

The background of the entire cover is a close-up photograph of avocado flowers and leaves. The leaves are large, dark green, and have a prominent vein pattern. The flowers are small, light green, and clustered together. Some flowers are in full bloom, showing yellow stamens, while others are buds.

Second Edition

Avocado Production in California

A Cultural Handbook for Growers

Book One – Background Information

Technical editor: Gary S. Bender, Ph.D., Farm Advisor

A joint publication of:

The University of California Cooperative Extension, San Diego County
and The California Avocado Society

Supported by the California Avocado Commission

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TABLE OF CONTENTS

Chapter 1
***History of the
Avocado Industry
in California***
Page 1



Avocado Production In California

Chapter 2
***Avocado Botany
and Commercial
Cultivars Grown
in California***
Page 19



A Cultural Handbook for Growers

Chapter 3
***Avocado
Flowering and
Pollination***
Page 33



Book One- Background Information *Second Edition*

Chapter 4
***Avocado
Rootstocks***
Page 45



Chapter 5
***Site Selection,
Road Engineering
and Erosion
Control***
Page 55



Chapter 6
***Planting the
Avocado Tree***
Page 65



Book 1

Chapter 1

History of the Avocado Industry in California

Authors: John S. Shepherd and Gary S. Bender

Discovery of Avocado in the New World

Avocado is native to the New World, originating in southern Mexico, Central America and the West Indies. The fruit has long been used as a food by Native Americans in these regions and was known by the Aztecs as “ahuacatl”. Avocado was first mentioned in print in the report *Suma de Geographia* by Martin Fernandez de Enciso, published in Spain in 1519 (Popenoe and Zentmyer 1997). He observed the fruit growing in what is now Santa Marta, Colombia during an expedition with the Spanish explorer Juan de la Cosa. A more extensive description of avocado was written by Gonzalo Fernandez de Oviedo (1478-1557), historian for the conquistadors traveling with expeditions led by Hernando Cortez in 1519. His account was published in 1526 in the *Summario de la Natural Historia de las Indias*:

“They are large trees, with broad leaves similar to those of the laurel, but larger and more green. They bear pears weighing a pound and even more, though some weigh less, and the color and shape is that of true pears, and the rind somewhat thicker, but softer, and in the center of the fruit is a seed like a peeled chestnut...and between this and the rind is the part which is eaten, which is abundant and is a paste similar to butter and of very good eating and of good taste, and such that those who have these fruits guard them and esteem them highly and the trees are wild as are the others which I have mentioned, for the chief gardener is God, and Indians apply no work whatever to them. These pears are excellent when eaten with cheese, and they are gathered before they are ripe and stored, and when treated thus they ripen perfectly for eating but after they have reached this stage they spoil quickly if allowed to stand.”

The Spanish name, Aguacate, was first used in 1550 by Pedro de Cieza de Leon (1518-1554), Spanish conquistador and historian, in a journal of his travels. (The Spanish apparently couldn't pronounce the Aztec name ‘ahuacatl’. ‘Ahuacatl’ in the Aztec language meant ‘testicle’, most likely because of the shape of the avocado fruit.) He noted that at that time the avocado grew in Panama, Ecuador, Colombia, and Peru.

Avocados were encountered continuously by various explorers during the sixteenth century from Ecuador and Peru northward through Central America and Southern Mexico, as far north as Mexico City. Avocados were also encountered by explorers and travelers in the West Indies, although Popenoe and Zentmyer believed that they were introduced to these islands after the Conquest by Spain. George Washington wrote in 1751 that he had tasted “agovago pears” in Barbados as they were popular and abundant in the marketplaces.

In the 1700's the European sailors called avocados ‘midshipman's butter’ because they used them as a spread on hardtack.

The First Plantings in California

The first plantings of avocado in California probably occurred around 1850. It was reported in the California State Agricultural Society Report for 1856 that an avocado tree was grown by Dr Thomas White in San Gabriel (Butterfield 1963). This tree produced no known progeny, but other seedling trees were planted throughout Southern California by people interested in exotic fruit. It is recorded that three seedling avocado trees were brought in from Mexico and planted in Santa Barbara by Judge R. B. Ord in 1871. These trees are generally considered to be the foundation of the avocado industry in California. (Ryerson 1923).

In 1963 Butterfield reported that the oldest living avocado tree in California was probably at the University of California, Berkeley near the creek east of the Center Street entrance. The tree was thought to be a Guatemalan seedling brought to California by Tulio and Pedro Ospina of Guatemala (College of Agricultural Reports, 1879, p.76). At the time of Butterfield's report, the tree had only a few branches left alive.

In 1892, Juan Murrieta of Los Angeles became interested in avocados and brought in a large number of thick-skinned fruit from Atlixco, Mexico. From these he distributed seeds to his friends and he planted the others. From this selection came a number of the first varieties that looked interesting in California.

Nurseryman Kinton Stevens set out 120 seedling trees in Montecito in Santa Barbara County in 1895, establishing the first avocado orchard. The orchard prospered initially but died after several drought years.

Also planted in 1895 was a Mexican seedling given to George A. White for his ranch in Santa Barbara by Francisco Franceschi, an importer of subtropical fruits. In 1940 it was reported that the tree had been bearing since 1900 and, by October, 1937, had grown 56 feet high and had spread over a 50 foot lot. The trunk diameter was 37 inches four feet off the ground (Van Rensselaer 1940).

The first "commercial" avocado orchard of budded trees was planted in 1908 by William Hertrich for Henry E. Huntington on his estate in San Marino, Los Angeles County. During this time the chef at the Los Angeles Athletic Club saved seeds from avocados imported from Atlixco in the State of Puebla, Mexico (Coit 1963). The seeds were given to Hertich, grown in pots, and eventually four hundred seedling trees were planted and later budded to varieties then available. The orchard was heavily damaged by the catastrophic "1913 Freeze", but was rebuilt; a few of the trees still exist on the grounds of the Huntington Library. Other trees that had been planted in various locations in Los Angeles and had survived the freeze fruited well and demonstrated that avocado was adapted to the region (Coit 1963).

J. Elliot Coit reported that he gave fruit to Professor E. J. Wickson at U. C. Berkeley and he "liked it and considered it suitable to grow in home gardens by those who liked it". But, he also said "there was no prospect for commercial culture because it contained no sugar and fruits were supposed to be sweet--the sweeter the better" (Coit 1963).

Despite the remarks by Wickson, the possibility of growing avocado on an extensive, commercial scale began to be discussed. The development of the avocado industry gathered steam after several nurserymen began exploration in some of the best avocado districts in Mexico, and a freak accident (as a result of the freeze of 1913-14) led to the selection of the 'Fuerte' variety.

Development of Superior Varieties

Frederick O. Popenoe, owner of the West India Gardens nursery in Altadena, Los Angeles County, sent his son, Wilson Popenoe, and his employee Carl Schmidt, on collecting expeditions in 1911 to find superior selections of avocado that might be productive in California. Carl Schmidt sought out fruit that looked good in the market places, then tried to follow the trail back to the tree to sample budwood for shipment to California. Schmidt was familiar with the avocados sent from Atlixco and he did most of his collecting in this region. One of the budwood samples taken from a tree in the backyard of Senor Le Blanc in Atlixco was labeled "No. 15" – a producer of fruit of exceptional quality. These buds were grafted onto seedlings at the nursery in Altadena. A devastating freeze in the winter of 1913 killed most of the avocado trees in the nursery, however "No. 15" survived. A batch of 50 nursery trees of the hardy new No. 15 variety were reluctantly accepted by grower John T. Whedon in lieu of varieties ordered earlier, but frozen in the nursery. F. O. Popenoe, noting their hardiness for having survived the freeze "named them 'Fuerte' after the Spanish word for strong" (Poole and Poole 1967).

"The Fuerte trees were planted on Whedon's place near Yorba Linda (Orange Co.) on March 12, 1914, thereby establishing the first orchard of the cultivar that would come to be for many years the industry's

principal, market-preferred variety—the variety, indeed, upon which the California avocado industry was built, and that was introduced and grown successfully in many other countries” (Shepherd 1991).



The Parent 'Fuerte' Tree in the Garden of Alejandro LeBlanc, Atlixco, Mexico, December 1918

This small orchard was to prove profitable for Whedon. As described by Poole and Poole, “When his orchard came into production he had standing orders from hotels in Los Angeles and San Francisco who were willing to take all he could ship, paying as much as \$12.00 per dozen. Because of the Fuerte’s cold resistance and high quality fruit, the buds from his trees were in great demand, and in some years, he realized as much as \$6,000 from buds alone (Poole and Poole, 1967).

Other nurserymen also brought in important selections. E. E. Knight of Yorba Linda brought in budwood of superior varieties from Guatemala, including selections that would later be named Queen and Linda (Hodgson 1947).

The United States Department of Agriculture’s (USDA) Dept. of Plant Exploration and Introduction noted that private nurseries could not be expected to do a complete exploration of Mexico and Central America for promising avocado varieties, so they hired Dr. Wilson Popenoe for nine years to do a thorough exploration of all of the known avocado areas. Popenoe introduced many selections but none became as famous as the Fuerte (Hodgson 1947). Hodgson noted that “the avocado growers of California and Florida early had the best that the world affords in the way of varieties upon which to build a commercial industry”, an important contribution from the USDA.



Plant Explorer Wilson Popenoe Ready for a Day's Hunt, 1918

Noting the success of Whedon and others, interest grew in the avocado and soon ten nurseries were growing budded trees. Nurseries were using Mexican type rootstocks because they were abundant and more tolerant of cold weather than the Guatemalan rootstocks. Enthusiasm grew but there was a great deal of confusion concerning varieties; it was soon realized that some sort of organization was required to help make this a successful industry (Coit 1963).

Formation of the California Avocado Association

The first association of California avocado growers began with a meeting on May 15, 1915, at the Hotel Alexandria in Los Angeles. Its most important result was the formation of a California Ahuacate Association for the purpose of "...the improvement of the culture, production and marketing of the Ahuacate". The word "ahuacate" was used because it was the word in common use in Mexico for this fruit. Following spirited debate, **Avocado** replaced **Ahuacate** as the official name of the association *and* the fruit (Shepherd 1991). The word "avocado" was apparently a new word not found in dictionaries at the time, and the Association eventually informed the dictionary publishers of the correct spelling and definition, and that the plural form would be "avocados", not "avocadoes". Coit (1963) noted "It was early decided that any member caught using the detestable term 'alligator pear', then in common use in Florida, should be severely reprimanded".

On October 23, 1915, the first semi-annual meeting of growers was held with Edwin G. Hart as the first president and chair of the Board of Directors. At the end of the year there were 74 members composed of growers, researchers and others interested in avocado. The Association was renamed the California Avocado Society in 1941.

This organization has been the main driving force for variety improvement, grower education and working with the University of California on research solving cultural problems. The California Avocado Society is famous worldwide for its production of useful and informative Yearbooks. The Yearbooks serve as a library of information for growers and researchers in California and worldwide. Over the years the Society has sponsored many grower meetings, and since 1990, the Society has co-sponsored six meetings a year with the U. C. Cooperative Extension farm advisors to present timely cultural and research information to growers.

The Variety Committee

In 1916, nurseryman F. O. Popenoe published descriptions of 86 varieties. Nurserymen and growers were rapidly coming up with new varieties along with "overly optimistic claims", and it was apparent that a variety committee was needed to evaluate the varieties, standardize the names and publish recommendations for

growers (Coit 1963). The Variety Committee, under the auspices of the Association (later the Society) has functioned since this time and provided an invaluable service to growers.

In 1926, Dr. I. J. Condit (with the help of the Variety Committee) published a list of 400 named varieties. In 1933 the Committee revised the list and reduced the number of varieties. In 1936 the Association started a seedling registration. To be registered, the “owner of the seedling suggested a name, which would be adopted and made official by the Association only if it conformed to the rules of horticultural nomenclature”. The name had to consist of only one word (not a verb or adjective), could not have been used previously, and a description of the tree and fruit, its location and owner’s name and address were submitted. One of the problems eventually solved by the Variety Committee was the argument over thin-skinned Mexican varieties vs. thick-skinned Guatemalan varieties. Coit reported the Committee eventually settled on the use of hybrids ‘Fuerte’ and ‘Hass’, each of which had good qualities of both avocado races (Coit 1963).



Store Door Avocado Delivery, About 1915

Organization of the California Avocado Grower’s Exchange

One of the original purposes of the Association was to market fruit, but with high prices (\$0.50 to \$1.00 per large Guatemalan fruit) and a shortage of fruit, growers found it fairly easy to do their own marketing (Coit 1963). By 1922, however, growers were faced with a very heavy fruit set and the Association’s directors decided that the members needed to try cooperative marketing. Arrangements were made with the American Fruit Growers packinghouse in Los Angeles to pack and sell fruit from all of the members on a commission basis. The plan didn’t work because “some members ignored the rules and sold their best grade to old customers and took the low grade and cull fruit to American Fruit Growers.”.

At that point the Association’s board of directors examined the idea of cooperative marketing set up under California law much like Sunkist and the Walnut Grower’s Exchange. By the summer in 1923, it was felt that the crop of avocados in sight made urgent the formation of an organization solely devoted to the marketing of avocados. The California Avocado Exchange was formally established on January 24, 1924 to handle cooperative marketing, and the Association retained all of its previous functions except marketing (Coit 1963). J. Elliot Coit worked as the coordinator between the organizations for the next twenty years, while George B. Hodgkin served as general manager of the marketing cooperative until 1956. The name of the Exchange was changed to Calavo Growers of California in 1927 (Shepherd 1991). In addition to the exchange, a number of independent packing houses developed which gave growers marketing alternatives.



California Avocado Growers Exchange Office and Packing House, Los Angeles, 1925

Introduction of the ‘Hass’ Variety

The green-skinned ‘Fuerte’ was a favored variety by consumers in the early days, but it, and many of the other new selected varieties, was plagued by short harvest seasons and erratic yields. The black-skinned ‘Hass’ variety was selected by a stroke of luck in the 1920’s at the farm of Rudolph Hass in La Habra, California. In 1926 Hass bought Guatemalan avocado seedlings (thought to be of the ‘Lyon’ variety) from the Rideout nursery in Whittier and planted them at his new grove. On the recommendation from Rideout, Hass planted three seedlings in each hole with the idea that the strongest would be grafted and the other two pulled out. The seedlings were to be field-grafted to the popular ‘Fuerte’ variety, but after three attempts, Hass could not get the Fuerte buds to take on one of the seedlings. After the last attempt at grafting, Hass let the seedling tree grow, but the tree was ignored. Hass thought the fruit was ugly, with rough purple-black skin. According to Charles Hass, Rudolph’s son, “My brothers kept telling him, Dad, it tastes great, you gotta try it!” Rudolph eventually tasted the fruit, liked the creamy flesh, the nutty taste, the lack of fiber and the 18% oil content, and the long harvest season. His new selection, which he named after himself, was granted U. S. Plant Patent No. 139 on August 27, 1935. Hass made a deal Harold H. Brokaw, a nurseryman in Whittier, to grow and promote the Hass avocado, but by the time the patent expired in 1952, Rudolph Hass had made only \$4800 on the new variety (Dillow 1996). The original ‘Hass’ mother tree lived in a suburban setting in La Habra Heights until 2002 when it died from avocado root rot disease; the tree was 76 years old. Harold Brokaw’s nephew, Hank, removed the wood from the dead tree and it is now kept in storage and occasionally pieces are used by the California Avocado Society for plaques and other special items.

Market acceptance of the dark-skinned variety was slow as the consumers had learned to recognize “green” as the proper color for an avocado. Steady promotion by packers and growers gradually resulted in increased market acceptance so that, by 1957, ‘Hass’ comprised 15% of the crop in California. By 1972, forty years after its introduction, ‘Hass’ surpassed ‘Fuerte’ in total volume marketed from California. By 1990, ‘Hass’ accounted for 83% of California’s avocado production (vs. only 2% for Fuerte). By the end of the crop year 2010-2011 ‘Hass’ comprised 94.5% of the avocados grown commercially in California.

‘Hass’ is also dominant in the mountainous state of Michoacan, Mexico (the main area in Mexico growing fruit for export) and other subtropical avocado regions in the world, but the variety does not fruit and grow well in the more tropical regions such as southern Florida, the Caribbean islands, and Hawaii. West Indian varieties are more commonly grown in these tropical areas.

Root Rot becomes Epidemic

In the late 1930’s growers began to notice a decline and tree death in some areas of their groves. The problem was called “apoplexy”, “asphyxiation”, “decline”, “melanorhiza” or “waterlogging”. (Shepherd 1991). Finally,

in 1939, a graduate student from South Africa, V. A. Wager, working at the Citrus Experiment Station in Riverside, proved that the cause of the problem was the fungus *Phytophthora cinnamomi*. The California Avocado Society donated \$3700 to the University in 1943 to begin research on this devastating disease. Dr. George Zentmeyer at U. C. Riverside began a comprehensive program in 1948 to study the disease. This work eventually included studies on the life cycle and biology of the fungus, factors affecting disease initiation and development, and all phases of disease control including resistant rootstocks, fungicides, biological and cultural control and disease prevention. Dr. Zentmeyer retired in 1981 but continued to work on avocado root rot research projects and writing until his death in February 2003.



Avocado tree showing the effect of root rot disease

The avocado root rot research program at U. C. Riverside came under the direction of Dr. Michael Coffey during the 1980's, and later under the direction of Dr. John Menge in 1990 and Dr. Greg Douhan in 2006. Emphasis has been on selection and breeding of more tolerant and resistant rootstocks, and biological, chemical and cultural control. Significant progress has been made on the understanding of this disease and several new rootstocks with increased resistance to the disease have been introduced to the industry, but avocado root rot is still the most important disease problem in California avocado production.

Production research funding was dramatically increased beginning in 1972 when the marketing order was amended to create an industry Production Research Committee. Funding for research was continued by the California Avocado Commission (CAC) when the marketing order became inactive. From 1990 until 2000 the CAC contracted with the California Avocado Society to manage the research program. Since 2000, management of the research program has been done by the Production Research Committee of the CAC. Funding for avocado research in 2001 was second only to citrus research funding for industry-sponsored research funding for tree crops in California. Funding from the industry to the University has enabled research on many other worthwhile projects, including breeding, pest control, irrigation, fertility, pruning and post-harvest studies.

Issuance of the Marketing Order

Almost all market development during the first forty years of the industry was done by the growers who had organized, first with the Association then later with the Cooperative, Calavo Growers of California. As the number of independent packers increased and the production increased, it was perceived that an industry-wide program of advertising and promotion was needed for the industry to remain successful. An Avocado Promotion Committee was formed in 1958 and in 1959 a proposal was placed before the growers to apply for a State Marketing Order that would allow for mandatory assessments to pay for promotion, advertising and market development. Calavo growers were opposed to the Order, as were most avocado handlers (Shepherd 1991).

A voluntary program was proposed that would have been managed by the handlers under an organization known as the California Avocado Development Organization (CADO). Funding would come from assessments from

the growers, but it was agreed that 95% of the crop must participate in order to make this industry-wide program work; this level was never reached and the CADO plan was dropped. CADO still exists as a forum for discussion among handlers (Shepherd 1991).

With the failure of the voluntary plan, Calavo and the Avocado Promotion Committee petitioned the California Department of Food and Agriculture to issue a state marketing order, which was approved after hearings in October, 1959. An injunction forced by a small group of handlers delayed the order until October 1961.

The marketing order was managed by a new organization of growers and handlers known as the California Avocado Advisory Board. Their purpose was to design and implement promotion programs funded by assessments on grower receipts. Unfortunately, state marketing orders are often encumbered with bureaucratic problems from Sacramento, so the industry leaders petitioned for the establishment of a commission, which was created in September, 1977 by Assembly Bill 1602. Again, opposition within the industry delayed the operation of the California Avocado Commission until August 1978.

The California Avocado Commission Board of Directors is composed of ten growers of commercial avocados from five districts (2 per district), four handler representatives and a public member. Through innovative promotion programs, the Commission has largely been successful in the introduction and establishment of the avocado to the American diet. Strong demand has been built for the California avocado both in the domestic market and some foreign markets. In recent years the Commission has been faced with many thorny issues, including convincing local bureaucracies that avocado growers can only be successful if they have affordable water, and informing leaders in Washington

D. C. about the dangers of importing potentially insect-infested fruit from Mexico and Central and South American countries.

The Challenge from Foreign Countries

The avocado industry has long been concerned with the importation of avocados from foreign countries. The concerns came from two angles. The first concern was that foreign fruit may introduce new pests or diseases that would be difficult, if not impossible, to control. Second, fruit produced in countries with low labor costs and low water costs (in many cases there are no costs for water) would compete with unfavorable results against California fruit at the marketplace.

During the early fruit explorations in Mexico and Central America, it was discovered that some fruits being sent to the United States contained species of seed weevils that were not known to occur in the United States. On February 27, 1914, the USDA imposed a quarantine on avocados grown in Mexico and Central America to prevent the introduction of seed weevils, stem borers and other pests. Not only did this quarantine keep out the unwanted pests but, as an important side benefit, it allowed the young California industry to nurture and grow without excessive competition. The complete quarantine lasted until 1997 when the USDA decided to amend it and allow Hass avocados from certified “pest-free zones” in Mexico to enter nineteen states in northeastern U.S. and the District of Columbia during the months of November through February. The purpose of the change was to satisfy requirements of the North American Free Trade Agreement passed by Congress in 1994, yet still keep Mexican fruit away from the avocado production areas in California and Florida.

On November 1, 2001, after formal requests by the Mexican government, USDA/ APHIS (Animal and Plant Health Inspection Service) published in the U.S. Federal Register the “Mexican Avocado Import Final Rule” which increased the number of states where Mexican Hass avocados could be distributed to 31 states. The additional states in the proposal included Idaho, Utah, Montana, Wyoming, Colorado, North Dakota, South Dakota, Kansas, Nebraska, Minnesota, Iowa, and Missouri. The Rule also lengthened the time of the shipping season through April 15 of each year. On December 18, 2001, the California Avocado Commission filed a lawsuit in federal court asking that the rule be declared invalid based on phytosanitary issues – namely, the importation of fruit from areas that are known to have seed weevil, stem borers, and/or fruit flies put the California industry at risk.

Mexico was (and still is in 2012), the largest producer of avocados in the world, with production at 940,000 tons in the calendar year 2001. During 2001 the United States was second with 164,500 tons. Other countries included Indonesia (130,000 tons), Chile (120,000 tons), and Peru (89,800 tons). Although avocado production from Mexico is high, the domestic market in Mexico takes most of the fruit.

Other avocado-producing countries, namely, Chile, New Zealand and the Dominican Republic, have access to ship avocados to all states in the U.S. Chile has made the most out of this opportunity. Starting in 1985, Chilean avocado growers began shipping Hass avocados in the fall and winter months to the U.S. in such quantities that California growers no longer found a home for their winter greenskin varieties. In the winter of 2002-03 Chile shipped 157 million pounds of Hass to the U.S., more than a third of the annual Hass production from California. Chile is expected to increase shipments as more of their groves reach maturity, and they are expected to lengthen their season. Industry analysts expect that California growers will only have the summer months to ship fruit without competition from Chile.

Understandably, California avocado growers fear competition from Mexico, but they also fear pest introductions. With rapid movement of goods in the United States, Mexican avocados imported into Utah can be trucked into Los Angeles in less than a day. Avocado consumption in California is much higher than those other states, and fruit tend to get sold and moved to the good markets.

Is there a legitimate fear of pests? California growers have already had to deal with devastating pest introductions from Mexico and Central America. Two of the most important pests were *Persea* mites and avocado thrips, probably introduced in illegal shipments of fruit or plants from infested areas. These pests have been difficult to control since most groves are planted on steep slopes and are difficult to spray from ground equipment. In addition, spraying pesticides usually upsets the delicate biological pest control on which growers rely.

Are there pests in areas where fruit is shipped from Mexico? In a report published in 2001 by the California Avocado Commission, “Nearly 700 fruit flies and 2,120 weevils have been trapped since 1997” in the municipalities approved for shipment of avocados to the U.S. (California Avocado Commission, 2001). The point is made that the McPhail trap used in these pest surveys only catches a small percentage of the pests actually present in the grove.

The Federal Marketing Order – Hass Avocado Board

As more avocados from foreign countries entered the U.S., many California growers began complaining that the assessment paid to the Commission to promote generic avocados were in fact also promoting avocados from Chile and other countries. Growers and marketers were also concerned that, with the increasing foreign fruit in the market, a billion pounds per year could eventually lower fruit prices, possibly forcing an end to production in California. Under the leadership of Charley Wolk, chairman of the California Avocado Commission, the “Hass Avocado Promotion and Research Order” was proposed to USDA to authorize a marketing assessment on all Hass avocados sold in the U.S. The assessment would primarily for promotion and expansion of avocados in the U.S. The Order was approved by a referendum of producers and importers and passed by an 86.6% vote on July 29, 2002. This federal promotion order would be administered by 12 members of a board composed of 7 domestic producers and 5 importers, under the supervision of the USDA. This board was officially seated on March 18, 2003. Producers and importers would pay an initial assessment of 2.5 cents per pound on domestically produced and imported Hass avocados. The money is collected by U.S. Customs as avocados are imported and sent to HAB. Then 85% of the money collected is returned to the avocado associations representing each country for their promotion efforts. Domestic producers also pay 2.5 cents per pound on Hass avocados, of which 85% is rebated to the California Avocado Commission for their use in promotions, research and information for consumers.

The goal of the Hass Avocado Board was to increase consumption of Hass avocados in the U.S. Trade promotions in the U.S., especially in areas that were not consumers of avocados, were successful. It’s a good

thing, because the vision of the California Avocado Commission was correct in that eventually 1.3 billion pounds of fruit were sold in the U.S. market in 2010. The movement of fruit to the markets turned out to be relatively smooth and with the planning by the Hass Avocado Board and the various trade associations, dumping of fruit in the market during Superbowl weekend and Cinco de Mayo was avoided.

The mission of the HAB changed somewhat in 2010 (as reported by Chairman Jim Donovan in the 2010 Annual Report).

“HAB’s mission has always been quite straightforward: To increase consumption of Hass Avocados in the United States.

This means focusing on long-term, demand-building activities rather than on promoting immediate sales, a job that the Californian, Chilean and Mexican avocado communities have done extremely well over the years. In addition and following the direction of our stakeholders, the emphasis on nutrition research and communication continues to expand and now represents almost half of all activities for 2011.

The 2011 Marketing Program reflects this long-term view with three core objectives: 1) to enhance the marketing effectiveness of our stakeholders; 2) to establish a compelling, ever-stronger nutrition research platform; and 3) to provide relevant information and data to facilitate stakeholder decisions.

These three objectives and their supporting activities speak to both our mission and a 2011 marketing budget that is less than half of that available in 2010. Specifically, they steer HAB away from trade promotions – an area of considerable emphasis for our sister associations – and keep the concentration where it belongs: on a sustainable, longterm path toward increasing demand and consumption.”

Following this change in tactics, HAB funded three interesting research projects aimed at providing information for dieticians.

1. A research project at Pennsylvania State University that will evaluate the benefits of one avocado a day on heart disease risk factors beyond the known advantages of monounsaturated vegetable oils.
2. A study at Loma Linda University in which researchers will evaluate whether one half of an avocado a day promotes feelings of fullness and promotes food intake control.
3. Researchers at Ohio State University will determine whether adding one avocado a day to carotene-rich meals enhances fat-soluble vitamin adsorption and promotes cardiovascular health.

In 2012 the Hass Avocado Board represented importers from Mexico, Chile, Peru, Dominican Republic and New Zealand, and domestic producers in California.

Chronology of Selected California Avocado Industry Highlights

1856. Dr. Thomas White first reported planting avocados in San Gabriel, California.

1871. Three seedling avocado trees planted in Santa Barbara by Judge R. B. Ord marked beginning of interest in avocado cultivation in California.

1895. Nurseryman Kinton Stevens planted 120 Mexican-race avocado seedlings on his property in Montecito, Santa Barbara County, to establish the first “orchard” of avocados in California.

1906. First commercial orchard of avocados in California was planted by William Hertich on the estate of Henry E. Huntington in San Marino. Seedlings from avocado seeds collected by Huntington from the Jonathan Club (Los Angeles) were grafted to cultivars favored at the time.

1910. Frederick O. Popenoe founded West India Gardens nursery in Altadena, Los Angeles County.

1911. Budwood of seedlings discovered in Atlixco, Mexico, by Carl Schmidt (employee of West India Gardens) introduced into the United States and propagated by West India Gardens, including No. 15, renamed 'Fuerte' in 1913.

1913, January. Major freeze devastated susceptible plants throughout California, severely damaging avocado plantings and nurseries, including the Huntington orchard and West India Gardens.

1913, March. John T. Whedon accepted from West India Gardens 40 Fuerte nursery trees in lieu of freeze-killed trees ordered earlier, planting them on March 12 to establish the first commercial orchard of the Fuerte variety.

1914, February 27. Quarantine imposed by United States government on avocados grown in Mexico and Central America to prevent introduction of avocado pests not found in the United States.

1915, May 15. California Avocado Association organized at an advertised meeting held in the Alexandria Hotel, Los Angeles.

1923. Formation of cooperative marketing association of California avocado growers initiated by California Avocado Association, motivated by prospective heavy crop on trees. Part-time manager employed (George B. Hodgkin), and organization of "California Avocado Growers' Exchange" accomplished in August. Office established in packinghouse of American Fruit Growers, Inc., 2160 East Seventh Street, Los Angeles.

1924, January 21. California Avocado Grower's Exchange incorporated in California.

1924, May 15. Exchange "on brink of disaster" with over-supply of avocados coming in on top of inventory of softening and decaying fruit. (The 'disaster' was averted.)

1924, June 1. Exchange moved closer to market (1405 East Eighth St., Los Angeles) began direct dealing with buyers, started promotion campaign (publicity, \$200 of purchased advertising, store displays, recipe booklets and leaflets, and recipe bags).

1924. Exchange opened and for six months operated retail avocado store in Los Angeles. Operation continued by private parties.

1925, July. California statutory standard of avocado maturity enacted, requiring minimum of 8% of oil by weight in edible portions of fruit.

1926. Rapid refractometric method for avocado oil content determination officially adopted, replacing earlier time-consuming "soxhlet" method.

1926. Development of avocado ice cream base and avocado sandwich spread initiated by Exchange as products of cooperative research program with University of California.

1926. Program of research on vitamin content of avocado commissioned by University of Southern California.

1926, December 17. First full carload of avocados from California shipped to Chicago. About same date, first half carload shipped to New York.

1927, January 28. First full carload shipment of California avocados shipped into New York market. (Sales report stated: "...the market in the east doesn't want black fruit.")

1927. Successful experimental shipments of California avocados made to London, Paris, and other European markets.

- 1927.** California Avocado Grower's Exchange renamed: Calavo Growers of California.
- 1929.** Tariff on imports of foreign avocados sought by California and Florida growers. (Cuba was a major exporter to the U. S.).
- 1933.** U. S. Customs Court ruled Cuban avocado could continue to enter the United States duty free. Imports of Cuban avocados totaled 7.5 million pounds in the year.
- 1934.** Buildup of latania scale on avocados became a serious problem for California growers, effectively controlled in a few years by natural means.
- 1935.** California avocado crop nearly quadrupled 1934 crop production, under-developed demand resulted in low unit returns and a temporarily demoralized industry.
- 1935.** Board of directors of Calavo Growers of California considered proposal of a marketing order for the California avocado industry and other industry-wide programs, endorsing none but "leaving the door open" for future reconsideration.
- 1936.** Program of regular market-developmental shipments of avocado (small quantities) begun by Calavo Growers of California to England, France, Germany, and Panama.
- 1937, January 8-22.** Low temperatures during the longest cold spell on record caused major damage to avocado fruit and trees in most avocado-growing areas of California. The loss of crop was estimated to be 33%; 3.2% of industry's trees died.
- 1937.** Calavo Growers of California filed a legal brief attacking duty-free entry of Cuban avocados into the United States.
- 1940.** The University of California began a long-term study to ascertain the best method for avocado fruit maturity determination and a proper basis for standardization.
- 1942.** V. A. Wager, South African plant pathologist, identified *Phytophthora cinnamomi* as cause of avocado root rot disease.
- 1942.** Low-cost nutritional values of avocados were promoted-"the five vitamin fruit" – in response to government call for greater production of high-nutrition foods. Biological assay of avocado vitamins was initiated. Experiments were begun for large-scale production of avocado oil in view of war-created shortage of fats and oils.
- 1943.** Nutritional research revealed nine important vitamins in avocado in appreciable quantities.
- 1944.** Comprehensive five division, two-campus "avocado tree decline research" program begun by University of California with financial support by the industry.
- 1944.** George A. Zentmyer appointed to staff of division of plant pathology of Citrus Experiment Station, Riverside, succeeding late Prof. W. T. Horne; thereafter served as principal investigator of avocado root rot disease until retirement.
- 1947.** Extensive experimentation with acetate and foil wrapping of avocado fruit and various coatings initiated. Results were largely negative, and practices were adjudged economically infeasible.
- 1949.** California avocado crop significantly reduced and damaged by a major "freeze".

1950. Pasadena Research Laboratory of the U. S. Dept. of Agriculture announced development of a commercial avocado paste.

1951. Etiolation technique for rooting of avocados successfully developed by E. F. Frolich, University of California at Los Angeles, laying groundwork for commercial propagation of clonal avocado rootstocks.

1951. Frozen avocado paste test-marketed in San Diego. Reception positive, but production problems caused termination of the project.

1957. Representatives of Florida avocado industry filed suit challenging California law requiring that all avocados sold in California contain a minimum of 8% oil.

1958, December. Three-judge federal district court ruled that it did not have jurisdiction in the Florida v. California suit and required the plaintiffs either to appeal to the U. S. Supreme Court or to attack the California standard in California courts.

1958. Informal industry committee of growers formed to study problems affecting grower prices and possibilities of an industry-advertising program. The committee became “permanent” later in the year as the “Avocado Promotion Committee”, with grower Walter Beck as chairman.

1959, January. Florida plaintiffs challenging provisions of the California Agriculture Code relating to avocado maturity decided to appeal to the United States Supreme Court.

1959. A divided industry considered proposals to request issuance of a State Marketing Order for California Avocado Promotion. Opponents proposed the creation of a voluntary organization of avocado handlers (California Avocado Development Organization) to handle advertising and trade promotion, to become effective if a set sign-up level were achieved. The CADO plan received the endorsement of the Avocado Promotion Committee. The required sign-up was not achieved. The Committee, Calavo Growers of California, and others petitioned the Director of the California Department of Food and Agriculture to issue a marketing order.

1959, October 7. The Director of the California Department of Food and Agriculture issued a marketing order for California avocado advertising, promotion and marketing research, to become effective February 1960. Implementation of the order was delayed by a court injunction obtained by a group of avocado handlers.

1961, October. The California Supreme Court ruled against the challengers and the marketing order became effective. An advisory board was formed (November 10); Walter R. Beck was elected chairman and Ralph M. Pinkerton was employed as manager.

1963. The United States Supreme Court, in the suit brought by Florida plaintiffs, upheld the constitutionality of California law requiring 8% oil content in avocados sold in California.

1964. Commercial freezing of table-ready avocados by cryogenic methods developed by two California avocado growers, Hirtenstein and Miller, was initiated by Calavo Growers of California and Frigid Foods, Inc. in partnership, test marketed in September in New York, Chicago and Dallas.

1968. The California avocado crop was significantly reduced and damaged by a major “freeze”.

1972, January. By referendum, a Production Research Committee was established under the state marketing order to administer funds generated by assessment of growers, initially at the rate of 0.4 cents per pound of avocados marketed.

1973. The California Legislature enacted a statute requiring certification of packed avocados to be in compliance with state regulations.

1973, September. Florida avocado growers again sued to nullify the California requirement of 8% oil in avocados, on this occasion prevailing. Grounds in this suit were different from those considered in 1963.

1976-80. Industry expands to 80,000 acres with over 8,000 growers. “Gold Rush” euphoria eventually turns to market glut and low prices (Affleck 1997).

1977, September 2. California Governor Edmund G. Brown Jr. signed California Assembly Bill 1602 authorizing a California Avocado Commission.

1978, April 27. Two California avocado growers sued the director and a bureau chief of the Department of Food and Agriculture in an attempt to block formation of the California Avocado Commission. A restraining order issued in June prevented the counting of referendum ballots. A ruling against the plaintiffs, July 3, upheld the constitutionality of the Commission’s establishment and dissolved the restraining order.

1978, August 4. The California Avocado Commission was made operative, the Director of the Department of Food and Agriculture having determined that the referendum vote was favorable, and eventually took over all functions previously performed under the state marketing order.

1981. An Avocado Inspection Committee was established by California Senate Bill 70 to be an independent advisor to the Director of the California Department of Food and Agriculture, with power to assure enforcement of avocado maturity standards and other elements of the Agricultural Code.

1984, November 1. The California Avocado Commission contracted with the California Avocado Society to develop and manage the industry production research program funded by Commission-collected grower assessments.

1990, December 20-23. The California avocado crop was significantly reduced and damaged by a “freeze” rated by some as the most severe since 1913. At least 20% of the statewide avocado crop was lost. In parts of Ventura and Santa Barbara Counties, crop losses were total.

1991. A new mite pest of avocado was discovered on backyard avocado trees in Coronado and La Jolla, near the port of San Diego. The mite, named *Persea* mite, infested almost every avocado leaf on every tree in San Diego County within 2 years. The mites were quickly moved to the other avocado-producing counties, most likely in picking bins. Many groves had to be sprayed with Omite by helicopter in the early years of infestation, but the pest eventually came under fairly good biological control.

1992-1998. Significant amounts of Hass avocado imports from Chile begin to show up in U.S. markets. Importation of foreign fruit in the California off-season for Hass supplants the market for the greenskin avocado varieties. Shipments from Chile for the fall of 1998 estimated at 60 million pounds.

1996. Another new pest, avocado thrips (*Scirtothrips perseae*) arrived in Ventura County and quickly spread to all groves. The pest eventually spread to the other avocado-growing counties, probably on infested fruit and picking bins. Groves in the more coastal climates had up to 100% losses in scarred fruit. Research on biological and chemical control is a high priority in the research program.

1997, February 5. USDA approves Rule to allow importation of Mexican avocados to nineteen states in the northeastern U. S., and the District of Columbia, during the months of November through February. Only groves in Mexico that are inspected and certified to be free of seed weevil and stem borer are allowed to ship to U.S. California Avocado Commission launches program to monitor USDA enforcement of rules and regulations to make sure Mexico ships fruit free of quarantine pests.

1997, November. First shipments of avocados from Mexico arrive in the U.S. Thirteen million pounds of fruit from Mexico arrive during the winter of 1997-1998.

2002, May. USDA announces it will conduct a referendum on the establishment of a Federal Promotion Order for the purpose of assessing all Hass avocados sold in the United States. The California Avocado Commission initiated the request for the promotion order because assessments from the California growers were paying for almost all of the promotion for Hass avocados in the U.S., in the face of increasing shipments of Hass avocados from Chile, Mexico, Dominican Republic and New Zealand. The promotion order would authorize an initial assessment of 2.5 cents per pound on fresh avocados produced in and imported into the U. S. The promotion order would be administered by a new National Avocado Board.

2002, July 29. The Hass Avocado Promotion and Research Order passes in a vote of Hass avocado producers and importers.

2002, November. A Mexican Fruit Fly infestation is discovered in the Valley Center region of San Diego County. All fruit in a 130 sq. mile quarantine zone are restricted from moving out of the quarantine zone; fruit in core areas (1 mile diameter zones surrounding each fly find) are not allowed to be harvested. By February 2003, over 270 flies are found, along with maggots in grapefruit. Growers in the region incur staggering financial losses. An estimated cost for the entire quarantine program, including monitoring traps, treatments (ground and air), fruit loss, inspector overtime, inspector living expenses (USDA brought in inspectors from around the United States) and grower meetings exceeded \$30 million. It was later discovered by USDA researchers that Hass avocados, when hard and freshly harvested from the trees, are not hosts for Mexican fruit fly.

2007, January. A devastating freeze occurs in many of the avocado producing areas from San Luis Obispo to San Diego. Temperatures at one of the farm advisor trials in San Diego were measured at 18°F during the night, freezing the three-year old avocado trees to the ground.

2007. After several years of drought in California, reservoir levels were dangerously low. Growers who were part of the interruptable agriculture water plan were forced to cut back water to their groves by 30% or face paying stiff penalties. Growers tried to cope by using the time to stump back trees that had grown excessively tall, but water districts found that they were not bringing in enough money to meet their fixed costs. The result was an increase in water rates.

2007. The departure of Mark Affleck, 20-year President of the California Avocado Commission, provided an opportunity for growers to re-organize the board, re-evaluate the production research and move to less expensive headquarters in Irvine, CA.

2010. The state declared that the drought was over and growers could now buy all the water they wanted. However, the water districts did not lower their water costs. This set up a downward spiral of groves going out of business (in San Diego County).

2012. Water costs in Fallbrook reached \$1100/ac ft, and \$1300-1400/ac ft in the Valley Center Water District.

McDonald Avocado Ranch in Fallbrook (1948) showing furrow irrigation on contour of hillsides (*Courtesy James McDonald, Fallbrook CA*)



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Book 1

Chapter 2

Avocado Botany and Commercial Cultivars Grown in California

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1. The Lauraceae Family

Avocado belongs to the laurel family (plant family: Lauraceae). This family includes camphor, cinnamon, the California laurel and the eastern sassafras. The California laurel (*Umbellularia californica*), also known as the California bay, Oregon myrtle or pepperwood, is the only native laurel to California (Bergh and Ellstrand, 1986).

Most of the laurels are tropical or subtropical in origin, but two American natives, spicebush and sassafras are exceptions. These two are hardy and withstand cold winter temperatures in the eastern United States. The powdered bark of sassafras is still used as an herbal medicine and flavorings in teas and carbonated beverages.

In the laurel family, the most significant genus in agriculture besides the avocado genus *Persea* is the genus *Cinnamomum*. The latter has two species that are adapted to the tropics (origin Southeast Asia) and the ground bark from these trees provides cinnamon spice. A third species (camphor) provides a pungent medicinal extract and lives quite well in southern California.

The *Persea* Genus

There are about 50 described species of *Persea*. Most of the *Persea* species originated in the New World, but *P. indica* apparently originated in the Canary-Madeira-Azores islands. Some species originated in Southeast Asia. *Persea* has been divided further into subgenus *Persea* (includes *P. americana*, the commercial avocado) and subgenus *Eriodaphne* (a group of species of which most are immune to avocado root rot, but unfortunately are not graft compatible to avocado).

In the subgenus *Persea*, three species have been of interest to avocado growers. *Persea shiedeana* is cultivated on a small scale in Mexico and Guatemala for its fruit, but the fruit is inferior to that of *P. americana*. *P. shiedeana* is of interest because it is a parent of the G755 rootstock, a rootstock with improved resistance to avocado root rot. *P. indica* is a small seeded relative that is especially susceptible to avocado root rot. It has been used by laboratories as a sensitive biological indicator for the presence of *Phytophthora cinnamomi* (the fungal cause of avocado root rot) in soil samples submitted by growers. The third species, *P. americana*, is the commercial avocado.

The Avocado – *Persea americana* Miller

Persea is the genus, *americana* is the species (relating the avocado to its origin in the New World) and Miller is the name of the first scientist to print a description of the avocado (Miller, 1754). The avocado species have generally been divided into three races: Mexican, Guatemalan, and West Indian. Some classifications split off the Mexican race into its own species, *P. drymifolia*. Kopp concluded that they were not separate species, but the Mexican race should be classified as a sub-species (Kopp 1966). Williams separated the Guatemalan into its own species, *P. nubigena*, leaving the other two races in *P. americana* (Williams 1977).

Bergh and Ellstrand, researchers at the University of California, Riverside, used isozyme data, along with morphological, geographical, physiological and biochemical data, to come to the conclusion that the three races

were more related than not, and that they should be called “varieties” rather than separated into species (Bergh and Ellstrand 1986). They suggested that the proper separation should be for Mexican *Persea americana* var. *drymifolia*, for Guatemalan *P. americana* var. *guatemalensis*, and for West Indian *P. americana* var. *americana*. Most researchers still use the term “races” to separate the three types. It should be noted that the term “variety” is correct botanically when referring to “sub-species” or “races”, but “variety” is commonly used to refer to “cultivars”, such as ‘Hass’ or ‘Fuerte’. In this chapter, we will use the commonly used terms “races”, and the botanically correct term ‘cultivars’. Characteristics of the three races are presented in Table 1.

Table 1. Comparison of three avocado races. (Bergh and Ellstrand, 1986)

TRAIT	MEXICAN	GUATEMALAN	WEST INDIAN
TREE			
Climatic adaptation:	“semitropical” ¹	subtropical	tropical
Cold tolerance:	most	intermediate	least
Salt tolerance:	least	intermediate	most
Hairiness:	most	less	less
Leaf anise:	present	absent	absent
Leaf color:	medium	often redder	paler
FRUIT			
Months to mature:	6	12 or more	5
Size:	small	variable	variable
Pedice (stem):	small	variable	variable
Skin thickness:	very thin	thick	medium
Skin surface:	waxy bloom	rough	shiny
Seed size:	large	small	variable
Seed cavity:	loose	tight	variable
Seed surface:	smooth	smooth	rough
Oil content:	highest	high	low
Pulp flavor:	spicy	often nutty	mild
Some varieties:	Topa Topa, Mexicola, Duke, Mentone	Reed, Nabal	Waldin, Booth, Trapp

¹ In regions in Central America where all three races are found at the same latitude, the West Indian race will thrive from sea level to an altitude of 1000 meters (tropical), the Guatemalan race from 1000 to 2000 meters (subtropical), and the Mexican from 1500 to 3000 meters (termed “semi-tropical”) (Lee 1980).

The Mexican Race

Seeds from the Mexican race of avocado have been used as rootstocks in California since the beginning of the industry. Nurserymen like the big seeds and fast-growing qualities, and growers have found that Mexican rootstocks usually have better and more consistent production than do the Guatemalan and West Indian rootstocks. Of the three races, Mexican seedling rootstocks do best in the colder soils and the calcareous soils that can induce iron chlorosis in leaves. Mexican rootstocks are the least tolerant to soil salinity.

Fruits from the Mexican race have thin, delicate skins that tear easily when shipping or handling. Fruit skin color varies from dark green to deep purple. Crushed leaves from Mexican and most Mexican hybrids have a characteristic anise smell.

There are no pure Mexican varieties grown for fruit commercially in California. However, genes from the Mexican race are important components in the Mexican-Guatemalan hybrid cultivars such as ‘Hass’ and

‘Fuerte’. Two important traits from the Mexican race are imparted into the hybrids. These are the addition of more cold hardiness to the Guatemalan race and advancing the harvest season of the Guatemalans by half a year.

The Guatemalan Race

The Guatemalan race of avocado is native to the highlands of Central America and is less cold tolerant than the Mexican race. The leaves have no anise scent and the young foliage is often reddish. The seed is almost never loose in the cavity.

A characteristic of the Guatemalan race is the much longer time to fruit maturity (compared to the other races). Guatemalan cultivars such as Nabal and Reed may take 15 months or more from bloom to maturity. Historically, this trait was used in California to stretch out the harvest season: hybrids with strong Mexican traits were harvested in the winter; Guatemalan cultivars such as Reed, Nabal, Dickinson, Queen, and Anaheim were harvested six to nine months later in the summer; and Hass (a mostly Guatemalan hybrid) filled in between the two seasons.

A disadvantage to the Guatemalan cultivars is the thicker, woody skins (not all cultivars have this trait). One of the problems with the thick skins was that the consumer could not tell when the fruit had softened enough for eating. The hard-shelled Dickinson cultivar was tested for softening by inserting a toothpick into the stem end of the fruit. The stiffness of the peels did not allow easy peeling; peels were “chipped-off” instead of peeled. The popular Reed cultivar has a thinner skin, but is still very shell-like.

The West Indian Race

The West Indian race is native to the tropical lowlands of Central America. The leaves have no anise scent. Fruit size ranges from small to very large. Seeds are relatively large and are sometimes loose in the cavity. The West Indian fruits have relatively low oil content and are often reported to be “watery” by consumers.

This race is the most cold sensitive of the avocado races and pure cultivars do not grow well in California. Selections of this race appear to have greater salt tolerance and may be useful as rootstocks if selections can be found that can tolerate the colder soils in California. West Indian cultivars and hybrids are well-adapted to southern Florida and provide fruit on the market just ahead of the California winter fruit. Selections have been made in Florida to stretch out their harvest season, but a given cultivar will be on the market for just a few weeks. Thus, the Florida industry relies on early, mid and late season West Indian cultivars.

Mexican-Guatemalan Hybrids

Mexican-Guatemalan hybrids make some of the best avocado cultivars imparting positive traits from both races. The most important cultivar currently in production is ‘Hass’ which has been described as 85% Guatemalan and 15% Mexican (Bergh and Ellstrand, 1986). The Mexican genes enable Hass to reach maturity earlier than the pure Guatemalan cultivars, and impart more cold tolerance to the tree and fruit, although not as much as a pure Mexican cultivar. The Guatemalan genes impart a thicker skin to the fruit, but still thin enough to peel easily.

Fuerte, which is about half and half Mexican-Guatemalan, has more cold tolerance than Hass. Bacon is mostly Mexican with even more cold tolerance than Fuerte. As a rule of thumb, Hass fruit can stand temperatures as low as 29°F for four hours before showing freeze damage in the fruit, Fuerte fruit can similarly withstand temperatures to 26-27°F before showing damage, and Bacon can withstand temperatures as low as 25°F before showing fruit damage.

Cultivars that are predominantly Mexican include Bacon, Zutano, Shepard, and Rincon. Cultivars that are equally Mexican-Guatemalan include Fuerte and Ryan. Cultivars that are predominantly Guatemalan include Hass, Lamb Hass, Gwen, Pinkerton, Edranol, Hazzard, Sharwill, and Wurtz.

Guatemalan-West Indian Hybrids

Cultivars from these hybrids are generally not important to California, except for the Lula. In years where there may be a shortage of seed, some nurserymen have purchased Lula seed from Florida for propagation. Lula is popular in the nursery because of its fast-growing qualities. Chlorosis symptoms have occasionally been noticed on trees grafted on these rootstocks; more work needs to be done to determine which locations are more acceptable to use Lula as a rootstock in California. Lula (as a rootstock) does best in well-drained soils.

2. Commercial Avocado Cultivars for California

Seedling avocados may take up to 10 years to bear fruit (some seedling trees never bear fruit). Therefore, all commercial avocados are grafted with budwood from a known cultivar to provide consistent fruit quality, trueness of type and precocious production. Most grafted avocado trees begin to bear fruit in the third year after planting, and most groves reach maturity (maximum production) in the eighth to the tenth year.

Every seedling avocado tree has the potential to be a new cultivar due to genetic re-combination during the pollination and fertilization process. The vast majority of these “new cultivars” are inferior to cultivars already known, but every once in a while a new selection may be found among seedling trees that may offer improved fruit set, flavor or any number of other qualities. The Avocado Breeding Project at the University of California, Riverside and at the South Coast Research and Extension Center in Irvine is currently the most active program in the world for breeding and screening new cultivars and rootstocks. This Project is funded by grants from the California Avocado Commission and the California Avocado Society, with substantial volunteer effort from members of the California Rare Fruit Growers and the Cooperative Extension Master Gardener Program. The Breeding Project has been managed by Dr. Mary Lu Arpaia since 1996.

Hundreds of cultivars were described during the 20th Century, most by individual growers and nurserymen, but a few were purposely bred and described by University researchers in the 1990's. The predominant commercial cultivars have been reduced from many to just a few; the ‘Hass’ cultivar in the 2011-2012 crop year was estimated to account for 96.9% of the commercial production (in pounds) in California. Other cultivars have been reduced in acreage due to poor market demand and low prices. ‘Lamb Hass’, a U. C. patented cultivar released in 1998, was estimated to account for 2.25% of California avocados in 2011-2012, and was the only minor variety increasing in acreage (Tables 2 and 3).

The following tables show the trend in avocado production in California in the last ten years. Note the decline in the minor varieties for demand in the markets.

Table 2. Estimated acreage and yield for avocado cultivars in California in 2001-2002
(California Avocado Commission).

Cultivar	Bearing Acreage	Estimated yield (lbs/A) in 2001-2002	Estimated yield in California (million lbs) in 2001-2002
Hass	51, 575	7,044	363.3
Fuerte	1,452	4,125	6.0
Bacon	1,961	6,645	13.0
Zutano	706	3,144	2.2
Pinkerton	1,035	4,715	4.9
Reed	430	7,163	3.1
Gwen	260	5,633	1.5
Lamb Hass	420	5,143	2.2
Other	388	3,058	1.2
Total	58,227	6,825	397.4

Table 3. Estimated acreage and yield for avocado cultivars in California in 2011-2012
(California Avocado Commission).

Cultivar	Acreage (includes 7,800 acres of topped/stumped groves)	Yield in lbs/A in 2011-2012	Yield in California (million lbs) in 2011-2012
Hass	56,548	7,924	448.1
Lamb Hass	1,964	5,295	10.4
Other	1,117	3,312	3.7
Total	59,629	7,753	462.3

Table 4. Decline in production from various avocado cultivars 2002-2012. Acreage from most of the minor cultivars is no longer determined, but AMRIC keeps track of yield (in pounds). Data is supplied by 13 of the major packers in the industry to AMRIC.

Season	Fuerte	Bacon	Zutano	Pinkerton	Gwen	Reed	Other greens
2002	3,476,645	9,734,690	888,980	3,230,570	1,746,815	3,185,455	465,340
2003	1,645,350	7,885,025	410,230	3,060,065	1,397,065	3,143,605	470,870
2004	2,743,590	7,399,135	346,795	5,226,390	1,603,630	1,715,270	668,140
2005	1,504,250	5,130,725	223,475	715,500	727,950	1,948,350	333,900
2006	2,321,050	3,747,775	160,425	4,186,900	908,475	2,331,925	486,150
2007	805,450	1,262,550	27,000	135,000	204,300	1,229,525	263,700
2008	619,825	1,823,700	58,500	1,288,400	470,250	1,334,750	190,800
2009	130,550	1,473,650	233,475	515,900	268,125	673,700	162,900
2010	708,650	1,372,700	229,925	638,200	267,300	583,800	519,300
2011	430,000	1,364,900	262,200	553,500	162,000	1,444,900	144,900
2012	655,900	1,068,700	133,200	399,100	184,500	817,900	132,300

Descriptions of the California Avocado Cultivars

Characteristics of the main cultivars were summarized in 1996 by Gray Martin (a former staff research associate with the University of California's Avocado Breeding Program) and Bob Gleinn (a farmer/volunteer with the breeding program). The summary was published as part of a Cooperative Extension county publication in San

Diego in 1996 (Martin and Gleinn 1996). This chart is presented as Table 4. It should be noted that this chart will be updated in the near future, but at this time it is the best information available.

The Major Cultivar

Hass. (Flower type: A). Hass originated as a chance seedling variety in La Habra Heights, California. The cultivar was selected by Rudolph Hass in the 1920's and patented in 1935 (see Chapter 1 – History of the Avocado Industry in California).

Hass is recognized as the best overall quality avocado available, has the longest harvest season (January - August in San Diego county, as late as June - October in Santa Barbara and San Luis Obispo counties), and is currently the recommended cultivar for new plantings. Hass is grown in most of the southern California coastal counties and the western end of Riverside County, especially in locations that have mild summer temperatures and little frost (if any) in the winter. Hass acreage by county is presented in Table 4.

Table 4. Hass avocado acreage and production (estimated) by county in California in 2001-2002 (California Avocado Commission).

County:	Estimated acres	Lbs/acre	Total lbs (millions)
San Diego	22,862	7,410	169.9
Riverside	5,980	8,459	50.6
Orange	1,653	3,705	6.1
Los Angeles	220	6,486	1.5
Ventura	11,608	7,383	85.7
Santa Barbara	7,660	5,237	40.1
San Luis Obispo	1,303	6,687	8.7
San Joaquin Valley	57	3,837	0.2
Other	232	4,248	1.0

Hass is also recognized to have several shortcomings, including poor fruit set in some locations, sensitivity to saline irrigation water, intolerance to cold temperature below 30°F (Bergh 1984), and susceptibility to persea mites and avocado thrips. These problems (discussed in further detail at the end of this section) have fueled the interest in new cultivars, and funding for the breeding program has remained a top priority in the California avocado industry.

Other qualities of Hass include a relatively heavy yield in some areas to light yields in others, somewhat alternating production, small seed and a nutty flavor. The industry has tried to stretch Hass into an almost year-round cultivar, but early season Hass fruits are not as palatable as mid-season fruits, and late season fruits often turn rancid rapidly upon softening. Since the strong entry from Chile in the winter market, the California industry is now focusing on harvesting most of the crop between February to August, with some later harvesting from the northern counties in September and October.

Hass is a Mexican-Guatemalan hybrid (mostly Guatemalan) tree that has a moderately spreading canopy. If left un-pruned, the tree may grow to 50-60 feet in height. The fruit varies from 6 to 14 ounces, turns black at ripening. The black color is useful for consumers to know when the fruit is ready to eat, and the dark color hides some defects in the peel, such as bruising and fingernail marks from pickers. The fruit is often “size-picked”, which means that 7.5-9 oz. fruits (size 48) and larger are usually picked as early in the season as possible to get the best price. This is followed by a least one more size

Table 5. AVOCADO CULTIVARS THAT ARE COMMERCIALY AVAILABLE

	HASS	FUERTE	GWEN	PINKERTON	REED	BACON	LAMB/HASS	SIR PRIZE
MARKET ACCEPTANCE (Compared to Hass)	Excellent	Good/Fair	Good	Good	Good	Fair	Very Good	Good
FRUIT Skin Color	Black	Green	Green	Gram	Green	Green	Black	Black
Overall Quality	Excellent	Excellent	Very Good	Very Good	Very Good	Average	Very Good	Excellent
Taste	Excellent	Excellent	Very Good	Very Good	Very Good	Good	Very Good	Excellent
Appearance	Hass	Smooth Green	Green Hass	Necky Hass	Round	Smooth Green	Large Hass	Black Fuerte
Early Pick	January	November	April	January	May	October	May	November
Late Pick	August	March	September	May	November	February	November	March
Dominant Size	48	48	40	40	32	40	36	36
Size Range	40-60	40-60	32-48	32-48	32-40	40-48	32-48	32-48
Peel Thickness	Medium	Med. Thin	Med. Thick	Medium	Thick	Thin	Thick	Med. Thin
Peel Pliability	Very Good	Very Good	Good	Very Good	Good	Fair	Good	Good
Seed Size	Medium	Medium	Medium	Small	Medium	Large	Medium	Small
TREE Productivity	100**	75	125	125	150	100	150	100
Bearing Habit	Somewhat Alternating	Alternating	Consistent	Consistent	Highly Alternating	Somewhat Alternating	Somewhat Alternating	Somewhat Alternating
Wind Tolerance	Low	High	Low	High	Moderate	Moderate	High	Moderate
Persea Mite Tolerance	Low	Moderate	Very Low	Low	Moderate	High	High	Moderate
Cold Tolerance	Fair	Good	Fair	Fair	Fair	Good	Fair	Good*
Precociousness	2-3 Years	2-3 Years	1 Year	1-2 Years	2 Year	1 Year	1-2 Years	2-3 Years
Shape	Spreading	Spreading	Upright	Medium	Upright	Upright	Upright	Upright
Tree Per Acre	50-100	50-100	100-160	100-140	100-140	80-120	100-140	100-140
Flower Type	A	B	A	A	A	B	A	B
Bloom Months	Mar-May	Feb-Apr	Mar-May	Jan-Mar	Apr-June	Feb-Apr	Mar-May	Feb-Apr
POST HARVEST								
Storage Shelf life	Good+	Fair	Good-	Excellent	Good	Fair	Good-	Excellent
Shipping Quality	Good	Fair	Good-	Good	Good	Fair	Good-	Good
Response to Ethylene	Excellent	Poor	Unknown	Excellent	Poor	Poor	Unknown	Unknown
Ripeness Detection	Good	Good	Fair	Good	Fair	Good	Fair	Good
Peelability	Good	Good	Shell-Like	Good	Shell-Like	Fair	Shell-Like	Fair
FOOTNOTES	*University of California, Riverside Avocado Breeding Program ** Productivity estimates all relative to Hass							
	All weather related data based upon South Coast Field Station location in Irvine, CA							

pick and concluded with a strip-pick. Some growers will strip pick early in the season; smaller fruit at this time will usually (but not always) bring less dollars per pound, but the average price for all fruit may be higher than the average price for all fruit later in the season. It is recommended that at least 1/3 of the crop be picked before April in order for the tree to have a good return bloom in the following spring.

Growers in the Ventura/Santa Barbara area have noted increased fruit set in Hass (an A flower type) when trees are near a B flower type cultivar such as Bacon or Zutano. This effect is occasionally noted in San Diego-Riverside counties. Recently, in a comparison of B flower type trees, it was noted that Hass yield was considerably higher when located one tree away from Zutano (M. L. Arpaia and B.A. Faber, personal communication). The effect progressively diminished when the Zutano tree was located two, three and four trees away.

Although Hass has become the cultivar of choice (due to market demand and return prices to the grower), many growers are unhappy with the performance of the trees. Bergh (1984) summarized the problems:

1. *"Cold tender"*. As mentioned, this is a characteristic of the Guatemalan race. When avocados were planted during acreage expansion in the 1970's, this feature was carefully considered and almost all Hass trees were planted on the upper slopes of hills. Warm air rising during cold nights usually kept the Hass trees from freezing. More cold tolerant cultivars were planted on the lower slopes. With the decline in prices in the 1980's for cold tolerant cultivars such as Bacon, Zutano and Fuerte, many of these trees were topworked to Hass and many eventually froze outright, or suffered enough chronic frost damage to make the grove unprofitable.
2. *"Productivity is inferior"*. Good yield data is difficult to obtain, and is conflicting because of the differences in irrigation (both amount of water and water quality), fertilization, location, presence of root rot etc. Despite this, a UC Cooperative Extension study in 1984 indicated that, for 19 years through 1982, Hass yields in California averaged 7,249 lbs/acre compared to Fuerte yields that averaged 4,842 lbs/acre (Takele 1984). Due to a variety of reasons, many Hass groves produce considerably less, but a few groves consistently produce more. Despite the differences in yield among the Hass groves, it has been consistently noted among growers that certain cultivars such as Zutano and Reed produce more fruit per acre than Hass. It is believed by many growers and researchers that avocado has the physiological potential to produce more fruit per acre, and they would like an improved cultivar with qualities like Hass.
3. *"Tree production alternates"*. In the "on" year, a tree can be so heavily laden with fruit that branches start to break, fruit will be small and competition for resources may lead to leaf drop and sun-burned branches.
4. *"Grove production varies from year to year"*. Fuerte yields have always been known to be severely alternating, often causing serious cash flow problems for growers. Unfortunately, in some areas, Hass yields from the grove can also be severely alternating. Bergh cites data from a ten acre Hass grove which averaged 8,752 lbs/A over a five year period, but individual year averages were 20,995, 4,057, 14,260, 1,813 and 2,635 lbs/A during this period.
5. *"Industry production varies from year to year"*. In Takele's economic study, the Hass industry in California (in the last four reported years) averaged 6,777, 3,396, 10,829 and 4,960 lbs/A respectively. This variation is probably a weather-related problem in the spring during flowering and fruit set, but it causes problems with marketing during the "on" years (resulting in low prices to growers) and servicing the market during the "off" years (resulting in abnormally high prices to consumers, with the resulting interest in Hass exports to the U.S. from foreign competitors).
6. *"Black color of the fruit is not universally preferred"*. Over the years, the black color has gradually replaced the preferred green color of Fuerte and other greenskins, but consumers on the East Coast who were used to green fruit from Florida, were slow to accept the black fruit.
7. *"The tree is too large"*. Large trees add to picking costs and picking can be hazardous. Spraying is also difficult with large trees. Pruning appears to be a necessary production practice, but this also adds considerably to production costs.

8. "*Hass requires more fertilizer*". This was an observation by former farm advisor Don Gustafson in San Diego County.
9. "*Hass is more subject to stresses*". Hass is thought to be more subject to drought, salinity, insect damage, and blackstreak disease, although there is little scientific evidence to substantiate these claims.
10. "*Fruit size averages too small*". Fruit is small in "on" crop years, and as the tree matures.

In spite of all these problems, Hass has done so well at the market that it has displaced the winter greenskin cultivars. The consequence of the popularity of this fruit is that produce buyers started purchasing Hass from Chile in the winter months to fill the displays at the supermarkets. This demand for Hass fruit in the market year-round eventually led to pressure on the USDA to allow importation of Hass from Mexico, Dominican Republic, New Zealand and Peru (in 2011). The California farmer that filled the fall-winter niche with greenskins had to topwork to Hass to stay in business. If the climate were too cold where the newly-topworked trees were located, these trees suffered chronic frost damage or were killed outright by a prolonged frost.

The Minor Cultivars

During the twentieth century, there were many cultivars selected from chance seedlings found in groves and dooryards in California. Many were named and registered with the California Avocado Society, but only a few had the qualities that made them a lasting success at the market place. Fuerte was a leading cultivar in the first half of the century, but is slowly disappearing due to the overwhelming popularity of Hass. Some of the newer cultivars were selected by researchers at U. C. Riverside in a continuing search for a more productive cultivar than Hass; these include Gwen, Lamb Hass, GEM and SirPrize.

Fuerte. (Flower type: B). Fuerte was found by Carl Schmidt as a dooryard seedling in Atlixco, Mexico in 1911 (see Chapter 1). It survived a freeze in Los Angeles in 1913 and eventually became the cultivar of choice in California prior to the emergence of Hass. The fruit is a greenskin when ripe, pear-shaped with a flat area on the bottom corner, 8 to 14 ounces in size and very high quality. The Fuerte is still thought by many in the avocado industry to be the best tasting avocado.

The Fuerte tree is large and spreading. The leaves have a strong anise smell when crushed, and there is red flecking on wood of new shoots. The tree is intermediate in cold resistance to about 27° F. The tree performs best away from the coastal influence, but not into the hot interior zones.

Fruit set is erratic; some trees never seem to have very much fruit. Groves are alternate bearing, usually more so than Hass groves. Fruit set in Fuerte often improves dramatically when the trees are interset with varieties that have "A" type flowers; in past years these varieties were usually Covacado, Jalna, or Topa Topa.

Some Fuerte groves have a long flowering periods, lasting sometimes from October to July. Some of the early flowers may set "off-bloom" fruit that mature in early fall, these often have the flat bottom on the corner. Early bloom fruit may be harvested just after the off-bloom fruit. When temperatures are less than ideal for fruit set, "cukes" may be formed (cukes are fruits that have been stimulated to grow by the pollen tube, but the fertilization event was never completed, leading to a small, narrow seedless fruit). Cukes are harvested and sold as "cocktail" avocados.

Zutano. (Flower type: B). This cultivar is believed to have originated as a seedling tree on the Truitt Ranch on Alvarado Street in Fallbrook, California (Koch 1983). Zutano is a vigorous upright tree that produces heavily. The fruit are green at ripening, thin skinned, glossy green skin, pear shaped and vary from 8 to 14 oz. The quality of the fruit is relatively poor; consumers comment that the flavor is poor and "watery". This a result of low accumulation of oil (or dry matter) in the flesh. Zutanos that are harvested late in their season have a more acceptable flavor, but surface corking, end spots and internal breakdown reduce or eliminate marketability. Most Zutanos have been removed or top-worked to a better cultivar. The remaining Zutano fruit is often used as "nurse" seeds for clonal propagation of avocados. Zutano by itself as a rootstock is very susceptible to avocado root rot caused by *Phytophthora cinnamomi*.

Zutanos may be useful in acting as a pollinizer tree for Hass, since Hass is an A flower type and Zutano is a B flower. Farm advisors have often noted that Hass trees near a Zutano usually have substantially larger crops than Hass trees farther away from the Zutano. Several trials were established in Ventura County in the late 1990's to determine the best pollinizer tree for Hass. Preliminary data indicate that Zutano appears to be the best of the B flower type trees, and the effect is best when the Hass tree is one tree away from the Zutano. Great variation may occur from year to year; however, some years there seems to be no effect (M.L. Arpaia and B. Faber, personal communication).

Prices have been so low for Zutano fruit that the sale of fruit seldom pays for the water. The dilemma for the grower remains, does the effect of the pollinizer tree on the surrounding Hass trees increase the yield enough to make up for the loss of a Hass tree in the space now occupied by a Zutano tree? This question has not been answered yet, but some growers are planting Zutanos around the edge of the Hass grove, or along the grove roads, and pruning them like a pole, not to produce fruit, but to provide some flowers for the bees to visit.

Zutanos are still grown in the San Joaquin Valley where it is too cold for Hass in the winter, but even this acreage is declining due to poor prices for fruit.

Bacon. (Flower type: B). Bacon originated as a seedling tree on the ranch of James E. Bacon in Buena Park, California in 1928. Mr. Bacon was screening large numbers of seedlings for cold hardiness, and settled on one that produced fruit early in the season (November-January) and is now probably the most cold-hardy of the commercial varieties. The Bacon variety was introduced to the avocado industry in the late 1920's.

It has been reported that trees will survive temperatures as low as 24° F, but the fruit stem will be damaged during the cold temperatures and the fruit must be harvested immediately after the cold snap. During warmer winters, if fruit is left on the tree past January, dark cracked areas will often develop on the bottom of each fruit.

The fruit is dark green, oval in shape of medium quality and 7 to 14 ounces in weight. The fruit is better quality than Zutano, but overall yields are not as good as Zutano. Bacon fruit are lumped with the "greenskins" at the market and consequently command a poor price. The tree is an upright growing tree and is commonly grown on a 15' x 15' spacing. The leaves, when crushed, have an anise smell. Like the Zutano, Bacon (a B flower) may be useful as a pollinizer for Hass.

Reed. (Flower type: A). Reed was found as a seedling at the James S. Reed Ranch in Carlsbad, California in 1948. The Reed is thought to be a cross between Anaheim and Nabal, two Guatemalan-type varieties. The fruit is almost round and relatively large, averaging 8 – 12 ounces near the coast and 12 – 18 ounces inland. The skin is green in color and "shell-like". The Reed is harvested from July through September, but will last on the trees in some groves until the middle of November. The fruit has a rich, nutty flavor and the cut surface does not darken. The fruit has good shipping and shelf-life qualities. In the early 1980's the Reed was thought to fill a niche late in the season when the Hass harvest was declining. Unfortunately, this niche has been filled by importations of Hass from Chile.

The tree has an upright shape and is a heavy producer. Some growers plant the Reed on a close spacing (8 to 10 feet), keep it pruned to 10-12 feet in height, and produce excellent yields per acre. Although the dollar return for Reed is less than Hass, increased yield per acre may be suitably profitable for the grower.

The Reed has some resistance to *Persea* mite. The Reed always seems to produce well (without a pollinizer tree nearby) in the backyard.

Pinkerton (Flower type: A). Pinkerton originated as a seedling about 1959 on the John Pinkerton Ranch in Saticoy, Ventura County, California. The cultivar is thought to be a hybrid of Hass x Rincon. The cultivar was patented in 1975.

John's son, Allan Pinkerton, was quoted as saying that "sloppy farm management produced the seedling" (Koch, 1984). Sloppy management means that a seedling was allowed to grow without timely removal, or a graft on a top-worked tree did not take, and it was not re-grafted in a timely fashion. This is certainly one instance where the avocado industry benefited from poor management.

The Pinkerton fruit has a green peel at ripening, with a small seed and very good fruit quality and flavor. Pinkerton is mostly of the Guatemalan race. The peel is pebbly like Hass, but the fruit has a longer neck than Hass. Under cooler conditions the neck can be especially long to the point that they are difficult to pack into standard cartons. The harvest season is from January through May.

Pinkerton blooms over a long time period. Fruit that set early in the bloom cycle are nearly round and can mature a month or two before the glossier and slimmer late set fruit.

The tree has a moderately spreading canopy, has the same tolerance to cold as Hass and is a more consistent and heavier producer than Hass. The tree has been noted to have stronger limbs than Hass and can withstand strong winds better. The leaves do not have an anise smell when crushed.

In the 1980's, it was thought by several industry analysts that Pinkerton could play a strong role in the California avocado industry. Koch suggested that growers should grow a mixture of Hass, Reed, and Pinkerton; this would allow growers in San Diego County to produce good quality fruit year round (Koch 1983). Warren Currier and Hank Brokaw spearheaded a special marketing effort that was fairly successful; prices in 1984 were almost equal to prices of Hass and about twice that of Fuerte (Bergh 1984). Unfortunately, importations of Hass from Chile starting in the mid 90's replaced most of the market for winter Pinkertons.

3. The New Generation of Varieties

The following varieties were developed and released from the Avocado Breeding Project at UC Riverside under the direction of Dr. Bob Bergh. The Breeding Project is now under the direction of Dr. Mary Lu Arpaia and she is investigating and developing many new potential cultivars such as Nobel and Marvel. GEM and Harvest were released to the nurseries in 2003. Holiday was released but not patented because it was thought that it would not become popular in the commercial industry but might become popular as a backyard tree with fruit being harvest around the holidays at the end of the year.

Lamb Hass. (Flower type: A). Lamb Hass originated as a cross between Gwen and Thille. Lamb Hass was selected because of its good flavor, superior production (side by side with Hass, Lamb Hass almost always has more fruit, often an increase of 50%), and a skin that turns black at ripening. Lamb Hass has increased in popularity in California, acreage increased from 420 bearing acres in 2002 to 1,964 acres in 2012.

Lamb Hass was originally named BL122. The 'Lamb' part of the name was chosen to honor Bob, Bert, and John Lamb whose ranch in Camarillo was the site of a large planting of seedlings from crosses made by Dr. Bergh. 'Hass' was kept in the name to indicate the close relationship to our main variety (Lamb Hass is a grandchild of Hass). The Lamb Hass variety was patented by the University of California in 1996.

The Lamb Hass fruit is usually larger than Hass, typical weight of a fruit is between 10 to 18 ounces. The fruit is distinguished from Hass by its broad shoulders. Consumer taste tests rate the flavor highly, but not quite as high as Hass or Gwen (M. L. Arpaia, personal communication). However, proper taste tests are difficult because the season is later than Hass; fruit should not be harvested before May-June. Thus, a Lamb Hass tested at the beginning of its season will likely not rate as well as the Hass fruit in the middle of its season. It remains to be seen how long the fruit will hold on the tree; some growers report that fruit will hold into November, but holding fruit late may contribute to alternate bearing. In 2011, the entry of Hass from Peru into the US in the late summer (the main harvest season for Lamb Hass) likely caused the depressed prices for Lamb Hass in California.

Further testing for qualities such as post harvest handling, shipping, alternate bearing, taste, etc. are currently being conducted by Dr. Mary Lu Arpaia, coordinator of the Avocado Breeding Project. Lamb Hass seems to be more tolerant of wind, heat, and *Persea* mites (compared to Hass). Lamb Hass is not expected to have good cold tolerance, probably showing frost injury at 29-30° F.

Gwen. (Flower type: A). Gwen is a selection from seedlings of the little-known variety 'Thille'. (Thille is a seedling from Hass). Thille seedlings were planted at the University of California's South Coast Field Station in Irvine, California in 1963; one of those seedlings (at the time called T225) was selected as a promising cultivar because of excellent fruit quality and heavy set. T225 (later named 'Gwen') had the Guatemalan traits of thick, rough skin, a small, tight seed and a "nutty" flavor. The fruit at the station would hang on the tree for 1½ years after set and had a sensitivity to cold, further evidence of a strong Guatemalan influence. However, the skin color remained green at ripening, unlike the black Hass color. The cultivar was thought to be an important contribution from the UC Avocado Breeding Program, and Gwen was patented by the University of California (with Dr. Bob Bergh as the inventor) in October, 1984.

From 1985 to 1990 almost 600 acres were top-worked to Gwen (Currier, 1991), but several problems developed that stalled its introduction as an important new cultivar.

- Although Gwen trees set fruit in abundance at the South Coast Field Station, large solid blocks of Gwen in San Diego County often had poor fruit set. A grower from Escondido, Tom Markle, inadvertently discovered that Gwen trees set much better when they were close to his Zutano trees that had grown back from failed Gwen grafts. Gwen apparently had a strong requirement for cross-pollination to a B flower type variety.
- Gwen maturity was later than Hass. Misinformation to the industry caused fruit to be picked as early as January 15th, but it was eventually shown that fruit picked before April 15th often shriveled. Fruit that were held later on the tree to reduce the shriveling had a high drop rate. Eventually it was determined that the dry weight of Gwen should be 25.9% before the fruit is harvested, but many growers reported that an excessive amount of fruit was on the ground before that dry weight could be achieved.
- Freezes in 1987, 1988, and 1990 severely damaged many of the Gwen groves, usually because the Gwens were topworked onto Bacon and Zutanos that were originally planted on the lower slopes. Gwen also seemed to be particularly sensitive to soil dryness and wind, resulting in fruit drop and leaf drop. In order for the trees to carry extra heavy crops, the environmental stresses had to be eliminated.
- Buyers for the chain stores still preferred the black Hass fruit. Gwen growers organized to form the Gwen Growers Association, assessed themselves ¾ cents per pound and developed a marketing plan. Despite this effort, returns for Gwen fruit were seldom more than half the returns for Hass fruit. The bumper crop for Hass in 1993 further reduced prices for all avocado growers and resulted in discouragement for the Gwen growers.

Despite the problems with the new Gwen cultivar, an important step had been taken in the UC breeding program. It was thought that a new cultivar could be successful if it was closer to Hass in color and provided the grower with more fruit set. This optimism led the way for the discovery and development of Lamb Hass. In 2012 it can be seen that Gwen is disappearing as a cultivar in California.

Sir Prize. (Flower type B). In the search for black fruit that could be a good winter variety, a selection was chosen from the Lamb Ranch that had promised to replace Bacon and Zutano. The fruit of Sir Prize looks like a black, rough Fuerte, has a small seed and has an excellent, nutty rich flavor. The maturity season appears to be November – March. It was hoped that it would have good cold tolerance and could be a good cultivar for the San Joaquin Valley, but most of the early plantings froze in the winters of 1999 and 2000. There is speculation that it could be a good cross-pollinizer for Hass, but this remains to be proven. Peak bloom period is earlier than 'Hass' by several weeks. Yield may be rather light, but it hasn't been properly tested in many areas.

GEM (Flower type A). GEM is also a black-skinned fruit that was selected from the Lamb Ranch. The average fruit weight is 7-11 oz and the harvest season is roughly that of Hass. The tree has an open and spreading growth. Perhaps the best character of GEM is that the fruit, when cut in half, has a much slower oxidation rate (the flesh stays greener longer) than does Hass. The tree has less alternate bearing than does Hass. GEM was patented under the experimental name 3-29-5 in 2003.

Holiday (also known as the XX3) (Flower type A). A very large, attractive fruit with a green skin at ripeness. Average fruit wt is 18-24 oz. The tree is a semi-dwarf and smaller than a Wertz tree. The harvest season starts around the holidays in December-January. This cultivar shows promise as a fruit to be sold at farmer's markets. This tree was not patented, but was released from the breeding program for propagation by nurseries in 2001.

4. Miscellaneous Cultivars.

Miscellaneous cultivars that are still seen in some groves and dooryards are summarized in Table 6. The cold tolerance listed for each cultivar assumes that the tree is at least 3 years old. The cold tolerance depends on many factors, including length of time at the given temperature, hardening of the tree, and irrigation status. Other minor cultivars can be found on Dr. Arpaia's UC Riverside website:
<http://www.ucavo.ucr.edu/AvocadoVarieties/AvocadoVarieties.html>

Table 6. Descriptions of Miscellaneous Avocado Cultivars (after Silva et al. 2002)

Cultivar	Parentage	Fruit peel color	Fruit peel texture	Fruit peel thickness	Fruit quality	Fruit flavor	Seed size	Bearing habit	Flower type	Cold limit	Mature season
Duke	Mexican	green	smooth	Very thin	Good	spicy	large	consistent	A	20 F	Sep-Oct
Not commercial due to its thin skin and short season. Valuable to the backyard grower for its good flavor and cold tolerance.											
Jim	Mostly Mexican	green	smooth	thin	Very good	Mild spicy	medium	Fairly consistent	B	24 F	Nov-Feb
Jim has a longer season and better fruit quality than Zutano, better fruit set than Bacon and shorter trees than both cultivars											
Mexicola	Mexican	purple	Very smooth	Very thin	good	Anise-like	large	consistent	A	20 F	Aug-Oct
Extremely cold hardy, but not commercial due to thin skin and too small a fruit. Flavor is very good.											
Stewart	Mostly Mexican	purple	leathery	thin	excellent	flavorful	medium	variable	A	25 F	Oct-Dec
Stewart is rated as one of the best cultivars for cold regions. Production good in some areas and inferior in others.											
Wurtz	Guatemalan	green	pebbly	medium	good	mild	large	alternating	A	31 F	May-Aug
Small tree ideal for gardens. May be sold as Littlecado, "Dwarf" or Minicado											

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Book 1

Chapter 3

Avocado Flowering and Pollination

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A typical full grown healthy avocado tree in California can produce up to a million flowers a year, but, on the average, fewer than 200 flowers per tree will set fruit that will hold and develop to maturity and harvest (about 10,000 lbs/acre, or less). Upon occasion, we have seen some groves with trees setting an average of 500 flowers per tree (25,000 lbs/acre), but this is rare. More commonly, only 100 flowers (or less) per tree will set and hold fruit to maturity (5,000 lbs/acre or less), much to the distress of growers. In short, there is a significant yield potential in most groves that has not been achieved. While there are many factors that contribute to poor yields, some of this failure to reach high yields is related to factors that affect flowering, pollination and fruit set, and probably more factors remain to be discovered. In addition, the avocado flower has a very interesting bisexual quality in which the flower opens twice; first opening in the female stage, then closing and opening the next day in the male stage. This chapter will discuss several factors that influence the ability of trees to flower and set fruit, and the interesting flowering behavior found in avocado will be described.

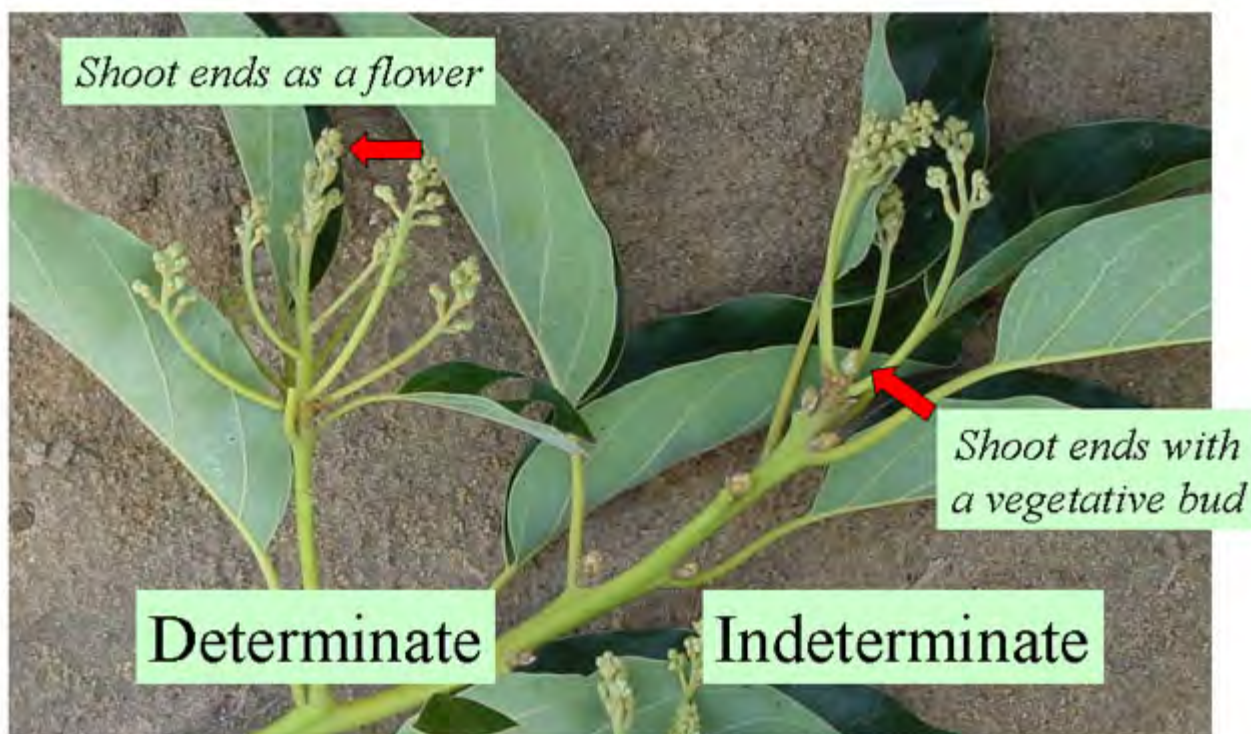
1. Factors that Affect Flower Formation.

The following factors affect flowering in avocado. Further information can be found in the review of avocado reproductive biology by Gazit and Degani (2002).

a. Juvenility. Most grafted avocado cultivars will not begin to flower until the third year after planting. Some cultivars are more precocious; ‘Gwen’ and progeny siblings with the ‘Gwen’ line of genetics, such as Lamb Hass, will often flower in the second year after planting. Most un-grafted seedlings have a long juvenile phase and may not flower for 10 – 15 years after planting.

b. Phenology. Flower primordia are found in terminal or subterminal buds on shoots that grew in the spring and summer flushes of growth. Recent research has shown that differentiation from vegetative buds to reproductive buds takes place at the end of shoot expansion of the summer growth, usually in August in California (Salazar-Garcia et al. 1999). Later, these reproductive buds grow to form multi-branched panicles upon which the flowers form. A tree can have hundreds of panicles and the tree as a whole can have up to a million flowers (Bergh 1986). The panicles are usually determinate (no leafy buds emerging from the panicle), but some are indeterminate (with leafy buds eventually growing from the panicle). Usually these panicles are found on the outer surface of the tree, with maximum exposure to light. This presents a problem in a pruning program; when doing hedgerow pruning or shaping later in the season, many of those shoots that are ready to form panicles and flowers are removed. Research is underway which should address the question whether late season pruning is more detrimental than early season pruning.

Figure 1. Example of determinate and indeterminate inflorescences in avocado



The length of the flowering season is variable according to race, cultivar and temperature. In general, Mexican cultivars flower earliest, West Indian cultivars next, and pure Guatemalans last.

West Indian cultivars flower well in tropical climates, but often flower poorly in the subtropical climate of Southern California. On the other hand, Guatemalan and Guatemalan x Mexican hybrids flower poorly in tropical climates, but flower profusely in California. The lack of flowering in a tropical climate is the reason 'Hass' (a Guatemalan x Mexican hybrid) is not grown as a commercial avocado cultivar in Florida and Hawaii. The 'Hass' cultivar in San Diego County usually has the bulk of flower opening occurring over a six week period from late March to early May. 'Hass' in the more northern counties may have a flowering period about 2 to 4 weeks later than San Diego. However, in some years in San Diego, flower opening begins as early as late January. Flower timing can also vary considerably in a given location. In one grove in San Diego County, in an attempt to apply a bloom spray at 50% flower opening, it was discovered by the author that this occurred on April 7 one year and April 30 the next year.

The length of flowering season for 'Hass' is reduced at higher temperatures. One report has the length of flowering season at 85, 42 and 15 days at 17/12, 25/20 and 33/28 C (day/night respectively) (Sedgley and Annelis, 1981).

Flowering is usually seen to start earlier in the warmer areas of the grove, along the grove roads where there is abundant light and perhaps warmth from the asphalt roads, and on the southwest side of the trees where there is long exposure to sun in the afternoon.

c. Temperature. Flowering in 'Hass' and the other subtropical avocado cultivars is induced by a period of low temperature. 'Hass' did not flower when kept at temperatures of 30/25, 25/20 or 20/5 C (day/night), but did flower when exposed to 3-4 months of 15/10, 18/15, 20/15 and 23/18 C (day night). Under the two last temperature regimes the flowering was delayed and sparse (Buttrose and Alexander, 1978).

d. Day Length. Day length does not seem to be a factor in flower induction in avocados. In Mexico, off-bloom in Hass (known as 'crazy bloom') is induced in September after long (greater than 12 hr) day length. Certain cultivars in California, most notably 'Pinkerton', have a significant off-bloom in the summer. Buttrose and Alexander (1978) reported that 'Fuerte' flowered under both 15 hr day lengths and 9 hr day lengths.

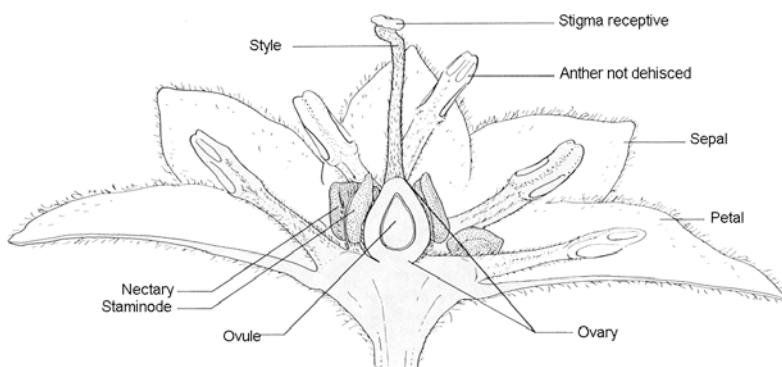
e. Water Stress. Water stress did not appear to increase flowering in trees subjected to either high temperatures or low temperatures. Flowering was delayed after the water stress (compared to the non-stressed control trees) and occurred about a month after cessation of the stress (Chaikiattiyos et al. 1994). It has been observed by the author that water stress in California usually results in less flowering the following spring because water stress almost always leads to chloride tip burn, and eventual leaf drop. With severe tip-burn, leaf drop is excessive and an abnormal leaf flush in the spring is necessary to replace leaves that have dropped. It is believed that the resources in the tree are diverted to leaf growth rather than flower development. Controlled water stress as it affects flowering in avocado has not been studied in California.

f. "On Year" vs. "Off Year". More information needs to be learned about why avocados have "on" and "off" years, but it is suspected that starch levels and perhaps certain growth regulators need to reach certain levels and in balance with each other for the tree to flower heavily. It has been noted that not all shoots develop flowers; in an "on" year 46% of shoots developed flowers but only 13% of shoots developed flowers in the "off" year (Salazar-Garcia et al. 1998, Salazar-Garcia and Lovatt 2000). In the year after an extremely heavy crop, some trees do not develop flowers at all.

2. Basic Flower Structure.

Female Stage: The avocado flower opens twice, opening first as a female, closing overnight, then opening as a male for the final opening. The female flower has all nine stamens bent at almost a 90-degree angle to the central erect pistil. The stigma is white and receptive to pollen, but the pollen has not yet been released from the closed pollen sacs at the ends of the stamens. Nectar is secreted from the three staminodes.

Figure 1. Female Stage



Male Stage: After closing overnight, the flower opens as a functional male. The six stamens of the two outer whorls fold closer to the pistil (about a 30 to 40 degree angle from the pistil). The three stamens from the inner whorl stand erect next to the pistil. Nectar is secreted by three pairs of nectaries. Anther dehiscence (splitting to release pollen grains) occurs 1-2 hours after the second flower opening. The surface of the stigma sometimes will remain white, sticky and receptive to pollen, but normally the stigma is brown and shriveled by the time

pollen is released. About half of the avocado cultivars open as female in the morning, and the other half as female in the afternoon, leading to the classification of “A” and “B” cultivars (Lahav and Gazit, 1994). (See “The Remarkable Avocado Flower” below for further information).

Figure 2. Male Stage

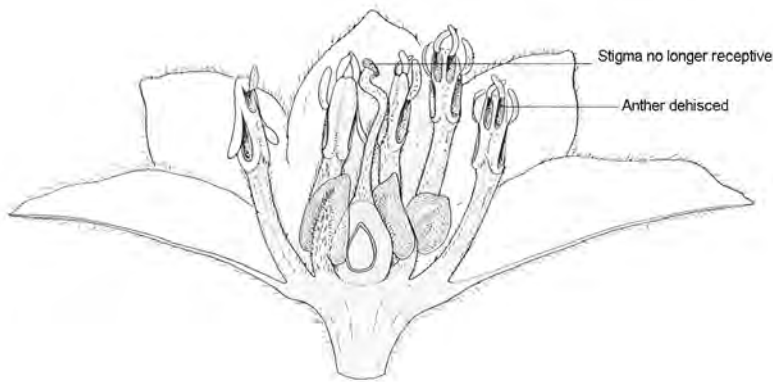


Figure 3. Stage 1 Floral Opening



Figure 4. Stage 2 Floral Opening

*Photos courtesy of Dr. Tom Davenport,
University of Florida*

The Remarkable Avocado Flower (adapted from Bergh, 1974 and Silva, Lovatt and Bergh, 2002).

“Avocado flower behavior is noteworthy – nothing quite like it is known in any other plant. The avocado flower has both female and male organs, which means it is structurally “perfect”, or “bisexual”, which is not unusual. What is unusual is that the avocado male and female organs within one flower do not function at the same time.

Each avocado flower is functionally unisexual. Each flower is female when it first opens. That is, its stigma will receive pollen from other avocado flowers, but its stamens do not shed pollen at this first opening.”

The female-stage avocado flower has a receptive stigma but also nonfunctional male parts (Figure 1). The female stage flower opens first, but for only 2 or 3 hours. The flower then closes and remains closed the rest of the day and that night. The following day, the flower opens again. But now the stigma will ordinarily no longer receive pollen. Instead, the flower now sheds pollen, and is known as a male-stage flower. After remaining open for several hours on the second day, the male-stage flower closes again, this time permanently. Thus each avocado flower is female at its first opening and male at its second opening.

In California, honeybees transfer pollen from male-stage flowers to stigmas of female-stage flowers. Once pollen has been successfully transferred to the stigmas, a process known as *pollination*, the pollen germinates, producing a pollen tube that advances through the style and ovary tissues to the ovule, which contains the egg. Depending on temperature, the pollen tube requires only about 2 to 4 hours to reach the ovule. Once the pollen tube delivers the sperm to the egg inside the ovule, the sperm and egg must fuse, a process known as *fertilization*, which results in formation of the embryo. The process of fertilization initiates the development of the ovary into a mature avocado fruit, and the ovule into the seed, inside of which is the embryo. This embryo can then develop into the young seedling avocado tree of the next generation. The seed provides plant growth regulators necessary for fruit set and fruit development.

Nature has provided for avocado cross-pollination by creating two kinds of botanical varieties. The A type flower is functionally female in the morning of the first day and functionally male in the afternoon of the second day, if the weather is warm. The B type flower is functionally female in the afternoon of the first day and functionally male in the morning of the second day, as diagrammed below.

	First Day		Second Day	
	Morning	Afternoon	Morning	Afternoon
A type	Female (stigmata receptive)			Male (sheds pollen)
B type	Female		Male	

Since different flowers open on different days, the two types of avocado cultivars complement each other with their diurnal synchrony. Both are functionally female on their first day and functionally male on their second day, but they differ in the time of day that they are male and female. A variety of one type provides pollen (functionally male) when a variety of the other type is receptive (functionally female). Therefore, the pollination and fertilization necessary for fruit set can occur.

On trees of an A-type cultivar, flowers open for the first time in early or midmorning, remain open and pistil-receptive until about noon, then close and remain closed until about noon of the second day, when they reopen and begin shedding pollen with the pistil no longer receptive. Finally, they close permanently that night. On a single tree, there may be thousands of flowers that open for the first time the same morning and then follow the same behavior pattern synchronously hour after hour for their 2-day existence. The total opening cycle on an A-type tree covers about 36 hours. Flowers on trees of a B-type cultivar function analogously but with transposed timing. The opening cycle on a B-type tree spans about 24 hours. The difference in cycle time reflects the relative length of the closed period between openings.

The two flowering types behave with clocklike exactness only when the average temperature (night minimum and day maximum) is above about 70°F (21°C). As the temperature falls, the daily openings for the functionally

male and female flowers become delayed and irregular such that a single tree may have flowers in both the female and male stages at the same time, which explains how large blocks of just one cultivar set heavy crops via self-pollination. With colder temperatures, the second (male) opening may be delayed 1 or more days, and other abnormalities in flower behavior may occur. Either opening may continue through the night and into the next day. Below 60°F (16°C), however, there may be zero fruit set.

Recent research at University of California, Riverside has shown a weak positive correlation between cross-pollination and yield in some Hass avocado orchards, but the total data suggested that self-fertilization was responsible for a substantial portion of fruit set in California groves. However, in earlier studies, when an A-type and a B-type variety grew with their branches overlapping or at least close together, fruit set increased by 40 to 150 percent. Many commercial growers plant B-type cultivars to provide a complimentary source of pollen for the Hass avocado, an A-type, and place beehives in their orchards. Since home gardeners are not concerned about yield and bottom-line profit like a commercial grower, they do not need to make provision for cross-pollination. Nevertheless, it is useful to understand the factors that can influence fruit set and that can be used to increase fruit set, if desired.

A sampling of cultivated varieties classified as A types or B types are listed below:

- A-type cultivars: Hass, Gwen, Pinkerton, Reed, Anaheim, Lamb Hass
- B-type cultivars: Fuerte, Zutano, Bacon, Whitsell, SirPrize”

Under typical California weather conditions, which are subtropical, both the A- and B-type cultivars bloom continuously for about 2 months, and it is rare for the earliest cultivar to finish blooming before the latest begins. Whereas summer flush vegetative shoots of the Hass avocado in California transition to reproductive shoots and initiate inflorescences sometime from the end of July through August, individual avocado flower buds are initiated at most about 2 months before the tree is in full bloom. The seasonal cycles of flowering, fruit set, and fruit development for the Hass avocado in San Diego—Riverside environmental conditions are shown in figure 5.

Avocados produce two types of floral shoots: determinate floral shoots, in which the apical bud is a flower, and indeterminate floral shoots, in which the apical bud remains vegetative and produces a vegetative shoot. Determinate floral shoots occur along the branch, and indeterminate floral shoots are formed at the end of a shoot (branch). The number of flowers per inflorescence of the Hass avocado is approximately 150.

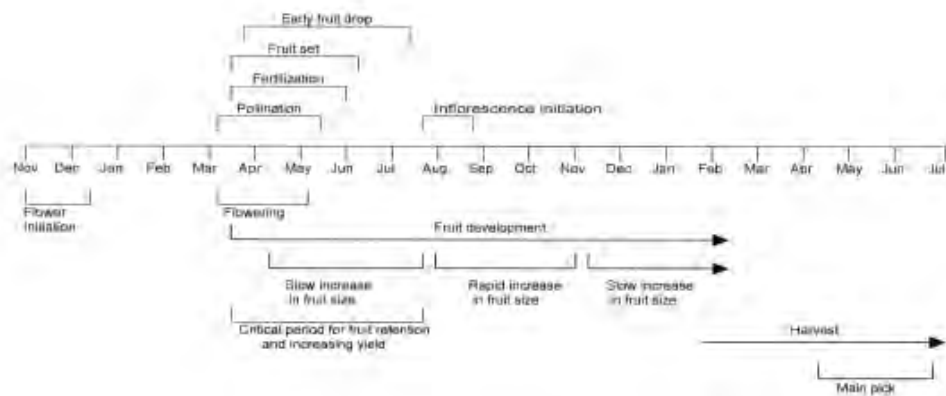


Figure 5. Flowering, fruit set, and fruit development of the Hass avocado in California.

Source: After Lovatt 1999; based on San Diego-Riverside environmental conditions

Hass avocado trees in California produce approximately 90 percent indeterminate floral shoots. This type of floral shoot sets less fruit than a determinate floral shoot. However, fruit set should not be a concern since a single tree will likely have a million flowers in bloom during a single spring bloom period. Despite the fact that

less than 0.1 percent of this total results in fruit that hold to maturity, good yields are obtained. A yield of 200 8-ounce (229-g) fruit, or about 100 pounds (45 kg) per tree, results from approximately 0.02 percent fruit set.

Avocado trees have a strong tendency to alternate or biennial bearing, alternating moderate to heavy crops one year with light crops (low yields) the next year. This condition can be initiated by climatic or cultural conditions that result in excessive fruit drop and poor yield or by optimal conditions for fruit set that result in a bumper crop. Spring flush vegetative shoots arising from indeterminate floral shoots that set fruit do not produce inflorescences the following spring. Thus, when trees are carrying a heavy crop, the number of shoots that can produce inflorescences the next spring is significantly reduced. This is the cause of the low fruit set and yield that occur in the year following the heavy crop.

3. Problems Created by Low Temperatures.

As mentioned by Bergh (see above), flower opening and closing follows a regular pattern when the average night minimum and day maximum temperature is above 70 F (21 C). As night minimum temperatures and day maximum temperatures drop, flower opening is delayed. The female opening of A flower cultivars may be delayed into the afternoon, while the B flower cultivars may open as females at night or the next morning. Under these cooler conditions there might be 2-4 days between opening of the female/male flower phases.

The B flower cultivars may completely fail to open as female flowers at the lower temperatures. When exposed to maximum day temperatures between 18 and 21 C, and minimum night temperatures between 7 and 12 C, no female flower opening occurred in Fuerte (B flower) (Leslie and Bringhurst 1951). Under these conditions, Hass (A flower) completed the proper flower cycle.

While cooler temperatures may delay flower opening, this may be a benefit to some degree because overlapping of female and male flowers increases, presumably insuring pollination in a grove of pure "A" type flowers such as Hass. An overlap of 45 min to 90 min was found to occur in Hass during the mid-day (Ish-Am and Eisikowitch, 1989).

In addition, cooler temperatures (and cloudy skies) reduce the bee activity in the grove.

4. Types of Pollination.

There are three types of pollination in avocado; cross-pollination, self-pollination, and close pollination.

Cross pollination occurs when pollen is transferred from male flowers of a type A cultivar to female flowers of a type B cultivar, and vice versa. The flowering behavior of avocado, in which one type will be in the female stage while the other type is in the male stage, seems to promote cross pollination. Indeed, there are several observations and studies that indicate increased yield when type A trees are close to type B trees, with bees present to move the pollen from flower to flower (Nirody, 1922, Stout, 1923, Peterson, 1955, Bergh and Garber, 1964, Gustafson and Bergh, 1966, Degani, et al. 1989, Markle and Bender, 1992). The efficiency of cross pollination depends on the distance between the pollen-donor (pollinizer) tree and the pollinated tree. The yield-increasing effect is best when A and B trees are one or two rows away from each other; if the trees are farther away there may not be a substantial yield increasing effect. Also, there must be a substantial overlap between the male and female bloom, and bees must be at sufficient density to carry the pollen back and forth from pollinizer trees to pollinated trees.

Isozymes and RAPD genetic markers have become useful tools for determining the amount of out-crossing (cross-pollination) in avocados. Recently, using RAPD markers, Kobayashi et al. (2000) found a weak correlation between yield and the rate of cross pollination in Hass in California, concluding that most of the pollination in their study was by close pollination or self-pollination. However, their yield data indicated that there was a definite effect when the B flower trees were adjacent to Hass (4 year average = 205 fruits per tree).

When the B flower trees were 5 rows away the 4 year average yield was 90 fruit per tree, and when 15 rows away the 4 year average was 54 fruits per tree.

In another study in Israel, Degani et al. (1989), using Fuerte and Ettinger as pollinizers, found that Hass fruitlets one month after set were mostly 'selfs' (Hass pollinated Hass), but as the season progressed, the percentage of Hass selfs decreased and the percentage of Hass hybrid fruitlets increased. By the end of fruit abscission, most of the fruitlets still on the trees were found to have been hybridized by pollen from Ettinger. Hybridization from Fuerte was not near as strong as it was from Ettinger. They reported "the Hass fruit yield was found to correlate significantly with the rate of out-crossing with Ettinger". The conclusion was that hybridized fruit tend to stay on the tree better; selfed fruit have a higher drop rate.

Ettinger is not normally grown in California, but Zutano, Bacon and Fuerte are B flower cultivars that should (in theory) serve as cross pollinizers. Lacking data to indicate which is best, it can only be said from observations in the field that Zutano, followed by Bacon, seem to consistently give good yields to nearby Hass trees.

In the past it was recommended in California to plant a pollinizer tree at every third position in every third row (Lee, 1973), but this recommendation was in an era when the fruit from the B flower trees had a relatively good market. As the market declined for greenskins (in favor of Hass), some growers tried using B flower Zutanos and Bacons as windbreaks around the grove. The age-old question remains: does the yield increase in the Hass near the pollinizers make up for the loss of yield when a Hass is replaced by another variety that does not have a good market? The answer to this question still has not been answered to any satisfaction, but in our observations in California it appears that if a grove is subjected to cool temperatures in the spring, there may be a definite benefit from pollinizer trees. There might not be a benefit when temperatures are mild.

One idea being tried by some growers is to thin a crowded grove (removing every other tree on the diagonal) and graft a Zutano bud into a sucker on the stumps of the removed trees. The Zutano tree would be kept small; essentially the trees would be used only as pollinizers and not as a crop to be harvested.

One of the main goals of the avocado breeding program in California is to develop a B flower Hass-like cultivar that could be inter-planted into every other row in a Hass grove, and be harvested and sold as Hass.

Close pollination occurs when pollen from male flowers land on stigmas of female flowers during the daily overlap period of male and female stage flowers in the same tree (or between neighboring trees in the same cultivar). During cool weather, the afternoon bloom may not occur until the next morning and overlaps with the normal morning bloom, but cool weather also slows down bee activity that could lead to less pollination. We have observed male/female overlap around noon in most groves, some more pronounced than others. With good bee activity, close pollination is probably most important during this time period.

Self pollination occurs in a single flower. In avocado, self-pollination happens only in a male-stage flower when a stamen releases pollen that falls into the stigma that is still receptive. This process may be completed by wind blowing the pollen a short distance, or by gravity. In California, caged tree studies without bees or an alternate flowering cultivar has always led to very poor fruit set. Because of this, we assume self-pollination in Hass is not important. Gustafson and Bergh (1966), in a review of pollination in avocado, stated "an individual flower apparently cannot pollinate itself and subsequently produce a fruit. It is important that the pollen not only reach the stigma, but that it arrive there at the proper time in the flower cycle." This statement has been somewhat controversial because cages invariably add a windbreak factor, a shading factor, and a cooling factor to the experiments. In the more tropical climate of southern Florida, however, Davenport et al. (1994) have shown evidence that pollination in the male stage is important, possibly because the stigmas stay white and receptive to pollen germination in the more humid climate.

In the dry Mediterranean climate of California, cross pollination and close pollination are probably most important for fruit set because the stigmas in the male-phase flowers dry quickly, precluding self-pollination. When humidity is high (as it is in Florida), self-pollination is probably the predominant method for setting fruit.

5. The Role of Bees in Pollination.

Bees appear to be very important for moving pollen from the male stage flowers to the female stage flowers, completing the pollination process in cross pollination and close pollination. O.I. Clark observed in the 1920's that heavy crops in avocado were associated with greater work by bees on the blossoms (Clark, 1922-23). He also observed some things that we see today:

- “Bees prefer other bee pasture to the avocado orchards.” We often see bees flying over or around avocados to get to citrus in bloom or other sources of nectar.
- “When bees are abundant or other pastures scarce, they do work freely on avocados.”
- “Bees have a strong preference to sticking to one avocado tree at a time.” This inhibits cross pollination between cultivars, unless the trees are very close, or intermingling with each other. Ish-Am (2000) added “Most honey bees collect nectar and pollen within a limited area of 1 to 3 trees. They often perform cross pollination only between neighboring trees that carry opposite-stage flowers and are at a distance of not more than two rows. A small percentage of the foraging honey bees (2 – 4%) move farther between rows and fields, and may carry avocado pollen for hundreds of yards away from its source.”

The importance of bees was confirmed by University of California, Riverside geneticist Peter Peterson (1955) when he caged four trees, two Zutano and two Hass, and put a small hive of honeybees in one the Zutano cages and one of the Hass cages. The results from that test were:

	Number of fruit on each caged tree	
	Beeless	Bees
Zutano	4	120
Hass	5	284

Steps to take to Improve Pollination

1. Bring beehives into the grove. The University of California farm advisors have usually recommended 1 – 2 strong hives per acre, but Ish-Am (2000) suggests that 1 hive is rarely sufficient, and in many cases 4 hives are required. California growers usually have to rent hives (in 2002 hive rentals averaged \$42 per hive), but sometimes beekeepers will drop a load of 80 hives for free if the grower has good bee forage nearby. Bees should have water available; floating boards on ponds or reservoirs enables them to land and drink without drowning.
2. Add pollinizers to the grove. Ish-Am recommends a pollinizer tree row be located at least every fourth row. Some growers in California use pollinizers as wind-breaks around the grove, and some replace thinned-out trees with pollinizers.
3. Keep the orchard open. Direct sunlight should reach the lower branches of each tree in order for the trees to produce a “wall” of flowers down the ground. In avocado production, this can only be accomplished by pruning the upper branches on a yearly basis. Keeping open channels through the grove encourages the flight of bees.
4. Other types of bees? Bumblebees have been reported to increase yield in avocados in Israel where honeybee populations were low. New World Carniolan bees have been used in an experiment in San Diego County for pollination: results were inconclusive as to whether they increased yield compared to

Italian honeybees, but it was found that they gather more nectar from avocado (Fetscher et al. 2000). Work with these bees, and other wild bees, may eventually reveal a more efficient pollinator for avocado.

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Book 1

Chapter 4

Avocado Rootstocks

Authors: Gary S. Bender, John A. Menge, and Mary Lu Arpaia

Commercial producing avocados are not grown to maturity from seedlings, but rather, like most commercial fruit crops, are grafted with good known varieties onto rootstocks. Common seedling avocado rootstocks in California have traditionally been selected from the Mexican or Guatemalan races of *Persea americana*. The third race, the West Indian, has not been used due to concerns that they would not tolerate California's cold winters. Most of the California avocados were grafted onto Topa-Topa rootstocks (a pure Mexican variety) because they germinated uniformly in the nursery and provided thick shoots that were ideal for tip-grafting. Horticultural traits were generally not considered, and in fact Topa-Topa is very susceptible to both root rot (caused by *Phytophthora cinnamomi*) and salinity.

In most fruit crops, improved rootstocks for production in California are selected to impart a beneficial horticultural quality to the tree, such as increased fruit yield, vegetative vigor, dwarfing, salt tolerance, lime tolerance, and disease resistance. The devastation caused by *Phytophthora* root rot in the avocado industry caused researchers to concentrate on finding tolerance or resistance to the disease problem as the first priority (Whiley et al. 1990). A program begun by Dr. George Zentmyer at the University of California, Riverside in the 1950's has resulted in the selection of a number of root rot "tolerant" rootstocks that have become available to growers, and identification of promising genetic material for breeding in the future. Rootstocks that originated from the Zentmyer (and later the Michael Coffey) research programs include Duke 7, G1033, G6, Martin Grande (collectively G755A, G755B, G755C), Barr Duke and Thomas (Coffey and Guillemet 1987). Other rootstocks of interest have emerged from efforts by private nurserymen; most notable is the Toro Canyon which has some degree of salinity and root rot tolerance. (H. Brokaw, personal communication). Starting in the early 1990's, John Menge carried on the rootstock selection program at University of California, Riverside that resulted in even more promising selections that are currently being field-tested. The Zentmyer and Coffey programs concentrated on testing rootstock material imported from Central America, and in selecting "escape" trees from local orchards in California. Menge is continuing to import and test selections from research programs in Israel, Mexico, Central America, Australia, and South Africa, and has begun to cross selections in special open-pollinated isolation blocks in California. Seedlings from these isolation blocks are tested for improved resistance to root rot.

While the search for root rot tolerance led the way in rootstock development in California, knowledge of other important characteristics of rootstocks has lagged behind. A notable example of a problem that almost developed was a University recommendation in the late 1980's to plant G755 (Martin Grande) rootstocks in *Phytophthora*-infested soils because of its consistently good ratings for tree growth in replant situations. Researchers were not aware that Hass/G755 was very slow to come into bearing until Arpaia, Bender, and Witney reported yield data from their rootstock trial on "clean" soil in Irvine, CA (Arpaia et al. 1995). While the search for root rot tolerance is still a top priority in the industry, it has also become a priority to study other cultural aspects of rootstocks.

Fortunately, the California avocado industry may benefit in the future from a rootstock selection program in Israel. It was discovered in the 1940's that West Indian selections generally had more salinity tolerance than Mexican selections (Oppenheimer 1947). In 1982 Ben-Ya'acov began a program to select the most salt-tolerant West Indian selections that also showed that least lime-induced chlorosis (Ben-Ya'acov and Michelson 1994). Some of these selections are also believed to have some degree of root rot tolerance. The best of Ben-Ya'acov's selections were brought to California in 1999 and, under a research program headed by Dr. David Crowley at

UC Riverside, are now out in field trials with highly saline water for irrigation. These selections will also be tested for root rot tolerance. Although West Indian selections are still believed to be sensitive to cold, most of the California avocado groves are located on slopes above the frost line, thus a good salt-tolerant West Indian rootstock may find an important place in the future in California avocado production.

Root Rot Tolerance and Replanting

There is no true “resistance” to *Phytophthora cinnamomi* in the avocado rootstocks that are graft-compatible to scions of *Persea americana*. There is (to date) only a degree of “tolerance” to the disease based on the capacity of the rootstock to regenerate roots rapidly (Duke 7), or a physiological response which retards lesion development (as found in Martin Grande) (Coffey 1987a). Therefore, successfully re-establishing avocados into a soil where previous avocados had died from root rot is not as simple as merely replanting with a tolerant rootstock.

Rootstocks that have root rot tolerance and are currently available for the commercial industry include Duke 7, Thomas, G-6, Barr Duke, D-9, Toro Canyon, and Martin Grande (G755). Of this group, Thomas has consistently given the highest ratings for tree survival and growth when replanted into root rot soils. Care must be taken, however, because Thomas is susceptible to a trunk canker caused by *P. citricola*. Thomas may also have increased susceptibility to trunk cankers caused by *Dothierella* fungi (Menge, personal communication). Martin Grande has also performed well in some root rot replant trials, but is not recommended due to poor performance in yield trials (Arpaia et al. 1995). A new selection that is performing better than Thomas in root rot trials is the PP4 (recently named ‘Zentmyer’). After further testing, this rootstock should be released to the industry by the year 2003. A summary of rootstock characteristics based on research and observation in California is presented in Table 1.

Also available to California growers will be two selections from South Africa known as Merensky 1 (a Duke 7 seedling formerly known as Latas) and Merensky 2 (South African selection formerly known as Dusa). In limited trials in California, they have been performing slightly better than Thomas in root rot tolerance, and about equal to Zentmyer. They have not been in horticultural trials in California; therefore, we do not know about their fruiting potential or other characteristics. Both of the South African selections performed well in salinity field trials.

**Table 1. Characteristics of Avocado Rootstocks
Commercially Available to Growers in California**

	Topa Topa	Lula	G-6	Duke 7	Thomas	G755A,B,C (Martin Grande)	Barr Duke	Toro Canyon	D9	Borchard
Normal Propagation Method	seed	seed	seed	clonal	clonal	clonal	clonal	clonal	clonal	clonal
Horticultural race	Mexican	Guat. X West Indian	Mexican	Mexican	Mexican	Hybrid- <i>P. americana</i> x <i>P. shiedeana</i>	Mexican	Mexican	Mexican	Mexican
Parentage			seedling	Duke	escape seedling	market collection	Selfed Duke 6 seedling		Irradiated Duke seedling	
Geographic origin	California	Florida	Antigua, Guatemala	UC Riverside	Escondido, CA	Guatemala	Fallbrook, CA	Saticoy, CA	UC Riverside	Camarillo, CA
Productivity "clean" soil (a)	3	?	3	4	2	1	3	3	2.5	4
Productivity "root rot" soil (b)	1	?	3.5	3	3	2	3	3.5	3	2
Tree size "clean" soil (a)	5	?	5	5	5	5	5	4	4	5
Tree size "root rot" soil (b)	0.5	0.5	1	2	4	1.5	1.5	3	2.5	0.5
Tolerance to <i>P. cinnamomi</i> (c)	0	?	2	3	4.5	5	3.5	2.5	3.5	0.5
Tolerance to <i>P. citricola</i> (d)	3	?	3	4	2	3	3	5	4	3
Salt tolerance (e)	2	?	2	3	1	2	2	3	3	3
Frost tolerance (f)	4.5	1	4.5	4	4.5	1	4.5	4.5	4.5	4.5
Tolerance to <i>Dothierella</i> (g)	5	?	2	5	2	?	5	5	5	5
Legend: 0 = poor, 5 = best										
Ratings by J. Menge, G. Bender, and M.L. Arpaia, 2002										
Footnotes:										
a. Yield and canopy volume expressed as percentage in comparison to Topa Topa, based on 7 years of data (6 years for Thomas) at South Coast Field Station (Arpaia et al. 1993)										
b. Yield and canopy volume expressed as percentage in comparison to Thomas (consolidated data from J.A. Menge, 2002)										
c. Consolidation of performance of young replant trials, ratings by John Menge										
d. Results from greenhouse trials by A. Alizadah and J. Menge (unpublished)										
e. Rootstock trial in sand tanks treated with three levels of saline water (Oster and Arpaia, 1991)										
f. Observations by G. Bender and J. Menge after freezes in 1988-1991.										
g. Results from greenhouse trials by A. Alizadah and J. Menge (unpublished).										

To increase the chances for survival and growth of the young replant tree, the root-ball should be drenched with a solution of fosetyl-Al (Aliette) or a solution of buffered phosphorous acid at the time of planting, followed by two to three foliar sprays with the same chemical that year. Mounding to improve drainage (to keep the root ball above the level of native soil), mulching with a wood-based mulch (3-4 inches deep, keeping the mulch away from the trunk to avoid excess moisture) and applications of gypsum (10 –20 pounds per tree) to the soil should all be done at the time of planting to help the young tree withstand *Phytophthora* infection. Great care must be taken to water the young trees correctly. Avocado trees that have been watered daily at the nursery cannot be placed on a once-a-week irrigation schedule, the schedule often seen in a mature grove. At the same time, they cannot withstand standing water and poor drainage. The young trees should be placed in their own irrigation block, with a tensiometer placed at the edge of the root ball of a representative tree guiding the irrigation frequency.

The Clonal Rootstock. Since the early 1950's, researchers at the University of California, Riverside have scouted for avocado trees apparently surviving *Phytophthora* root rot in areas of southern Mexico, Guatemala, and other countries in Central America. Unusual-looking avocado fruit have also been purchased from local markets (in the hopes of finding wild hybrids) and the seed from these selections were shipped to the University of California under USDA permit. These selections, along with local selections found in California, are subjected to rigorous screening either in water-bath tanks infested with *P. cinnamomi* zoospores, or in soil infested with high populations of *P. cinnamomi* propagules. Surviving trees are usually subjected to a second screening; the survivors are grown up and eventually placed in field trials in infested groves.

Promising selections are also grown as un-grafted trees for later use by the University and by private nurseries. Most of these trees produce seed for propagation, but some do not, and some are very slow to come into production. In addition, seedlings grown from these seeds are variable in quality and usually do not have the same degree of root rot tolerance as the parent tree. To overcome this problem, a "cloning" technique was developed by Edward Frolich at U.C.L.A. in order to preserve the desired characteristics of the parent tree (Frolich and Platt 1972). To produce the clonal rootstock, budwood from the Duke 7 tree (for instance) is grafted onto a vigorous seedling in the greenhouse. After six to eight weeks, the young plant is placed into a darkened chamber for about 10 days. The lack of light causes "etiolation", a blanching of the green bark. Etiolation is necessary because avocados have difficulty rooting from cuttings with green bark, but less so with bark that is blanched by lack of light. Rooting hormone is then applied to the lower part of the Duke 7 scion, soil is either brought up around the lower part of the Duke 7 scion, or the whole plant is re-potted so that the lower part of the Duke 7 scion is buried, and rooting takes place from the etiolated Duke 7 bark. Eventually a Hass or other suitable avocado variety is grafted onto the Duke 7. Some nurseries place a constriction ring around the base of the clonal rootstock (below the clonal roots) so that the seedling roots are constricted and eventually die, leaving only the clonal roots. Other nurseries will clip off the seedling roots, and still other nurseries will leave the seedling roots attached with the belief that the extra roots will help the tree establish better at planting time.

Unfortunately, because of the extra care required to produce a tree on a clonal rootstock, the trees are more expensive, usually about twice the cost of a tree on a seedling rootstock. Given the problems that can occur in the grove with an eventual invasion by *P. cinnamomi*, the initial investment in clonal rootstocks is prudent.

Yield. Yield is obviously an important factor in choosing a rootstock. The only long term trial comparing yield and other horticultural attributes of Hass grafted onto various rootstocks in "clean" soil (without the presence of *P. cinnamomi*) is at the UC Research and Extension Center in Irvine, CA. That project was started in 1986; results were reported in 1995 (Figure 1) (Arpaia et al. 1995) and in 1996 (Arpaia et al. 1996). The rootstocks that were evaluated were clonal-propagated G755A, G775B, G755C, Toro Canyon, Borchard, Duke 7, D9, Thomas, and G1033. Clonal propagated Topa Topa is also in the trial to serve as a control. (Most of the avocado trees in California are grown on seedling Topa Topa). Thomas and G1033 were planted a year after the initial planting because the trees weren't available at the time of planting in 1986.

Yield per Tree (lbs)

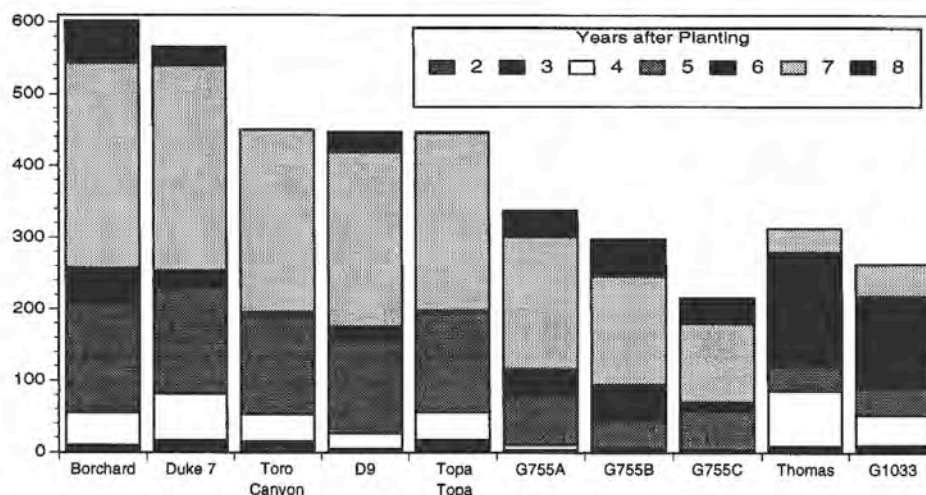


Figure 1. Cumulative yields (lbs/tree) of Hass avocado on clonal rootstocks after 8 years field production under *Phytophthora* – free conditions (Arpaia et al. 1995).

After nine years, Borchard and Duke 7 were the highest producing rootstocks. It should be noted, however, that Borchard is susceptible to *P. cinnamomi* and would probably not be recommended if there were a possibility of root rot contamination in the grove. The Toro Canyon, D9 and Topa Topa rootstocks have comparable and moderate yields, and the three G755 rootstocks were less productive. Although they can't be compared directly, it should be noted that through the eighth year, Thomas and G1033 were bearing at a rate slightly ahead of G755A.

Yield efficiency was also calculated with the thought that trees with more fruit per canopy volume could be the better choice of rootstock, especially if the trees were planted on a closer spacing than the 20' x 20' spacing in this trial. After 6.5 years, Borchard produced the largest trees and Toro Canyon and G755C produced the smallest trees; the others were comparable in size. After 7.5 years, the Borchard still produced the largest trees, G755C produced the smallest trees, and Toro Canyon was comparable to the others. When the yield in the seventh year (an "on" year) was divided by the 6.5 year canopy volume, Toro Canyon emerged as the most efficient in yield per canopy volume, followed closely by Duke 7, D9, Topa Topa and Borchard. In this comparison, Thomas in the seventh year ranked sixth in yield efficiency, followed in order by G1033, G755A, G755B and G755C.

Toro Canyon continued to be the most efficient tree in the ninth year, followed by Topa Topa, Borchard, and Duke 7.

Yields from the new generation of root rot-tolerant rootstocks from the Menge research program will continue to be evaluated in "clean" soil (and in root rot soil) in the coming years from new plantings at the South Coast Research and Extension Center.

Salinity Tolerance. Tolerance to saline irrigation water is emerging as a very important quality for avocado rootstocks in California. Not only are more growers drilling wells (which often produce water of higher salinity than district water), but also reclaimed water (with a higher salinity content) is becoming more available in the avocado-growing districts. The familiar "tip-burn" on the leaves in the fall is a sign that the tree is absorbing too much chloride during the season, and these leaves will have to drop off of the tree during the winter. Leaves

that grow to replace these leaves often grow at the expense of flowering and fruit-set, resulting in chronically low yields in some groves.

Rootstocks vary in their ability to absorb and transport chloride and sodium. Of the avocado races, Mexican rootstocks are most susceptible to salinity and West Indian rootstocks are the most tolerant of salinity. Guatemalan rootstocks are generally intermediate in their tolerance of salinity, although Embleton found that the Guatemalan cultivar 'Anaheim', when used as a rootstock, induced more chloride accumulation in the scion than did neighboring Mexican rootstocks (Embelton et al.1962). As previously mentioned, Mexican rootstocks are the most common type in Southern California due to their tolerance of cold weather, colder soils, and heavier soils. Unfortunately, only limited research has been conducted in California on comparative salinity tolerance of the different types of Mexican rootstocks

One study reported in the literature compared the effects of salinity on young Hass grafted onto Thomas, Toro Canyon, Parida, Duke 7, G755B, or Barr Duke (Oster and Arpaia, 1991). These plants were grown in sand tanks, irrigated once a day with one of three different saline water solutions (2.2, 3.2 or 4.2 dS/m). The trees were grown for nine months under these saline conditions, then harvested and analyzed.

Trees were visually rated on a scale of 1 to 5, where 1 represented vigorous growth and 5 represented a dead plant. Toro Canyon and Duke 7 had the best appearance with ratings of 1.56 and 1.83 respectively. Barr Duke had the worst appearance with a rating of 2.56. Thomas, G755B, and Parida were intermediate in appearance with ratings of 2.00, 2.28, and 2.33. Toro Canyon, Parida, and Duke 7 had the lowest amounts of chloride in their leaves in that order; Thomas, G755B and Barr Duke had the highest chloride content in their leaves. Parida had the highest sodium levels in the new growth of any of the rootstocks whereas Toro Canyon and Duke 7 had the lowest levels of sodium in their new growth.

Field experience has indicated that Thomas would not be a good selection for replanting into areas with highly saline irrigation water. Of the rootstocks available to growers, Toro Canyon or Dusa (Merensky II) would probably be the best choices for this situation, but long-term trials under saline conditions have not yet been conducted.

Research is now being conducted by David Crowley (University of California, Riverside) with West Indian rootstock selections developed in Israel by A. Ben-Ya'acov. The Israeli program identified approximately 50 clones of high yielding West Indian selections when grown under saline conditions. Ben-Ya'acov and colleagues noted that under conditions where chloride in the irrigation water is 100 ppm, avocado production on West Indian vs. Mexican rootstock is approximately equal. However, when chloride levels equal 300 ppm, Hass avocado production from the VC 51 rootstock (West Indian) was approximately double that of VV57 (Mexican) (Ben-Ya'acov et al, 1991). Ben-Ya'acov noted that these trees must be grown under well-drained conditions in order to be successful.

A recent field trial in which the California rootstocks were compared to the West Indian selections from Israel and two selections from South Africa gave surprising preliminary results: the Merensky I (Latas) rootstock from South Africa did better than any of the other rootstocks as far as growth and appearance of the Hass scions, followed closely by Merensky II (Dusa) (Crowley, Arpaia and Bender, unpublished). Research is continuing to determine if Hass, Merensky I, and Merensky II rootstocks will perform satisfactory in long-term yield trials.

If we can find a salt-tolerant rootstock that shows some degree of cold tolerance and root rot tolerance, we might be able to greatly improve the rootstock choices for California growers.

Frost Tolerance

There are no reported data on the effect of frost on Hass according to rootstock variety. There is, however, a rating by Menge of the foliage of un-grafted rootstocks. This rating was performed two weeks after a freeze event in Riverside, California in January, 1991. The rating value was the average rating of two rootstocks of the

same variety. Due to the low number of trees per rootstock, this cannot be construed to be a scientific rating, but the information may be of interest. In this rating, 0=healthy, 5=dead.

Table 2. Frost damage on various un-grafted rootstocks at UC Riverside – January 1991

Rootstock	Visual Rating 0=healthy, 5=dead	Rootstock	Visual Rating 0=healthy, 5=dead
Thomas	0	1033	2.5
D9	0	Nabal	3
G6	0	Hass parent	3
Barr Duke	1	Bacon	3
Topa Topa	1	G755 A	3
Duke parent	1	Reed	3.5
Fuerte	1.7	Anaheim	3.5
Duke 7	2	G755B	3.5
Rincon	2	Lula	4
Wurtz	2	G22	4
Susan	2	McArthur	4
Duke 6	2	Hass Prince	4
Zutano	2	G755C	4

Flower Timing

Certain rootstocks may have an effect on the timing of flowering. The first author has noted that, in side-by-side plantings, Hass on G6 are often two to three weeks later in flowering than Hass on Topa Topa. This effect has either not been noticed in other rootstock trials, or has not been recorded in the literature.

This effect could be important if bees work the flowers better late in the bloom due to warming temperatures, or the trees are able to take up more nutrients later in the spring because of warming soil temperatures. Hopefully this can be an area of more intensive research in the future.

Rootstocks for the Future

The rootstock selection and breeding program in California is very active. Under the direction of John Menge, the program evaluates selections from foreign countries, escape trees in California, and seedlings from isolated breeding blocks. The primary focus is to select rootstocks with improved tolerance to root rot. Mary Lu Arpaia is evaluating the better selections for improved horticultural characteristics. As mentioned in the salinity section, David Crowley is beginning a program to select improved salinity tolerance.

Menge has approximately 40 different selections (all grafted to Hass) in 30 field trials throughout Southern California, all planted in *Phytophthora*-infested soil. Some of the better selections are Zentmyer (Barr Duke maternal parent), Spencer (Pauma Valley escape tree), Uzi, Rio Frio, Merensky 1 and Merensky 2. Forty-seven new selections from breeding blocks have been screened and are ready to be planted in the field. All of these are grown as clonals, however Spencer initially showed some resistance as seedlings; Spencer is being tested further for tolerance to *Phytophthora* as seedlings vs. clonals.

Newly imported selections from Israel currently being tested for root rot and salinity tolerance include VC 31, VC 40, VC 51, VC 65, VC 66, VC 75, VC 204, VC 802, VC 803, VC 804, and VC 817. The 800 series are thought to have good tolerance to root rot. A previous import from Israel, the VC 256, was reported in Israel to have tolerance to both root rot and salinity. There is great interest in this particular rootstock, but initial results

in California do not show this rootstock to have a high tolerance to root rot, and perhaps not as much tolerance to salinity as had been reported from Israel.

In addition to having good tolerance to root rot and salinity, a successful rootstock, when grafted to Hass, must demonstrate that it will impart good fruit production in the scion. The Menge program collects at least three years of yield data before the rootstock is considered for release to the industry.

A new line of genetic research was launched in the late 1990's by researchers Witjaksono and Litz, at the University of Florida. They attempted to utilize protoplast fusion to create somatic hybrids between root rot-immune *Persea borbonia*, *P. caerulea*, and *Machilus* spp., and root rot-susceptible *Persea americana* in order to impart root rot resistance into a rootstock that would be graft compatible with commercial cultivars of *Persea* (Witjaksono and Litz, 1998). Apparently somatic hybrids have been created, but they have had difficulty regenerating the somatic hybrid embryos into plants. Recently they have attempted to graft the somatic hybrid embryos into seedling rootstocks in order to eventually create clonal rootstocks.

Transfer of genes and somatic hybridization offers an exciting prospect for speeding up the development of new rootstocks, but this program still has inherent difficulties; and it may take some time before the California grower can reap the benefits.



Gary Bender examining an avocado tree grafted onto a *Phytophthora*-tolerant rootstock

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Book 1

Chapter 5

Site Selection, Road Engineering and Erosion Control

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The success of a grove will depend largely on how well the site was selected. Trees on the correct rootstock can be planted properly, the roads can be engineered correctly, and the irrigation system installed by a qualified irrigation engineer, but if the site is located in a chronically frosty or windy area, the grove will likely be a failure. In this chapter, several important elements to consider are discussed under **Section 1 – Site Selection**. In **Section 2** we discuss **Road Engineering and Erosion Control**. The irrigation system is thoroughly discussed in Book 2, Chapter 1 – Irrigation under “Components of the Irrigation System”. For more complete information on proper sizing of pipe, friction losses, effect of gravity on water pressure etc., we suggest that you consult with a qualified irrigation engineer.

Section 1 - Site Selection

Selecting the proper site for the grove is critical for success. The ideal site would have the following characteristics:

- **Good soil drainage.** Soils that do not drain well due to soil compaction or clay layers may cause roots to die of asphyxiation. Root rot caused by the fungus *Phytophthora cinnamomi* is much worse in poorly drained soils. As a rule of thumb, if an 18 inch deep hole is dug and filled with water, and water is still in the hole the following day, then this is not a good site for avocados. Sandy loam soils are usually considered to be good for avocados, but only if the subsoil has good drainage. Clay soils are not recommended for avocados. When replanting a grove that had root rot and/or poor drainage, mounding is usually recommended in order to improve drainage. After building the mounds, the entire root ball is planted in the mound with the bottom of the root ball just above the surface of the native soil. A mound is constructed by scraping the surrounding soil into a mound about 6-7 feet in diameter, usually about 20 inches high. If the ground is flat enough, a scraper attached to a tractor pushing the soil to one side can create long, continuous mounds.
- **Warm climate.** The Hass variety of avocado will freeze at temperatures below 29° – 30° F, therefore the site must be located in a warm zone with good air drainage at night. During a cold night, warm air rises and cold air flows down the hill, collecting in low areas. Avocados should be planted above the frost line.
 - **Estimate the frost line.** The frost line can be difficult to estimate, but effort should be made to determine this as best as possible. Some tips for determining the frost line: first, laurel sumac is frost tender and only grows where it is warm enough for avocados to grow. It is best to observe the sumac right after a frost, but if this is not possible, and you see older sumac plants on the property, it would be likely that avocados would survive. Second, talk to the neighbors. Since we have damaging freezes about every ten years in California, it is likely that someone might remember where the frost line was on your property. Third, study the terrain.
 - **Evaluate the slope and elevation.** Cold air flows if the land is sloped, and on the hillsides cold air is not standing long enough to create a cold atmosphere. That is, unless the elevation is high enough that snow is common and would remain for a period of time--long enough to lower the temperature well below freezing. Also, if the elevation is high enough, it will be cold even if the air can flow. This is an elevation influence. For every 1,000 foot rise in elevation, there is a 3° F drop in temperature. Given a similar slope for cold air flow with the same sun exposure and prevailing winds, a location at 4,000 feet elevation would be 9° F colder than one at 1,000 feet.

- **Is there a basin?** In evaluating the frost hazard of an area, determine if the area forms a basin. This is the case with most valley bottoms. It could be a thousand-acre area, yet if all the slopes come down continuously around the entire area and form a sort of crater with no open sides, the air will flow to an extent, but just as it would be with water, cold air will fill up the basin and create a frost hazard for the trees that are planted there. If there is an opening in the basin, perhaps the cold air can flow out. The frost hazard would be a great deal less for elevations in the basin that are higher than the lip of the opening. If one thinks of the basin as filling with water, where will the water be able to spill out? Those spots where the water would not flow out are those spots that are too cold for avocados.
- **Temperature records.** Given the sizable investment required for development of an avocado grove, it would be wise to have some specific temperature data, especially if venturing into an area where avocados are not grown in the surrounding area. Digital recording thermometers that can be downloaded into a computer are better than a minimum-recording thermometer because they will give the duration of a frost. This is important because it is generally believed that if a frost below 29° F lasts for over four hours, severe damage to Hass fruit will occur. The minimum recording thermometers will not give the duration of low temperatures, but they will give a good indication of frost potential. A problem with weather data is that it can be misleading if only one year's data have been collected. One year this area may be warmer, the next year colder. It is for this reason that three years of data are needed to say with some confidence, "Well, I think it's pretty safe!"
- **Not too hot.** Avocados will start to drop fruit if the summer temperatures have prolonged periods over 100° F. Temperatures over 105° F in late May or June have been known to drop almost the entire crop of young fruit that were just set. This is one reason why we don't grow avocados in the desert.
- **Slope.** Avocados grow well on slopes, but steeper slopes make harvesting and fruit removal from the grove more difficult. If avocados are to be planted on the steeper slopes, more effort and expense must be put into grove roads and cutting paths down to the roads from the trees. Flat ground is easier to farm, but there is very little flat ground available for grove development in the Southern California coastal counties. If avocados are to be planted on steep slopes, it would be wise to have a topping/pruning program to keep the tree height under control.
- **Wind.** Care should be taken to locate the grove in an area that is not facing constant wind. High winds will cause leaf drop, fruit drop and a dramatic increase in water usage. Some east facing slopes will be subject to Santa Ana winds in the fall, and these winds have been known to cause almost complete fruit drop. Windbreaks can be constructed with rows of Lombardy poplar or Casurina, but these trees need to be watered and this can be rather expensive. Wind also has an influence on temperature during the bloom period. The daily winds may not be so strong that they affect tree growth, but they still may cause temperatures to be cool enough during spring that pollination of the flowers is affected. This greatly decreases the productive potential of the trees.
- **Water supply.** District water is piped to most groves in Southern California, but some remote areas do not have access to district water, or, due to the high cost of water, the grower may prefer to use well water for all or part of the irrigation. ("District water" for most areas implies that the water is sourced from the Colorado River, with some mixture of State Water Project water originating from the Delta region in Northern California and perhaps some local water sources.) It is important that the quantity of water required for the mature grove be calculated so that the production from the well or other sources match the irrigation requirement. Assuming that production of water from the well remains constant, this calculation will indicate as to how many acres can be planted. However, due to drought cycles in California, growers should be aware that water production from wells rarely remains constant (see below for further information).

- **Water quality.** Since avocados are especially sensitive to salinity in the irrigation water, knowing the quality of the water supply is crucial. Important mistakes have been made when growers calculated that the water output from a well was sufficient to meet the water requirement of the grove, but the water quality was too saline for avocado production (see below for further information).
- **Access.** In some cases, groves are established in areas where the only access is through private property. The grower should make sure there is an understanding (hopefully there is a legal agreement) that there will be access for all farming operations for the life of the grove. “Access” also means that your pickers will be able to get to the trees, pick them safely and get the fruit down the hill to a bin on a grove road. It doesn’t make much sense to plant a tree on such a steep ridge that the pickers can’t get access to the tree for harvesting!
- **Location of infrastructure.** It is less expensive to operate an avocado grove when the grove is located reasonably close to the packinghouse and other important components of the operation, including labor supply, farm supply stores, grove managers and trucking. During the harvest season most large groves have a truck coming from the packinghouse every day to pick up fruit; this trucking cost can become expensive for groves in remote locations. Also, if you are relying on a professional grove manager to manage the grove, but you want to plant your grove an hour away from the nearest grove manager, you must be prepared to manage the grove yourself.
- **County permits.** Last on this list, but quickly becoming one of the most important of the criteria for choosing a site is the necessity for obtaining a grading permit if working in an area that hasn’t been farmed in the last five years. In addition, approval by the county is required if you want to clear and plant in a zone that might be covered by a multi-species habitat plan. San Diego County is currently (2002) developing a plan that will, in effect, make it very difficult if not impossible to plant groves in certain areas of the county due to the necessity to preserve habitat for endangered species. Other counties face similar situations. Some counties require permits to drill wells (San Diego does not), and in most counties it is now illegal to cut down an oak tree. Before purchasing a site for grove development, it is very important that you check with the County Dept. of Planning and Land Use for any restrictions that might come with the property.

Determine the Quantity of Water. Most of the smaller groves were planted with the notion that the water would be supplied from the local water district. However, with the cost of water increasing, and the supply susceptible to cutbacks, many land owners are interested in drilling for water to supply part or all of the water needs of the grove. The question is, how much is available?

Even with drip irrigation, a *mature* acre of avocados will require at least 4,500 gallons per day during the summer in most interior areas of Southern California. With extra water for leaching, and extra water to meet the water needs on exceptionally hot, windy days, this figure can be much higher. That is the amount that ultimately must be provided for, not the amount needed in the first, second, and third years after planting.

From a conservative standpoint, the well pump should not have to run continuously 24 hours a day, day after day. It should run no more than 50-70% of the time. An ideal situation would be to run the pump 12 hours every day, or 24 hours every other day. On a 50%-use basis, a well will have to produce 6.25 gallons per minute in order to provide 4,500 gallons per day to the mature acre of avocados.

$$\frac{4,500 \text{ gallons}}{12 \text{ hours}} = 375 \text{ gallons per hour}$$

$$\frac{375 \text{ gallons per hour}}{60 \text{ minutes}} = 6.25 \text{ gallons per minute}$$

In this example, a mature 10 acre grove will require a water flow of 62.5 gallons per minute.

Determine the Water Quality. Just as important as the quantity is the quality of the water. It should not be too salty or have a high level of specific toxic ions, such as chloride. The only way to determine the quality of the water is to have it analyzed by a commercial laboratory.

Salt is measured in parts per million (ppm), which is reported by the labs as milligrams per liter (mg/L). The constituents in salt are often reported in milliequivalents per liter (meq/L). Total salinity is often measured by the lab in units of electrical conductivity (EC); a measurement of 1.0 is approximately equal to 640 ppm total dissolved solids (TDS). With increasing salinity in the water, there will be a reduction in yield, but the reduction in yield varies according to the ions in the water. For instance, saline water composed of more chloride anions will suppress yield more than water with the same salinity composed predominantly of sulfate anions. According to research by R. S. Ayers with the USDA Salinity Lab (1977), avocados are capable of producing maximum yields if the salinity levels are below EC = 0.9 (576 ppm). Avocados are expected to have a 10% decline in yield if the EC = 1.2 (768 ppm), and they are expected to have a 25% decline in yield if the EC = 1.7 (1088 ppm). Avocados are expected to have an unacceptable 50% decline in yield if the EC of the water = 2.4 (1536 ppm). With drip irrigation, irrigating on a daily basis, it may be possible to use water with 1,200-1,500 ppm salinity, but there will probably be substantial yield reduction at the higher salinity levels. With sprinkler irrigation, 800-1,000 ppm is the maximum acceptable range. For avocado production, water with an EC below 1.0 (640 ppm) is preferred.

As a comparison to well water, district water in Fallbrook (composed of a mixture of Colorado River water and water from the State Water Project, originating from the Feather River in Northern California), had an average TDS of 486 – 515 ppm, or an EC of 0.802 – 0.852 in 2001 (Fallbrook Public Utility District, 2002).

Avocados are very sensitive to chloride in the water. Chloride accumulation in leaves at the end of the season is the main reason for leaf tip burn, eventually resulting in leaf drop. Pure Colorado River water has an average of 113 ppm chloride (3.2 meq/L). This is acceptable with conscientious irrigation and regular leaching. If avocados are grown on Mexican type rootstocks, the chloride content in well water should be below 5 meq/L.

The sodium content in water can also be a hazard for avocados. If the proportion of sodium in the water is high, sodium attaches to the clay particles will cause the particles to “run together”, causing a slick surface and reduced water penetration. This does not seem to be a problem in the hillside soils with a high content of decomposed granite, but it can be a problem in the soils with high clay content. In addition, sodium can be directly toxic to avocado leaves causing a burning along the edges.

Section 2 - Road Engineering and Erosion Control for Avocado Groves

Avocados in Southern California have been planted on steep slopes since the 1970's. The advent of low volume irrigation systems, injection of fertilizers in the irrigation water, and biological control of pests have allowed the successful farming of groves on steep slopes. Good flat land is no longer available due to the pressure to build houses, and because flat ground is usually in valley floors where frost is a problem. We often hear comments from visiting avocado researchers and growers from around the world that it is impossible to plant groves on such steep slopes, but it is done and these groves are successful! Groves on steep slopes are successful in Southern California due to the following factors:

- Growers expend a lot of time and money to build good grove roads. These roads are often built over very rough terrain, but they are (for the most part) constructed well so that they don't wash out during rains, and they are not too steep so that bins of fruit can be removed readily.
- Rainfall is usually fairly low in Southern California, averaging 11 to 15 inches per year, with some years as low as 3.5 inches. This reduces the amount of erosion and road washouts in the groves.
- Pests are under biological control (usually). The terrain is too steep to pull a spray rig through a grove, therefore a great deal of effort, and money for research, is spent on maintaining biological control. In

the case where we may have a new pest causing significant damage (such as avocado thrips), helicopters are used for spraying groves, but only when recommended by a licensed pest control advisor.

- Fertilizers can be applied through the irrigation water (fertigation), and irrigation systems if properly designed can have very good emission uniformity, even on steep slopes.

Road Systems. The purpose of a network of grove roads is to facilitate removal of bins of fruit efficiently. Two types of road networks are used. If there is a hill in the middle of the grove, a continuous primary road is built upward and around the hill with a loop at the top of the hill. Secondary roads are built from the primary road; these roads run on the contour of the hill usually looping completely around the hill and rejoining the primary road. The second type of road network utilizes a primary road climbing up the hill with switchbacks at the end of each grade. Secondary roads are built from the primary road, usually on the contour of the hill. These usually have dead ends, with a wide-spot at the end for turning around.

Topographical maps are essential when planning roads with 10 percent grades. The maps do not show outcroppings of rocks and other obstacles, therefore “walking” the grove and marking the roads with flags is necessary to get the final adjustments for the exact road locations.

Contour roads are spaced with six rows of trees between them on the gentler slopes, and 4 rows between them on the steeper slopes.

Land Preparation. It is best to brush off the hill before building the roads because in thick brush it may be difficult for the tractor operator to see the terrain. There are several options available for brushing the hill. On the gentler slopes the land can be cleared by a dozer, or the brush can be cut with a heavy duty brush mower pulled by a dozer or tractor, or the brush can be crushed by a “sheeps-foot” (without the water) pulled by a dozer. On the steeper slopes the brush will have to be cleared by hand with a crew using machetes, chain saws and brush hoes. Sometimes a chain dragged behind two tractors, with the chain between the tractors, is used to clear brush out of gullies. The more work that can be done by machinery is the most economical method.

Brush is either chopped into small pieces and left on the ground (to reduce soil erosion), or stacked into piles and burned on “burn days”. (The grower will need a burn permit from the Fire Dept., and permission to burn on what is deemed a “burn day”. Merely having a burn permit does not imply that a burn can occur on just any day.)

Erosion Control in Grove Development

Erosion control practices are a necessary part of avocado grove development. The USDA Natural Resources and Conservation Service has developed several “Best Management Practices” (BMPs) that need to be considered during the development stage.

Access Roads

Grading roads for any development can be the largest source of water runoff and erosion. This practice is usually one of the first measures to provide access to the property. The key to proper road design and drainage is to frequently divert runoff water from the road before it causes erosion on the road itself or on the slope below. All roads that are properly designed, constructed and maintained will avoid long-term costs of erosion and grading. Initially, the landowner will need to have the necessary permits from the regulatory agencies before commencing work. This will require the submission of an engineering plan for the roads along with specifications and an environmental assessment.



Figure 1. Access roads on a slope in a new grove

When determining the design of your access road system several guidelines should be followed:

- Evaluate soils types for erodibility and suitability from the local USDA Soil Survey. In San Diego County, use Area Soil Survey, Part II, Table 11 and Table 16 respectively.
- Main roads should be a minimum of 14 feet wide for two-way traffic. Haul or pick roads can be 10 feet wide for single lane traffic. Avoid slopes in excess of 66% or 1 1/2:1 (horizontal: vertical) which is the natural angle of repose of soil or a pile of sand. Steeper slopes require excessive cut and fill, and this consumes usable land.
- For roads with less than 8% gradient, the road should be sloped slightly away (or outsloped) at 2% from the cutback and toward the outside edge of the road. Do not leave a berm along the outside of the road because the flow off the road is designed to sheet evenly onto a well-vegetated fill bank, thereby reducing the erosive action of water runoff. Optimum gradient for haul roads is 0-2%. Main access road should be 2-10%. If gradients exceed this then surfacing with rock, asphalt or concrete should be considered.
- For roads with greater than 8% gradient (usually the main access road), the road should be sloped slightly into the cutbank (or insloped) at 2%. The collected water can then be conveyed safely under the road with culverts and outletted into stable material or existing drainage-ways. Provide rock energy dissipators as needed so that additional gullies are not created.
- Final road grading should be done after mid-April to reduce chances of exposing loose soil to rainfall.
- Both cut and fill banks should be 2:1 if practicable. On steeper slopes, this is not possible and will have to be graded according to existing terrain.
- All exposed soils, including the roadbed, should be seeded with annual ryegrass at 24 lbs/acre or 0.56 lbs/1000 square feet and mulched with straw (not hay) at two tons per acre and tacked into or tucked into the soil. This rate is equivalent to 1.5 bales/1000 square feet. Fertilizer is also needed, such as ammonium phosphate (16-20-0) at 500 lbs/acre or 11.5 lbs/1000 square feet. Vegetation should be established by mid October on all the exposed areas including the surface of roads. The main access road may be excluded. The procedure is to seed first, then straw and finally fertilize as you see the seedlings emerge through the straw.
- Waterbreaks, also called water bars, are effective in diverting accumulated water from the road surface onto the vegetated fill banks or toward the cutbank on gradients over 8%. The following points need to be considered:
 - Install before the middle of November.
 - The optimal size of an earthen waterbreak is 6 inches above the road surface and 6 inches below the road surface. If it is smaller, it may be less effective in diverting water, will require increased maintenance, and will probably break down faster.
 - Don't allow diverted water to flow directly into unstable areas, septic fields or natural water courses.
 - Avoid placing waterbreaks in swales, gullies or low areas where water has no escape. Place waterbreaks above these areas whenever possible.

- Place waterbreaks above changes in grade to minimize water flowing down steeper portions of the road.
- Place waterbreaks above road intersections and curves in the road.
- Runoff water from waterbreaks should not be directed onto fill material unless a downspout or other conveyance measure (i.e. rocks, pipe, chute) is provided and the water is drained away from the fill. This is a case where compacted berms need to be placed along the outside bank to divert the concentrated water to the outlet.
- Each waterbreak should have a continuous, firm berm of soil at least six inches high and six feet wide that is parallel to the waterbreak cut.
- All waterbreaks need to be open at the lower end so the water can run off easily.
- Ponding of water behind a waterbreak should be avoided. The ponded area may become filled with sediment and the waterbreak may fail as continuing runoff flows on the road.
- All waterbreaks should be installed at an angle of between 30 and 45 degrees downhill from the perpendicular to the road; this will catch and direct runoff water to the outlet.
- Keep the waterbreak and outlet clear of debris and sediment so that water drains freely.

The recommended spacing of waterbreaks for grove roads is as follows:

Road Gradient (%)	Interval between bars (feet)
5	125
10	78
15	58
20	47

Culverts will be needed at all natural drainages. Install them at right angles to the road. Determine the size of the culverts based on the hydrology (amount of water produced) from the watershed. Reduce plugging by installing catch basins or debris racks several feet upstream of the culvert entrance. Drop inlets to culverts create proper hydraulics and also reduce siltation.



Figure 2. Culvert draining into a rock dissipater

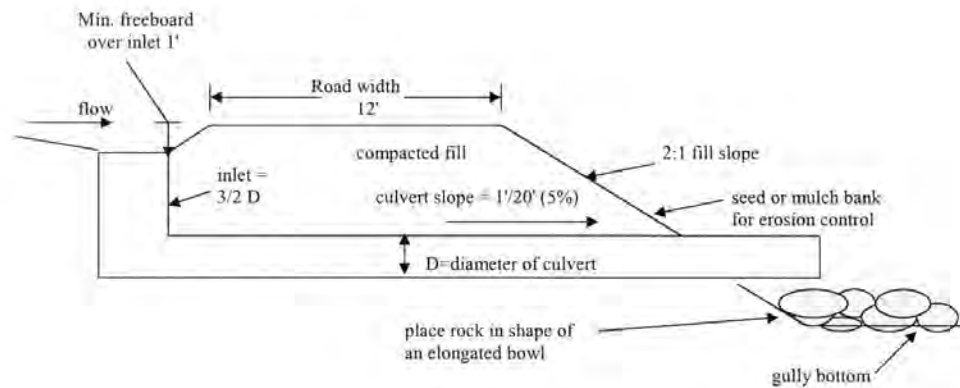


Figure 3: Profile of Culvert Installation

Maintenance is very important. There are several actions that can be incorporated into most road maintenance programs that reduce the long-term cost and need for annual road maintenance.

- Restrict access during wet weather. You only aggravate erosion and drainage problems. Usually roads will dry out within a day or two in coarse-textured soils.
- Make adequate drainage more important than vehicle speed.
- Inspect and clean out culverts after first rains creating surface flows.
- Avoid excessive road maintenance. Whenever possible, retain stabilizing vegetation in road ditches by removing small blockages by hand. Avoid undercutting cutbanks and retain bank sloughage when adequate road width remains.
- Only regrade to remove deep ruts or damaged areas during severe storms. This should be done in the spring when soil moisture allows for good compaction of graded material.
- Inspect the road system at regular intervals and immediately apply soil erosion and water control measures necessary to prevent damage.
- For larger operations it behooves the owner to have a night watchman during an expected major rainfall event to insure all drainage systems are functioning properly.
- Abandon or relocate road sections with repeated high maintenance.
- Consider mowing roads or "driving out" vegetation across the full width if the primary purpose for conducting road maintenance is to reduce fire hazard and minimize soil disturbance.

Filter Strips

In addition to controlling erosion on slopes below the road, it is important to avoid polluting streams with sediment produced from soil erosion upslope. A filter strip is a vegetated area below the road which can catch sediment before it reaches a stream.

Design a drainage system so that each waterbar or culvert releases onto an energy dissipater. Each energy dissipater in turn should release onto a filter strip adequately vegetated to trap sediment. If necessary, seed the filter strip area with suitable grasses to improve its stability and sediment-trapping capability.

“Critical Area Planting”

This practice is applied to roads and other exposed soils. If the land is cleared by hand the erosion potential is reduced and critical area planting may not be needed. For erosion control in the grove area, native annuals are encouraged but seeding and mulching will be required if the land is cleared with equipment since much of the seed base can be buried during clearing. A good operator can clear just the brush and leave the topsoil and seed base. Sometimes the seed base is annual broadleaf weeds instead of grasses which may require additional herbicide control measures. For insurance, a specific seed mix can be used for the first few years as a vegetative

cover until the tree canopy shades the ground. Planting should be avoided in the sprinkler pattern of the tree. The use of erosion control nettings over a straw mulch is an effective alternative but may be more costly. Nettings are tucked in or pinned and rolled down the slopes.

Mulching

The application of clean organic material such as straw can be done around the tree in the area of the sprinkler pattern for erosion control since this area is not to be planted to a cover crop. Mulching 2-4 inches deep will reduce weed growth, conserve moisture and improve soil tilth. Do not incorporate the mulch into the soil.

Underground Outlets

This BMP is designed to carry surface runoff to a controlled outlet or natural drainageway. It is an underground pipeline properly sized to carry storm flows down steeper terrain and control gully erosion. The hydrology of the watershed must be evaluated to size the pipe. It is recommended that a design be done prior to construction because each property and situation is different.

Cover Crops

Planted annual grasses or natural vegetation should be established on the contour between tree rows to control sheet erosion. This will replace the Critical Area Planting in the long term. The types of equipment used and the cultural operations performed should maintain a population of planted and/or desirable resident species not including any noxious weeds that provides at least 60 percent ground cover during the erosive period. Plant height shall be controlled by mowing. As the trees grow and the canopy shades the cover crop it is slowly eliminated. It should not be allowed to grow around the sprinkler as this will disrupt the spray pattern and result in poor distribution to the root zone.

Figure 4. Cover crops planted between young trees on a slope.



Irrigation Pipeline

When larger sub main and main pipelines are backfilled, it is usually necessary to control erosion on the exposed soils with Critical Area Planting. Seeding, mulching and fertilizing are done to the same specifications to control sheet erosion.

Cutting the Roads

A large dozer is used initially to build the roads. Slope boards are used to create the inner slope. A smaller (less expensive) dozer is then used to clean the dirt berm at the base of the slope. The inner edge of the road needs to be clean or the dirt will flow into the culvert and clog it during the first rain.

Drainage across Roads

In addition to culverts and drain pipes running underneath roads (as described above), it may be necessary to build small Arizona drains to move small amounts of water across roads where it is difficult to build culverts. Arizona drains are built with rock and concrete across dips in the road, draining water into gullies.

The Final Steps

The final step is to install the main irrigation lines (described in Book 2 Irrigation).

Most large groves will asphalt the main entrance to the primary road. This is done to reduce the dust in the most heavily traveled areas, and it makes it easier for the boom trucks from the packinghouse to gain entrance on rainy days.

Figure 5. A good grove road



Book 1

Chapter 6

Planting the Avocado Tree

Author: Gary S. Bender

Avocado trees, especially those with rootstocks that are propagated clonally, have rather weak root systems and large sections of the root ball may break off during planting. This problem, along with susceptibility to water-logged soils, and dry soils, makes the correct planting of the avocado tree a crucial step in the successful establishment of the grove.

Site Selection. The first step in planting avocados is to select a site that provides at least a reasonable chance for success. A site should be selected for planting that is not prone to frost in the winter, is protected from the wind, and has good soil drainage (see Chapter 5 for further detail). While most growers of avocados understand the importance of climate, the necessity for good soil drainage is often overlooked.

Avocado roots have few root hairs, making water uptake into the roots relatively inefficient. Therefore, avocados need plentiful soil moisture to grow, but excess free soil water (defined as a state in which drainage is impeded leaving excess water and little air between the soil particles) begins to suffocate roots and provides a medium for the zoospores of the root rot fungus *Phytophthora cinnamomi* to attack the roots. Even without the fungus, avocado roots will begin to die from lack of oxygen after 48 hrs of flooding.

In Southern California, soils should have free drainage for at least 3 feet in depth. This means that, if possible, there should not be any clay layers, hardpan layers or solid rock layers in areas where trees are planted. Most hillsides have rock in the subsoil, but the rock is usually cracked or fissured allowing free drainage. Some slopes, however, have solid, un-cracked rock just inches below the soil surface and the water-logged areas just above the rock have been blamed for the rapid spread of root rot in some groves.

Tree Spacing. The goal in planting an avocado grove is to maximize light interception by the tree canopy as quickly as possible, but this is balanced by the need to maintain a full productive canopy at tree maturity. Generally, in California, tree spacing has usually been set at a 20' x 20' spacing (probably influenced by the fact that PVC irrigation pipe comes in 20' lengths), but many groves were also planted at a 15' x 20' spacing, with the 15' spacing between trees on the irrigation line, and 20' spacing between the irrigation lines. The 20' x 20' spacing will have 109 trees per acre. The 15' x 20' spacing will have 145 trees per acre. The advantage with the closer spacing is that yield would be greater in the early years, and every other tree would be removed when canopies start to crowd. Unfortunately, many growers did not remove the trees at the proper time and the groves became very crowded, with production only in the upper canopy.

It has been suggested by Reuben Hofshi (Hofshi 1999) that Hass avocados might be grown on a high density close spacing, the benefits being improved yield per acre and less costs for harvesting. Hofshi has been experimenting with other avocado cultivars that have a single dominant trunk (Lamb Hass, Reed, and Gwen) on a 7.5' x 7.5' spacing and has dramatically increased yields per acre. Reed yields from Hofshi's planting were reported to be 2-3 times higher in the third to sixth year after planting than has been previously recorded in avocado production (Whiley 2002). Hass with its more spreading growth is difficult to maintain on a close spacing without excessive pruning removing fruiting wood.

Mounding can improve soil drainage immediately under and around the root ball. Mounds are built with about 2/3 cubic yard of soil and the tree is planted into the top of the mound. Trees are irrigated with drippers on the

top of the mound, or with 90 degree spitters aimed at the base of the tree. Some growers used small bulldozers to shove soil to one side to build long continuous mounds. Of course, the ground must be relatively flat in order to use bulldozers. Mounding is useful for starting trees, but trees will eventually have their roots into the native soil. For long term health of the trees, it is better to plant a site with good internal drainage.

When to plant

Avocados can be planted any time of the year, except when frost is a problem. Trees are best planted in the spring; roots usually flush in May so it is best to have the trees in the ground in March or April. If trees are planted in the summer, careful irrigation must be maintained until roots grow into the surrounding soil. This means that trees will usually have to be watered every two to three days in the summer, but care must be taken not to over-water.

When the trees arrive

As soon as the trees arrive, examine the bottom of the root balls by removing a few trees from the pots or sleeves (very carefully!). If roots are found that have dark brown discolorations in the interior of a given feeder root, then a lab or a University farm advisor should take root samples and have them examined for Phytophthora. In previous years, on rare occasion, some nurseries had trees that were infected with Phytophthora root rot. This hasn't been the case in recent years, but it is still a good idea to double-check. Once the trees are planted, and trees start to die, the source of the root rot cannot be determined.

If the trees are not planted immediately after arriving from the nursery, keep the trees in a well-protected area and water them daily. If the sides of the pots are exposed to full sun, especially in the summer, the pots should be shaded to keep the roots cool. Do not store the trees on plastic because root rot fungi may spread from pot to pot in the water. It is best to store them on a raised bed of gravel, away from mature avocado trees that may have root rot.

If trees came directly from under shade cloth at the nursery, trees should gradually be moved into stronger light over a two-week period.

Planting procedure

Digging the holes. Holes are dug after the tree spacing is marked out and the irrigation system has been installed. It is best to pre-irrigate the soil to make it easier for digging. On flatter ground, a tractor-mounted post-hole digger can be used. A two-man power post-hole digger is often used on moderate slopes, but these are difficult to use when there are rocks in the soil. On the steep slopes, holes are usually dug with a shovel. If post-hole diggers are used in heavy soils, the sides of the holes should be scratched with a narrow shovel to break up the slick sides before planting.

The holes should be dug about the same depth as the root ball. Deep holes that are backfilled with soil will usually lead to the tree settling and the graft union may sink below the soil line. The width of the hole should be about 2-3 times the diameter of the pot or sleeve.

Carrying the trees to the site. It is tempting to carry the trees to the planting site by grasping the trunk and lifting, but trees will be ruined if the scion breaks off at the graft union. Also, with open bottomed sleeves, large chunks of soil and roots may break off. The correct way to carry a tree is to carry one tree at a time, with one hand supporting the bottom of the root ball and the other hand supporting the side of the pot or sleeve.

Placing the tree in the hole. If the tree was grown in an open-bottomed, polythene sleeve, the tree is placed into the hole with the sleeve intact to support the roots. The tree is positioned so that the ball is resting on firm soil to avoid settling, and the top of the potting mix is slightly above the soil line. The sleeve is then slit with a knife and the sleeve removed. (If the tree was grown in a pot with a bottom, the tree is gently pulled out of the

pot after rolling the pot on the ground to separate the roots from the side of the pot. Then the root ball is gently placed into the hole).

Filling the hole with soil. Through experience we have found that it is unnecessary to add composts to the backfill mix. In some situations, where manures have been added to the backfill, the salt and ammonia gas emanating from the manure have been responsible for root death and poor tree growth.

Moist backfill soil is packed into the hole to fill 1/3 of lower space in the hole. The soil is tamped down with hands or the end of a shovel handle. Tamping is necessary to remove air pockets and insure that the roots come in contact with the backfill soil. If the backfill soil is dry, the hole should be filled with water immediately after filling the lower 1/3 of the hole, and allowed to drain. When drained, the rest of the backfill soil is added and tamped until the hole is filled, leaving a slight basin to contain water. The upper surface of the ball is left uncovered by soil so it can absorb water readily. A final irrigation is then done which will fill the basin. If a dripper is used for irrigation, it is important to have the dripper placed on top of the ball so that water will run into the ball.

Mulching. The young tree is then mulched with several inches of straw or wood chips for moisture retention and cooling of the soil. Manure is not used as a mulch because it usually adds too much salt to the soil. Straw with some horse manure (fresh stable bedding) is usually acceptable as a mulch. Since mulch cools the soil, mulching is useful in the summer, but not in the winter. Young trees that may be subjected to frost should not be mulched in the winter; this allows the sun to warm the soil around the tree during the day.

Wrapping. A thermal wrap (available from farm supply stores) is placed around the trunk to prevent sunburn in summer and to provide some frost protection in winter. The wrap should be removed after the first year.

Staking. Most trees come with a thin bamboo stake from the nursery, but these are little use in supporting a growing tree in the field. It is best to support the young tree with two stakes, one on each side driven into the soil outside the root ball. The tree is loosely tied between the stakes with 1 inch wide grafting tape. Most growers, however, use one stake per tree (a substantial 2" x 2" stake) and in most cases (non-windy areas) this is sufficient.

Irrigation. Over-watering, and under-watering, are probably the most common reasons for tree failure at planting. The ball should never be allowed to dry out. Remember, trees get watered often in the nursery, but when planted as inter-sets in a grove, they often get watered once a week, usually with too much water. Thus, they are alternately being drowned, and allowed to get too dry between irrigations.

Trees should be watered with enough water to thoroughly wet the ball every few days. Under most conditions, 5 – 10 gallons per week split into 2 – 3 irrigations per week is sufficient. As mentioned, it is important for water to wet the ball. Irrigation should be done by drippers next to the trunk, spitters aimed at the trunk, or a mini-sprinklers in the microspray mode.

Weed Control. Weed control is important because weeds steal water and fertilizer from the young tree. Weed control should be accomplished by mulching and hand weeding. Herbicides are not recommended during the first year of growth.

Fertilizing. Trees are usually not fertilized at planting time, although a cup of a slow release fertilizer in the hole at planting is probably useful. Fertilizing is normally started about four weeks after planting with a half cup of urea every 4-6 weeks during the growing season. Total actual nitrogen for the first year should be about ¼ lb N.

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The Proper Method to Plant an Avocado Tree



Figure 1. The hole is dug twice the width of the rootball; the depth of the hole should be about the same depth as that of the rootball. The depth is measured with a shovel handle.



Figure 2. If the tree comes in an open-bottom sleeve, the tree with the sleeve is carefully set into the hole. If the tree comes in a pot with a bottom, the tree is carefully removed from the pot and set into the hole. The bottom of the rootball should always be supported with a hand to prevent breakage of the ball and loss of roots. The top of the rootball should be slightly above the grade of the surrounding soil.



Figure 3. The sleeve is cut with a knife. The cut should not be deep in order to avoid damage to the feeder roots.



Figure 4: The hole is partially filled with soil while the sleeve is in place. The sleeve is temporarily left in place to support the root ball.



Figure 5: Don't forget to remove the sleeve!



Figure 6: Soil is backfilled into the hole. Mulch and soil amendments are not added to the backfill to avoid problems with excess salinity and ammonia gas.



Figure 7: The fill is completed with tamping of the soil to eliminate air pockets.



Figure 8: When re-planting in root-rot infested soil, it helps to add gypsum around the base of the young tree. Gypsum is applied at the rate of 10-20 lbs per tree.



Figure 9: A wood or bark-based mulch is applied around the tree to complete the planting process.