1957).

The first step in wet processing is to remove the outer skin of the cherry and the pulpy flesh beneath it. This flesh and the fruit skin are collectively called the "pulp" after their removal in a process called "pulping."

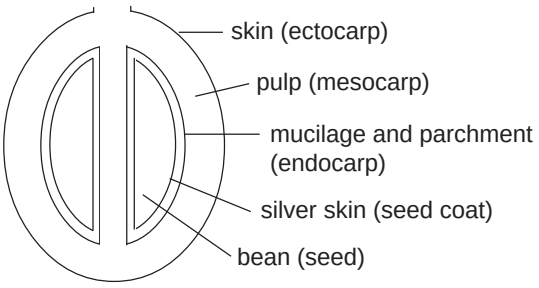
Beneath the fruit flesh is a layer of slimy, mucilaginous matter, and beneath it is the parchment skin, a very tough, almost shell-like coating that is difficult to remove. The mucilaginous layer is removed after the harvested cherries are pulped, either by natural fermentation during soaking or by mechanical means. Coffee beans when dried and ready for milling are covered by their parchment skin and are referred to as "parchment coffee."

Beneath the parchment skin and covering the coffee beans is a thin membrane called the "silver skin"; a small portion of this skin is usually found on the cleft of the bean after hulling. After hulling the bean is referred to as "green coffee."

The coffee cherry normally contains two beans (its seeds), which are flat on one side and develop in the center of the fruit with the flat sides facing each other (Fig. 5). When only one bean is produced in the fruit, it is round and called a "peaberry." In rare instances, three beans develop that are roughly triangular in shape.

Cherries are processed as soon as possible after harvesting to avoid deterioration of the bean. Another

Figure. 5 Diagram of a coffee fruit. The coffee fruit is called a "cherry" because it roughly resembles the popular stone fruit in its shape, size, and deep red color (of the red-fruited coffee varieties).



reason for rapid processing is to control loss of bean weight. After the cherry is picked, it begins losing moisture. If the cherry is sold by weight and it is not delivered quickly, then weight and therefore dollars are lost. The beans are also losing weight due to physiological respiration. The rate of weight loss is greatest during the fermentation process, when from 3 to 4 percent of the weight of green coffee is lost. If the coffee is completely processed within 24–36 hours instead of over a period of several days, as is the case in "dry processing," as much as 6 percent of the bean weight can be saved.

Care of harvested coffee before pulping

One of the chief causes of quality deterioration in coffee in Hawaii is decomposition of the cherry pulp before pulping. Detrimental effects occur when harvested cherries are left in bags or boxes for more than 24 hours. If the mucilaginous coating protecting the bean decomposes before pulping, the bean can be mechanically damaged in the pulping process. Without mucilage, the beans will not slip through the pulper grooves and may be nicked, scratched, or chipped by the rough surface of the pulper drum. Beans with mucilage stuck behind ones that are not slippery can also be damaged. The mucilage layer deteriorates when the cherry pulp is allowed to ferment by becoming overripe on the tree or by delaying pulping after harvest.

Also, heat generated by fermentation of the pulp causes the bean to respire and ferment, resulting in weight loss and discolored, sour beans. The sour characteristic of fermented beans is one of the worst defects.

Flotation is recommended before pulping to separate immature, dried, and overripe cherries, which will float, from the better quality ripe berries, which sink. The floaters are pulped separately.

Recommendation:
Pulp coffee on the same day it is harvested, within 12 hours if possible. Never delay pulping more than 48 hours after harvest. If overripe cherries are present in the harvested coffee, the pulping must be done immediately. Never leave bagged cherries on the roadside or in the pulping house for more than a day.

Pulping

Drum-type pulpers are commonly used in Hawaii; other types are disc and rubber-breastplate pulpers. The drum pulping machine consists of a drum about 1½–2 ft in diameter that revolves at high speed. The drum exterior surface is roughened. As the drum revolves, coffee cherries are forced between the rough surface and a fixed plate; the cherry is squashed, and the beans are separated from the pulp. The pulp is then ejected from the pulper. The space between the drum and the plate, through which the pulp is carried out of the machine, is not large enough to accommodate the beans, however. Accordingly, grooves are provided in the plate through which the beans can move, facilitated by the slippery, mucilaginous coating on the parchment skin, which is abundantly present when the cherry is fully ripe. The beans that slip through these grooves are ejected out of the opposite side of the machine from the pulp.

Pulping systems used with mechanical harvesters generally remove raisin cherries by flotation and use a classifier-type pulper that separates hard, immature cherries from mature ones. The cherries pass through a cage with bars spaced to permit beans but not cherries to pass between. Soft, ripe cherries are forced through the bars, but hard, immature cherries pass through the cage and exit at one end.

Recommendation:
Be sure your pulper is in top operational condition for the season by inspecting, adjusting, and repairing it before harvest time.

The pulper should be thoroughly cleaned and overhauled every year. It is advisable to adjust every operating part of the machine to avoid bean damage. For example, if one defective point in the pulper were to nick or otherwise damage one bean per revolution, the pulper could damage six pounds of parchment coffee per hour in a small-capacity pulper (Goto and Fukunaga 1956).

Demucilaging

After pulping, the mucilage covering the parchment must be removed before drying. The slimy mucilage is insoluble in water and very difficult to dry. When mucilage-coated beans are dried in an oven or on a drying floor, the mucilage will reabsorb moisture and become sticky afterward. Sun-drying mucilage-coated beans takes a long time because the coating picks up moisture each night. Drying without removing the mucilage is advocated by some equipment manufacturers in Brazil, where the humidity is lower.

Two methods are used in Hawaii to remove mucilage: natural fermentation and mechanical demucilaging. Natural fermentation is the most common. Freshly pulped coffee is placed in a fermentation vat where bacteria and fungi decompose the mucilage to a soluble material that is readily washed off with water. This method works best at a temperature of between 80° and 90°F. Too high a temperature will ruin the quality of the coffee, while too low a temperature will retard fermentation.

The fermentation vat is usually made either of wood (generally redwood), concrete, fiberglass, or stainless steel. A benefit of wood is that it holds more of the heat generated by the fermentation process. The temperature gradually rises without artificial heating, but steam can be introduced into the vats as a means of warming the fermenting beans.

The vats are usually 4 ft deep, 4 ft wide, and 6 ft long. They should be cleaned and washed thoroughly after each batch of coffee is fermented, in order to remove all undesirable odors. As the coffee comes out of the pulper, it falls into the vat. It is important that a relatively large volume of coffee be placed in the vat, so that heat from fermentation will not dissipate as soon as it is generated, in which case it will take longer to complete the process. When the vat is half full, about 14–18 hours will be required to complete the fermentation. The length of time required also depends on the prevailing temperature, and the process is faster when the nights are warm. Experience will teach the processor to judge the approximate amount of time it takes to complete fermentation of a given amount of coffee in the vat under familiar temperature and other conditions.

Caution: If the beans are left in the vat too long after fermentation is completed, the coffee may be ruined.

The fermentation must be stopped as soon as the mucilage is completely broken down. This can be determined by a very simple test: wash a handful of the beans from the vat in clean water. If they are no longer slippery, the fermentation is complete.

In the fermentation process, the action of certain bacteria and fungi breaks down the mucilage into simple sugars and proteins. After completion of this breakdown, putrefying bacteria begin to multiply on the dissolved protein compounds, and the beans should be removed and washed because they will absorb odors if left in the vat too long. The putrefying bacteria also can affect the proteins in the bean itself, and their access is made easier when the bean has been damaged by the pulper. This can result in discolored beans with a foul odor, known as "sour beans," which can ruin the quality of an entire batch. Therefore, the beans should be washed with clean water as soon as the fermentation to remove mucilage is complete. The water is drained off the beans by a "shaker" machine equipped with a framed screen bottom. As the beans are being shaken, they move toward the drying platform or dryer. Clean water is sprinkled on them as they move, washing them as clean as possible.

The pulper, the fermentation vats, and the shakers should be completely cleaned of coffee beans after their operation is completed. Any beans left will ferment and become sour before the next batch is processed. One sour bean per pound is a serious defect.

Mechanical demucilaging

Several types of commercial coffee demucilaging machines are available. Hydropulpers use water under high pressure, while other types use moving plates or brushes and the action of the beans moving past each other to wear off the mucilage. The mucilage on the coffee bean can be removed even more rapidly if the demucilaging machine is adaptable to using heated water (110–120°F).

The "Fukunaga" demucilaging machine was developed at the CTAHR Kona Research Station in the 1960s, but it was never commercialized. However, new pulping and demucilaging equipment is continually being developed and sold by various coffee equipment manufacturers. For example, the coffee research organization of Colombia's coffee industry, CeniCafe, recently developed a low-water-use demucilaging system, which uses only 2–5 percent of the water required for the standard wet method in Colombia. CTAHR is in the process of evaluating it with grower-processors in Hawaii to determine the effect on cupping quality.

Drying

As soon as the beans are demucilaged and washed, they are dried either by sun-drying or in artificial dryers. A combination of the two is most popular.

Sun-drying

On small coffee farms in Kona, drying is often done on platforms called *hoshidanas*. The beans are spread evenly over the drying area and turned over periodically. Provision is made to protect the beans from rain, usually with movable roofs over the platforms. Operations in the newer coffee-growing areas of Hawaii use fixed or movable clear plastic roofs or tunnels with fans for ventilation. In Kona, it takes from four to six days to completely dry coffee beans when sunny weather prevails. If the weather is cloudy, it takes much longer. The thickness of the layer of beans on the drying area also affects drying time. A layer 1–1½ inches deep should be turned three to four times a day.

Artificial drying

The use of mechanical dryers is becoming increasingly popular. The beans can be placed in the dryer right after washing. Alternatively, sun-drying and artificial drying can be combined, first drying the beans on a drying floor for 24–48 hours or longer, then finishing them in the mechanical dryer.

The rotary drier is the most popular of several types in use. It consists of two concentric, perforated drums mounted horizontally on the same shaft. The outer drum is closed at the ends, while the inner drum is open at one end. Beans are placed between the two perforated drums. Hot air is forced into the inner drum through the open end while the drums are rotating. The hot air enters the coffee chamber through the perforations of the inner drum. The heated air picks up moisture and escapes through the perforations in the drums.

Stationary dryers have enclosed, shallow trays with screen bottoms. Coffee is placed on the tray, and heated air is forced through the coffee via the screen bottom. Drying towers or vertical dryers steadily move the coffee down through shelves as dry air moves up through the coffee.

Air to dry coffee can be heated by solar or fuel-based methods. Heating may be either direct or indirect. In direct-type heaters, the heated air is blown directly through the coffee. Only efficient, high-pressure, nozzle-type burners should be used for this type of heating. Gas is a good fuel for direct-type heaters, because gas normally burns clean and without objectionable combustion products. In indirect heaters, the heat is extracted by a stream of air in a heat exchanger. With these, any type of burner can be used, because the coffee is not contacted by directly heated air and fumes. However, good design of the heat exchanger is important to its efficiency, otherwise considerable heat may be lost up the chimney.

The temperature and air volume are very important factors to consider. The most important principle in artificial drying is that heat should be introduced at a low temperature at first and gradually increased, particularly if an early model of rotary dryer is used. When possible, sun-dry for a day before using a dryer; otherwise, use a starting temperature of 95°F and gradually raise it to 140°F.

Overheating ruins the quality of the coffee. If the beans are heated to above 150°F, the coffee loses its aroma. Another danger in overheating, especially when the moisture content of the bean is fairly high at the

Recommendation:
The most effective temperature for drying coffee beans in rotary-type dryers is 135–140°F. A lower temperature of about 130°F is preferable in stationary-type dryers. Lower temperature protects the coffee from heat damage, but drying time is prolonged. All heaters should be equipped with thermostats to control the temperature of the drying air.

time it is subjected to excessive temperature, is a condition called "case-hardening," when the outer surface of the bean dries too fast, causing a hard shell to form. The interior of the bean then becomes difficult to dry, because moisture has difficulty in escaping through the hardened shell. Such beans, even when they look completely dry, often cannot be milled (hulled) because the interior of the bean is still soft. Even if milling were possible, spoilage would likely occur.

To be safe, the temperature of the incoming air should be less than 150°F. Some coffee dryers can be operated at higher temperatures, and it is important to check the manufacturer's operating instructions.

The volume of air introduced to a dryer should be sufficient to prevent any condensation on the walls of the dryer or on the beans near the air intake. Condensation at the outlet is common. Insufficient air causes "sweating," condensation of moisture on the surface of the bean, which results in poor quality coffee.

The moisture content of the beans after washing varies from 50 to 55 percent, depending upon the amount of surface moisture. Dry beans should have a moisture content of about 12 percent, roughly, from 11 to 13 percent. Beans with a moisture content higher than 13 percent will turn an opaque white during storage. Such beans are poor quality and will be downgraded.

When parchment coffee is just removed from the fermentation tank, the beans are soft and light green. As they begin to dry, their color turns to dark amber. As they dry further, it turns back to a light green, hence the name "green coffee." The beans should be hard at this stage. They may be tested for hardness by biting. If they are not quite dry, they will "give" when bitten. If they are dry, they will break if bitten hard enough (although teeth will probably break first!).

The dryness of the bean, whether dried in the sun or by artificial means, should be checked from time to time. This may be done by removing a handful of the parchment coffee and rubbing it between your palms. If the parchment does not rub off, the bean is not sufficiently dry. It is a good practice to peel the parchment off a few beans to more accurately examine their condition. Electronic moisture meters can determine moisture content of both parchment and beans in a few minutes. However, the most accurate reading is obtained five hours after removal from the dryer. By then, the beans have cooled, and the moisture content throughout the bean is uniform. By recording the difference in moisture soon after removal from the dryer and then five hours later, you can determine how much to adjust the first reading. Otherwise, follow the manufacturer's instructions.

Underdrying will cause quality loss. Overdrying will result in weight loss. However, it is safer to overdry than to store underdried coffee. Properly dried parchment coffee can be stored for from several months to years depending on the humidity and temperature. In the past, there was demand for "aged" coffee, parchment coffee that had been stored for a few years before roasting, during which time the green color faded. Today, many specialty coffee buyers reject faded coffee.

Milling and grading

Coffee is processed only to the parchment-coffee stage on some farms. The parchment coffee is then sold to a larger plantation or to a miller who mills (hulls) the coffee. Some farms today have their coffee "contract milled" and "contract roasted" and sell their green or roasted coffee as "estate coffee." Large farms frequently do all their processing, including roasting, although most coffee is sold as green coffee.

During hulling, the parchment and silver skin covering the green bean are removed. Several types of machines are available for hulling. After the parchment skin (hull) is removed, considerable amounts of silver skin are still attached to the green bean. The amount of silver skin remaining on the bean depends on the coffee cultivar and its growing and processing conditions. In Kona, for example, silver skin on coffee grown at lower elevations is generally harder to remove than the skin on coffee grown in the upper areas. Coffee is frequently "polished" to remove all the silver skin and give the coffee a more attractive, smooth, shiny appearance.

Grading

The hulled coffee beans are separated according to size with mechanical graders. The peaberry type beans are also separated from the flat beans. Peaberry coffee generally commands a higher price in the specialty coffee trade, because it is believed to have superior flavor. Some people claim that each peaberry has twice the flavor of a single bean because peaberries occur when only one seed instead of two develops in the cherry. Peaberries may result from poor pollination, boron deficiency, or when one seed dies.

Grading is done by first separating the beans according to thickness. This is done by "screening" the beans through parallel bars that are closer together at one end than the other. The coffee is dropped into the narrow end of the screen, and the flatter beans fall through first, while the thicker ones fall last. Peaberries also drop out last, together with the largest beans. After grading through parallel bars, the beans are further separated into sizes through screens with round-holed openings of various diameters. Peaberry coffee beans generally are of smaller diameter than the flat beans, and they go through the screen with the smallest holes.

In Hawaii, green coffee is separated by state administrative rules into six grades and five geographic regions: Hawaii (state of Hawaii), Kauai (island), Kona (North and South Kona districts on the island of Hawaii), Maui (island), and Molokai (island). The grades are Extra Fancy (screen size 19), Fancy (screen size 18), No. 1 (screen size 16), Select (any screen size), Prime (any screen size), and Hawaii No. 3 (any screen size). The screen sizes are in 64ths of an inch and apply to "Type I" beans that do not pass through round holes of the specified sizes; "Type II" beans (peaberry) have different size requirements.

Hawaii's grading is based not only on size but on cleanliness, defects, moisture content, color, roasting quality, and aroma and flavor when brewed. Green coffee graded No. 3, regardless of origin, may only be labeled Hawaii No. 3 coffee. Off-grade green coffee may be exported but must labeled OFF-GRADE COFFEE. Grading and certification of green coffee is conducted for a fee by officers of the Hawaii Department of Agriculture, Commodities Branch, P.O. Box 22159, Honolulu, HI 96823, telephone (808) 973-9566, fax (808) 973-9565. For the most recent standards and rules, contact the Commodities Branch or see the Web site <http://www.hawaiiag.org/hdoa/qad_comm.htm> and refer to Chapter 4-143, Standards for Coffee.

To raise the quality of size-graded green coffee, various procedures are used to separate out the imperfections. Imperfections, including shells, "quakers" (immature beans), stones, etc., have different specific gravity (heaviness, or weight per unit of volume) than normal beans and can be separated mechanically. Various types of machines are used to cull out the lighter and heavier beans, but air separators are most common. Imperfections such as sour beans and black beans cannot be separated by specific gravity differences, but electronic optical sorters can separate the coffee according to color.

After hulling and grading the coffee, it is bagged and shipped. Coffee is usually not roasted before long-distance shipping, because roasted coffee will not store as long as green coffee. However, one-way gas valves on foil bags have greatly increased the shelf life of roasted coffee. Green coffee can be stored for several years if storage conditions are cool and dry.

Processing summary

Because harvesting and processing are, after proper cultural practices in the field, the key to quality coffee, the following summary is presented with the intent of emphasizing essential steps in both of these key production areas.

- Pick only ripe cherries, or completely separate green cherries and raisins from the ripe cherries.
- Pulp preferably within 24 hours and no more than 48 hours after picking. Storage of cherries in bags or boxes for longer than 24 hours will result in fermentation in the cherry and deteriorated quality.
- Overhaul the pulper annually before the harvest season, and always keep it in good working condition.
- Remove shriveled, dry, and overripe coffee through flotation before pulping.
- Mechanical demucilaging immediately after pulping will decrease the loss in net weight that occurs during fermentation.
- The use of a clean wooden vat filled nearly full with coffee beans is recommended for effective fermentation. A clean vat is essential.
- Wash beans with clean water before drying.
- Dry coffee thoroughly either by sun, artificial means, or a combination of the two.
- If artificial drying is done, never heat beyond 150 °F. It will ruin the coffee. The best temperature range is between 135 ° and 140 °F.
- After drying, hull, grade, and bag carefully for marketing.

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Conversions from U.S. measure to metrics

In most cases, measurements in this book are given in the units most commonly used in the USA. For the convenience of other readers, the following conversions are provided.

1 inch = 25.4 mm = 2.54 cm
1 foot (ft) (12 inches) = 30 cm
1 pound (lb) = 0.454 kg
1 ounce (oz) = 28.4 g
1 acre = 0.4 hectare
1 lb/acre = 1.12 kg/ha
1 ton/acre = 2.24 tons/ha (2240 kg/ha)
1 gallon (gal) = 3.78 liters
1 square foot (sq ft) = 0.093 m^2
1 gal/acre = 9.35 liters/ha
1 pound/square inch (psi) = 6.89 kPa
1 mile/hour (mph) = 1.6 km/hr