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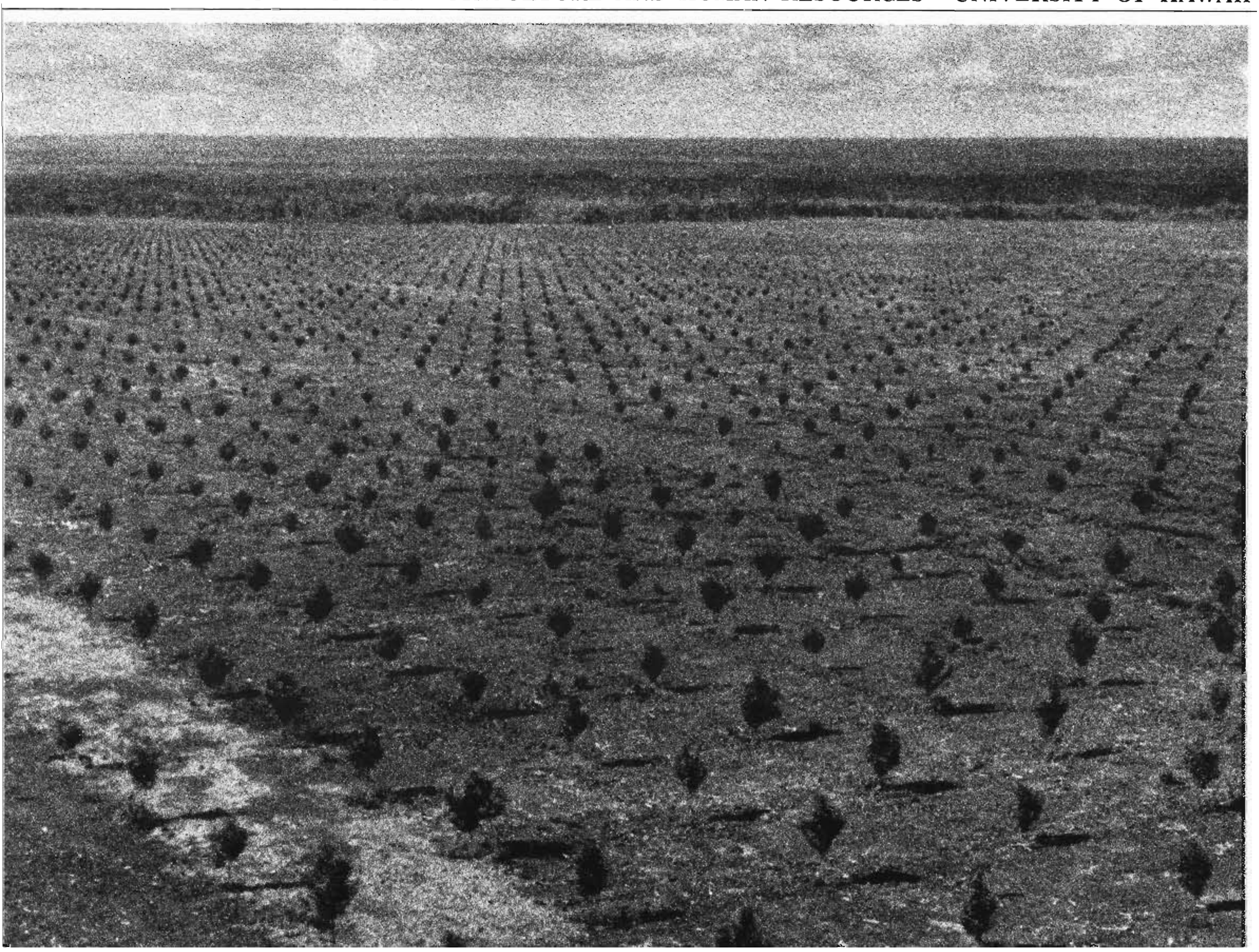
Macadamia Nuts in Hawaii: History and Production

Gordon T. Shigeura and Hiroshi Ooka

HITAHR · COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES · UNIVERSITY OF HAWAII



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To all of these friends, thanks.

THE AUTHORS

Gordon T. Shigeura was on the staff of the College of Tropical Agriculture and Human Resources, University of Hawaii, for a total of 22 years over two separated periods of employment. He helped with the initial development of Castle & Cooke's first large-scale commercial macadamia nut orchard in Puna, Hawaii, in 1949, and C. Brewer's Kau Macadamia (forerunner of Brewer Orchards) in Pahala, Hawaii, in 1956. After a 15-year period in industry, he returned to CTAHR as a horticulturist, retiring at the end of 1979.

Hiroshi Ooka, or "Porky" to his many friends throughout the macadamia world, began his professional years as a vocational agriculture teacher in the high schools of Hawaii. During this 20-year period he encouraged and developed many students who have gone on to become leaders in their fields. Ooka spent his last 25 years before retirement as a horticulturist at both Keaau Orchard and Brewer Orchards. In his spare time, he kept the Hawaii Macadamia Producers Association on an even keel by handling the macadamia nut research program for CTAHR with state, county, and private funds.

Cover: An early picture of Keaau Orchard, looking toward Mauna Loa.

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FRONTISPIECE

John Macadam, scientist, medical doctor, philospher, and politician, was born in May 1827 at Northbank, near Glasgow, Scotland. His name has often been misspelled in reference literature with a capital "A" as in "Adam," but as his accompanying signature on the photograph shows, he preferred the small "a." This issue has been clarified again by the senior author on his pilgrimage to Macadam's grave in Melbourne, Australia, in the fall of 1980. In spite of the fact that the grave registry again spelled the name with a capital "A," the name on the tombstone suggests otherwise.

Privately educated in Glasgow, Macadam studied chemistry at the Andersonian University beginning in 1842. In 1844, after advanced study at the University of Edinburgh, he was appointed senior assistant in analytical chemistry. He returned to Glasgow and taught in the classroom. He migrated to Victoria, Australia, in 1855 to fill the post of lecturer in chemistry and natural science at Scotch College, Melbourne. In 1861 he was appointed lecturer in practical and theoretical chemistry at the University of Melbourne. During this time, he also held the position of government officer of health and public analyst for the city of Melbourne.

He was elected a member of the Philosophical Institute of Victoria in 1855, and served on its council. From 1857 to 1859 he was honorary secretary, and he edited the first five volumes of the Society's *Transactions* from 1855 to 1860. He actively participated in the movement to obtain a royal charter for the Society, and in 1859, when the Philosophical Institute became the Royal Society of Victoria, he was appointed honorary secretary. In 1863 he was elected vice president.

Macadam was elected to the legislative assembly in 1859 and stayed in parliament until he resigned in 1864. He sponsored bills on licensing of medical practitioners and preventing adulteration of food, which became laws in 1862 and 1863.

Although in ill health by March 1865, he went to New Zealand to give his expert testimony as an analytical chemist in a murder trial involving the use of poison. On one of the several trips he took for this trial he fractured his ribs in rough weather. Subsequently, he developed pleurisy, and died at sea on September 2, 1865. Macadam's body was brought back for burial in the Presbyterian section of the Melbourne General Cemetery.

Tall, with long red hair and a powerful voice, Macadam always commanded attention. He was a skilled, popular, and eloquent lecturer with a thorough knowledge of analytical chemistry. In Glasgow he published several papers on analytical chemistry, and in Melbourne he wrote reports on public health, food adulteration, and soil analysis.

The macadamia nut is indeed distinguished in being named after a man who, as young as he was, contributed so much to his society and country, and was definitely ahead of his time in social attitudes.

John Macadam, Esq., M.D., 1827–1865.
(Courtesy of Mitchell Library, Sydney, Australia, through Ross Loebel, Lismore, Australia)

PREFACE

Although macadamia nuts were brought into Hawaii over 100 years ago, they remained a delicious oddity for about 50 years, laboriously prepared and consumed only by the affluent sugar barons who came to the Islands to start the sugar industry. In the period beginning about 1920, curiosity about the nuts became more intense with field planting of nuts on Round Top and on marginal sugarcane lands in the Honokaa area. Although Walter Naquin's obituary says he began planting nuts in 1918, plantation field records indicate planting began in 1924. Ernest Sheldon Van Tassel began planting on Round Top in 1922. Because of this confusion, the authors feel credit for development should be assigned to both men.

The historical aspect of this industry has been casually developed in past publications, which simply quote unresearched entries in the older papers, and neither justify nor do credit to all the work and effort that went into the development of this industry. Consequently, this paper is an attempt to put more substance into the efforts extended by past workers, in Australia as well as in Hawaii. The senior author was fortunate to make three study trips to Australia to gather historical and agricultural data on the nuts.

This paper is also an attempt to make available in one publication the large body of scientific and growing information scattered among many publications in several disciplinary areas in macadamia production.

MACADAMIA NUTS IN HAWAII: HISTORY AND PRODUCTION

Gordon T. Shigeura and Hiroshi Ooka

INTRODUCTION

The macadamia is indigenous to the Brisbane area on the eastern shore of Australia, where it was found growing in the native forest between 25° south latitude near Maryborough, where *M. integrifolia* was predominant, and Coffs Harbour at 31° south latitude, where *M. tetraphylla* made up the forest stand. Although Australian botanists discovered and named the nut tree more than 125 years ago, the Australian farmers did not take advantage of the tree until 1950, after the potential of macadamia nut was indicated by the successful planting at Keaau, Hawaii.

Macadamia was introduced to Hawaii by W. H. Purvis (Fig. 1) in 1881, by the Jordan brothers (Figs. 2 and 3) in 1892, and by the Territorial Board of Agriculture between 1891 and 1895. The Hawaiians, too, were slow in exploiting its commercial possibilities; however, Hawaii now is the single largest producer in the world. The development and growth of the industry have been based largely on the untiring efforts of the agricultural scientists of the United States Department of Agriculture (USDA) Federal Experiment Station and the Hawaii Agricultural Experiment Station of the University of Hawaii. Early industrial pioneers then took daring chances in order to establish a nut industry.

These notes have been prepared to (1) recognize the men associated with the taxonomy of the tree in Australia and its early introduction to Hawaii; (2) examine, credit, and focus attention on the early industrial and research pioneers who contributed enormously to developing Hawaii's macadamia nut industry; (3) record for posterity the contribution of each; (4) record under one cover reliable cultural and researched information pertinent to establishing a commercial operation from plantation through processing to marketing; (5) make note of the rather primitive equipment used through the years; (6) record interesting anecdotes and stories in the Hawaiian macadamia community and industry; and (7) preserve pictures illustrating points of interest and contention.

DISCOVERY OF MACADAMIA NUT

The discovery and the botanical identification of the macadamia nut tree in Australia in the period from 1840 to 1860 have been treated very lightly and impersonally in the literature. For posterity's sake, biographical notes[1] on each of the individuals involved, who became famous in their own right, will be recorded here to link these individuals with macadamia.

Storey *(80)*, in a thoroughly researched paper on nomenclature, credits Friedrich Wilhelm Ludwig Leichhardt (1813–1848?) (Fig. 4), born at Trebatsch, Prussia (a state in northern Germany and formerly a republic), who studied at the University of Berlin, as having collected the first botanical specimen of macadamia in 1843. Although Leichhardt assumed the title of "Dr.," available evidence indicates he did not earn a degree of any kind. Rather, Leichhardt was a vagabond wanderer who migrated to Sydney in 1842 to find a new life for himself in Australia rather than serve in the German military, thus making him a deserter. Upon his arrival, failing to gain an expected position at the botanical gardens, the wanderer from Germany did much botanizing throughout the Brisbane area, particularly in the direction of Moreton Bay. During this period he lived with and subsisted on the several new acquaintances he was able to make. On one of these trips, Leighhardt collected a macadamia specimen and deposited it, undescribed, in the herbarium at the botanical gardens in Melbourne.

In spite of his shortcomings as a botanist, Leichhardt is remembered in Australian history as an explorer who led the expedition to show that all the coastal land of Queensland to the Dividing Range to the west, and the coastal Northern Territory to Darwin were suited for settlement because of the many rivers he discovered throughout the area. Today, Leichhardt is mentioned in history books used in Australian schools. Among

[1]Biographical notes were obtained at the John Oxley Library in Brisbane, Australia.

Figure 1. William Herbert Purvis, 1858–1952(?).
(The picture, taken in Hawaii in 1885, was obtained through the courtesy of Mr. Sherwood Greenwell of Kealakekua, Hawaii, who telephoned Mr. Robert W. B. Purvis, a nephew of Purvis', in Scotland.)

Figure 2. Edward Walter Jordan, 1850–1925.
A longtime resident of Hawaii who came to Hawaii with his English father and owned a homesite on Wyllie St. in Nuuanu Valley that was used as a botanical garden during his time.
(Courtesy of Agnes C. Conrad, State Archivist)

Figure 3. Robert Alfred Jordan, 1842–1925.
An emigrant from Brisbane, Australia, who left a prospering business in Australia to come to Hawaii to join his brother.
(Courtesy of Agnes C. Conrad, State Archivist)

many honors, he has a river, a mountain range, and a first-class hotel in Rockhampton named after him. Many petty, derogatory comments have been recorded against him, but these should be considered minor in view of his greater accomplishments. Leichhardt's date of death is unknown, since he did not return from one of his expeditions. He could have been killed by the aboriginal natives or by his own men, who may have mutinied.

Baron Sir Ferdinand Jakob Heinrich von Mueller (1825-1896) (Fig. 5), and Walter Hill (1820-1904) (Fig. 6), first director of the Brisbane Botanic Gardens, collected the yet undescribed plant in 1857 along the Pine River (Fig. 7) in the Moreton Bay area in Queensland, Australia *(80)*. From these specimens, Mueller described *Macadamia ternifolia* in 1858 to honor his good friend, Dr. John Macadam. By doing so, Mueller also established the genus *Macadamia*, which was endemic to Australia.

Mueller, who received his doctorate from the University of Kiel, Germany, came to Australia in 1847 upon being advised to go to a warmer climate. During his active years he botanized throughout the continent, collecting and naming the many endemic plants. Some of his publications are *The Flora of South Australia, Fragmenta Phytographiae Australiae, Flora Australiensis*, and *Key to the System of Victorian Plants*.

In 1857 Mueller was appointed director of the botanical gardens in Melbourne, and immediately arranged for a building for what is now the National Herbarium. In 1861 he was elected a fellow of the Royal Society of London and in 1888 was awarded its royal medal. He was a fellow or a member of scientific societies throughout the world. His name lives forever as mountains, rivers, and other geographical features in Australia, New Zealand, Antarctica, South America, and other parts of the world. Upon his death the Mueller Memorial Medal was founded and awarded every second year, by the Council of Australia and New Zealand for the Advancement of Science, to the author of the most important contribution to natural science knowledge. Mueller was a simple and kind man who lived frugally to be able to spend a large portion of his income on scientific enterprises.

Walter Hill, Mueller's companion on his botanizing trips, was born in Scotland and trained as a gardener. He worked at both the Royal Botanical Garden in Edinburgh and at Kew Gardens. He came to Sydney in 1852 and was appointed first superintendent of the Botanic Gardens in Brisbane in February 1855 (Fig. 8). During his early tenure as director of the Botanic Gardens, Hill went on two expeditions, as Leichhardt did, to the northeastern portion of Queensland as far north as Cape York, near present-day Darwin. On these trips Hill invariably took seeds and useful plants that he sowed and planted in suitable areas on the mainland and the coastal islands. Hill was basically the "Johnny Appleseed" of Australia: he also has been credited with the introduction and distribution of jacaranda, poinciana, mango, pawpaw (papaya), sugarcane, ginger, arrowroot, and many other plants. The Botanic Gardens he headed were primarily used for scientific purposes, but the contributions he is most remembered for are techniques in the use of the garden to acclimatize new plants to the area. In recognition of his efforts, the Queensland Council of Garden Clubs honored him with a tombstone over the Hill family plot in Toowong Cemetery in 1972.

NOMENCLATURE

The systematic botany of *Macadamia* and its very closely related genus, *Helicia*, was handled very thoroughly in 1958 by Storey *(80)* in his treatment of the subject in the California Macadamia Society Yearbook. The nomenclature confusion persisted through the years until 1956, when L. S. Smith *(77)*, botanist of the Botanic Museum and Herbarium, Botanic Gardens, Brisbane, published his determination in the proceedings of the Royal Society of Queensland. The acceptance of Smith's suggestion by those in the production of macadamia nuts has been somewhat slow; however, Storey, to eliminate further confusion, suggested that the smooth-shelled species hereafter be called *integrifolia* and the rough-shelled species *tetraphylla*. A foliar distinction of these two species is that the *M. integrifolia* leaves have entire margins and very few irritating spines, and leaves occur three to a node. The *M. tetraphylla* has four leaves in a whorl that are nearly sessile and decidedly more spiny than the *M. integrifolia*.

Beaumont *(2)*, while on a study leave in the macadamia areas of Australia in 1956, noted that *M. tetraphylla* was found in the forest in New South Wales up the slopes of Mt. Tambourine,

Figure 4. Friedrich Wilhelm Ludwig Leichhardt, 1813-1848(?).
(Courtesy of John Oxley Library, Brisbane, Australia)

Figure 5. Baron Sir Ferdinand Jakob Heinrich von Mueller, 1825-1896.
(Courtesy of John Oxley Library, Brisbane, Australia)

Figure 6. Walter Hill, 1820-1904.
(Courtesy of John Oxley Library, Brisbane, Australia)

Figure 7. A view of the Pine River from the current-day freeway at Moreton Bay.

Figure 8. A *M. integrifolia* tree planted in 1858 in the Brisbane Botanic Gardens by Walter Hill. Photographed with Martin Sebastian of Honokaa, Hawaii, to show size in 1981.

Figure 9. The first of two Purvis trees, growing on the property now owned by Santiago Sumbad, Sr., in Kapulena. Paul DeDomenico, President of Hawaiian Holiday Macadamia Nut Company at Haina, Hawaii, plans to improve the tree site as a historical attraction.

between latitudes 28° and 29° south, while *M. ternifolia*,[2] Smith's nomenclature, was not found in New South Wales but naturally grew further north in Queensland up to latitude 26° south. Beaumont found hybrid trees in the overlapping sections between the two areas. These observations suggest that the difference between these two species of edible macadamia nuts is real, and circumstantially identify the indigenous areas of each species.

HAWAIIAN PIONEERS

The history of the macadamia nut industry in Hawaii *(46, 79)* may be divided into three distinct phases or developmental periods to enunciate the progression that the industry took to become what it is today. These are the periods of introduction, of basic and developmental research, and of commercial expansion.

Introduction to Hawaii

The macadamia nut was initially introduced to Hawaii in 1881 *(13)* by William Herbert Purvis (Fig. 1), who, as a young man from Scotland, managed the Pacific Sugar Mill at Kukuihaele on the island of Hawaii with his cousin Theodore before its merger with Honokaa Sugar Company. He was born in 1858, making him only 23 years old when he introduced the macadamia nut to Hawaii. Purvis apparently was a rabid plant collector; by 1885 he had a botanical garden, which included cinchona, planted in the Kukuihaele area. The seed nuts Purvis brought in were planted in Kapulena, Hawaii. The original trees, now 100 years old, are still standing (Fig. 9) and doing very well.

Purvis was reputed to be a carefree traveling man who even enjoyed going on horseback trips of over 100 miles, from Kukuihaele to Naalehu at the opposite end of the island, to do what he liked to do. However, on a trip back to Scotland, he married his high school sweetheart, Mabel Vida, and they came back to Hawaii for only a short period before returning to Scotland to make their home there. Sherwood Greenwell remembers having met Purvis, who still spoke and read Hawaiian, on his trip to Scotland in 1938. Henry Nicholas Greenwell, Sherwood Greenwell's grandfather, has a statement in his diary that "Purvis was not a wealthy man and he was not too smart to leave the islands to go back to Scotland," implying that Purvis would have had it made had he chosen to remain in Hawaii. In a recent letter to the senior author from Scotland, dated August 3, 1978, Robert W. B. Purvis, a nephew, ironically recalls that Purvis saw futures for coffee, tea, and quinine in Hawaii, and that he considered macadamia nuts and pineapple little more than nice domestic fruits. How time changed all that.

To further landscape his homesite, Purvis hired David MacHattie Forbes, a Welshman from the Kew Gardens in England. Forbes eventually became a sugar plantation manager at both Pacific Sugar Company and the Waiakea Sugar Mill in Hilo.

Pope *(60)* refers to Forbes' statement that the original Purvis nuts were small and bitter, suggesting that the gympie nut, *M. ternifolia*, was introduced by Purvis. While it is correct that Purvis also introduced the gympie nut to Honokaa, his introduction was predominantly integrifolia. The integrifolia trees Purvis introduced are still healthy and show no sign of decline, suggesting that macadamia trees can be profitably maintained for a long time. These trees are growing in a hollow of a small slope where, most probably, the topsoil has accumulated for years. Perhaps it should be noted that the gympie was found in Kalaheo, Kauai, and eradicated quickly.

The second introduction in 1892 is credited to brothers Edward Walter and Robert Alfred Jordan, who planted their trees on Edward Walter's homestead on Wyllie Street in Nuuanu Valley on the island of Oahu. Edward Walter, an old-time resident who came to Hawaii from England with his father in 1869, owned a 2.35-acre homesite on the Nuuanu Valley side of Wyllie Street. The lot has since been subdivided, but one of the six original trees still stands in 1982, making it 90 years old (Fig. 10). The present owner of the tree prefers anonymity.

The old homestead was in fact an experiment station and botanical garden where various small crops with economic possibilities, such as sapote and Bartlett pears, were grown. Edward Walter formed the Pearl City Fruit Company to grow pineapples in Manoa Valley before they were grown by James D. Dole, the founder of Hawaiian Pineapple Company. In fact, Edward Walter sold Dole 200 smooth cayenne pineapples for his homestead at Wahiawa.

[2]*M. integrifolia* (author's note).

Figure 10. A Jordan tree, 90 years old in 1982, is one of the original six growing on the old Jordan homestead, which was later subdivided into smaller lots.

Figure 11. A tree growing at Pimpama, New South Wales, Australia, presumably the area from which the Jordan nut seeds originated.

Figure 12. A *M. tetraphylla* tree still growing on the slopes of Mt. Tantalus. The senior author stands next to the tree to show growth comparison in 1978. The philodendron vine needed to be cut out to show the bole. Note vine marking on bole.

Men of Hawaii and old newspapers at the State Archives note that Robert Alfred Jordan spent his early years in Brisbane, Australia, engaged in "pastoral pursuits," after which, for several years, he managed the largest boot factory and importing business in the Southern Hemisphere. He married Marie C. C. Rode, daughter of one of the early missionaries in Queensland. In 1896 he moved to Honolulu to join his brother Edward Walter as treasurer and bookkeeper of his firm. Robert Alfred was also head of his Honolulu Honey Company. No exact manner of nut introduction has been determined; however, it may be that Robert Alfred, who was then about 50 years old, sent the seed nuts to his brother to plant in his yard, or he may have brought the seeds with him on one of his interim trips. Joint credit for this introduction is thus presumed correct. On file at the State Archives is a letter from Shirley Lahey of Taringa, Australia, in which she claims that her grandfather, an Irish immigrant to Australia, gave the seed nuts to "Captain Jordan," who brought them to Hawaii from Pimpama (Fig. 11), 27 miles south of Brisbane.

The Territorial Board of Agriculture and Forestry planted some *M. tetraphylla* trees on the slopes of Mt. Tantalus in a reforestation project between 1892 and 1894 (Fig. 12). J. E. Higgins, in his annual report in 1917 *(22)*, states that "a small group of *Macadamia ternifolia*[3] trees is growing at the substation."

A note of interest is that Louise (Shorty) Sales of Nuuanu Valley, an avid Trail and Mountain Club member in the 1940s and 50s, carried seed nuts of the original Jordan trees and stamped these into the ground along the mountain trails behind Honolulu. Many trees are growing on these mountain trails, thanks to Mrs. Sales' mischievous foresight.

Developmental Orchards

In 1922 Ernest Sheldon Van Tassel (Fig. 13), who had first tasted macadamia nuts at a party given by Gerrit P. Wilder, leased 75 acres of government land on Round Top above the city of Honolulu. By 1925 he had completely planted the area to trees with seeds obtained from the Jordan and Purvis trees. This plantation on Round Top was called Nutridge. Since more planting was beyond his financial means, Van Tassel converted his company into a stock company, the Hawaiian Macadamia Nut Company. Some of his financial backers were Walter Dillingham, Kelly Henshaw, Lester McCoy, and Kit Carson. Van Tassel then negotiated for 100 acres of Bishop Estate land in Keauhou, Kona, at 2000 feet elevation. More than 7000 trees were planted at the Keauhou orchard.

During these early times, cultivation information on macadamia was completely lacking. Van Tassel encountered the usual problems in any tree crop operation, i.e., planting, weed control, fertilization, wild animals, water drainage, windstorms, and, above all, the lack of standard improved varieties. Two persons, in addition to Van Tassel, must be recognized as having made enormous contributions to the macadamia cause. Though the whole venture finally failed, it would not have lasted as long as it did, nor would it have laid the foundations for future development, had it not been for these two who worked with him. The first is Ralph H. Moltzau (Fig. 14), who studied at Washington State University at Pullman, Washington, and was later employed at the Hawaii Agricultural Experiment Station, where he learned macadamia production from field through factory, eventually becoming Van Tassel's associate. Moltzau spent 10 years developing methods of growing, processing, and finally marketing macadamia nuts. Ralph Moltzau, horticulturist and entrepreneur that he was, encountered all the problems we, in later years, had to go through again.

The second major contributor was Lillian B. Jonsrud (Fig. 15), a registered nurse, who took care of Van Tassel through 15 years of declining health until he passed away in 1942. Van Tassel was an industrious, imaginative, and impatient taskmaster, but he was also very appreciative, fair, and honest with his macadamia cause and the associates who surrounded him. As Miss Jonsrud says, "He always wanted things done by yesterday." This team of Van Tassel, Moltzau, and Jonsrud laid a firm basis upon which the current industry prospers.

In 1931 Van Tassel established a nut processing factory on Pohukaina Street in the Kakaako area, where all the nuts produced at Nutridge and Keauhou were processed and sold as Van's Macadamia Nuts. Here again, Moltzau, with the help of Frank Anderson, was the prime mover. The junior author's mother worked in this nut factory as well as in the fields, and often talked

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[3] *M. tetraphylla* (author's note).

Figure 13. Ernest Sheldon Van Tassel.
(Courtesy of Miss Lillian Jonsrud)

Figure 14. Ralph H. Moltzau, who retired as a pineapple plantation manager about 10 years ago, is currently residing at Makawao, Maui. Picture taken in 1936.
(Courtesy of Ralph H. Moltzau)

Figure 15. Lillian B. Jonsrud, now retired and living in Honolulu.
(Courtesy of Miss Jonsrud)

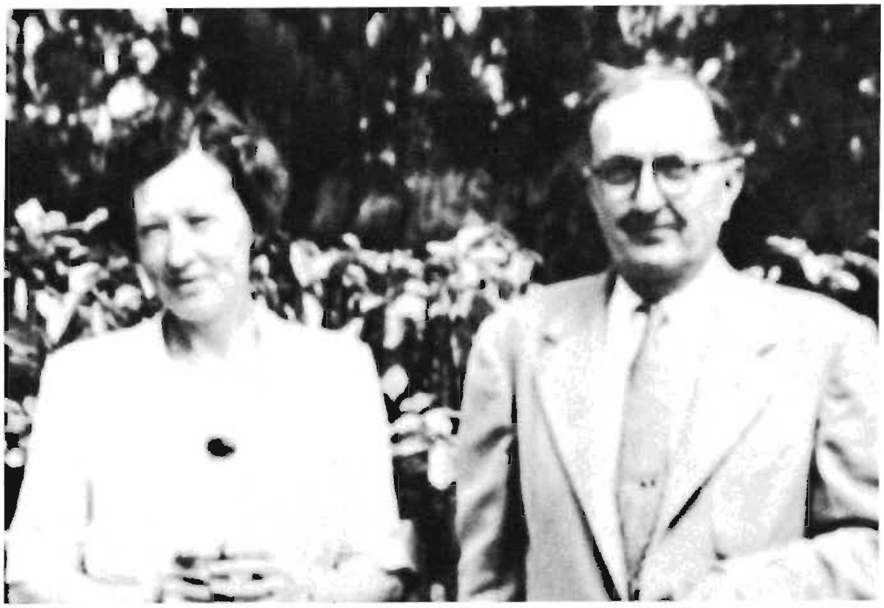


Figure 16. Mr. and Mrs. Walter Pierre Naquin.
(Courtesy of Paul Christiansen)

about the early hardships and poor future of the industry. She never lived to see the thriving macadamia nut industry that her son helped develop.

At about the same time, in 1924,[4] Walter Pierre Naquin (Fig. 16), former manager of Honokaa Sugar Company (a subsidiary of Theo. H. Davies), island of Hawaii, initiated the field planting of several acres of macadamia nut trees. Although some good sugarcane land was planted to macadamias, this project was basically for areas where sugarcane production was not profitable *(46, 79, 81)*. During this period Naquin was aided by Willis Jennings, who later developed the macadamia plantation at Honomalino, Hawaii. Naquin's original plants were predominantly *M. integrifolia* seedlings from the Purvis trees. For the record, however, Leon Thevenin did take out some bitter nut trees *(M. ternifolia)* in the orchards Naquin established.

When the nuts began maturing in the late 1920s, Mrs. Ethel Naquin spent a considerable amount of time and energy experimenting with various methods of cooking, salting, and flavoring the nuts. During the time that Mr. Naquin and his plantation engineers were developing and testing equipment to crack and prepare the nutmeats for processing, Mrs. Naquin was giving her friends samples of her efforts in the kitchen, using a wood-burning stove.

Concurrently, another milestone in the development of the macadamia nut industry was Walter Naquin's 1937 hiring of Leon A. Thevenin (Fig. 17), a recent University of Hawaii graduate, as sugarcane agriculturist. Thevenin was told that he also had to recover and revitalize the macadamia nut trees planted 14 years earlier, since the money to pay his salary supposedly had to come out of macadamia nut sales and profits. This salary procedure was never practiced, but Thevenin went to work cleaning out the undergrowth of guava, guinea grass, Christmas berry, and other weeds with off-season and student help. He fertilized the trees as well as he could, since at that time exact fertilization information was unavailable or very meager by today's standards. Thevenin also had to set up a factory to process the commercially untried nuts. He took trips to various parts of the United States to acquire field and factory equipment then available for use and adapted these to macadamia production. Eventually, the processed nuts were packed and sold under the Triangle H brand and marketed through Schaefer & Co. The culmination of all his efforts was the report he gave on the goodness of the nut at the 1945 Hawaiian Sugar Technologists Annual Meeting at the University of Hawaii in Honolulu. The sample nuts he served after his

[4]Naquin's obituary credits him with planting macadamia in 1918, but plantation field records show that his large plantings began in 1924.

Figure 17. Leon A. Thevenin later became manager of Hamakua Mill Company on Hawaii. He is now retired and resides at Puako Beach, Hawaii.
(Courtesy of Leon Thevenin)

Figure 18. An interesting stencil on nut bags sold by Arthur Gilroy Greenwell, spelling MacAdamia with a capital "A."

report were an added impetus. Needless to say, the interest in macadamia nuts developed very rapidly from his talk in 1945, truly a historic date.

For the record, several other orchards should not go unmentioned. Mark A. and James L. P. Robinson in the early 1920s planted their orchard at Hoaeae Ranch at Waipahu. Although the orchard has since been replaced by sugarcane and house lots, the senior author remembers his grade school years in the mid-1920s at Waipahu School, when he first ate macadamia nuts brought to school by students living at the orchard. L. W. (Bill) Bryan, a territorial and state forester now retired, planted 20 macadamia trees in the arboretum at Waikoikoi above Kukuihaele and along the Mud Lane Trail in 1922. The trees are now barely surviving, unkempt for these many years. About the same time, David McHattie Forbes planted several trees that are still growing at a homestead in Kamuela, and Dr. Benjamin D. Bond planted some trees on the Bond Estate land across from the Kalahikiola Congregational Church at Iole, Kohala. The fine nut seed 'Bond 23' originated from this early planting. The orchard, although very closely planted, is still in production. Dr. Bond, after 50 years of practice in Kohala, retired in 1926. During his practice years and into his retirement, Dr. Bond gave macadamia seeds to anyone who would plant them. Another of these early pioneers was Leslie W. Wishard, then manager of the Union Mill Sugar Company in Kohala, later manager at Honokaa, and now retired at Wailea Beach, Hawaii. He planted some trees in 1927 on the hillside area above Kohala Ditch and along George Hall Road, then the only road between Waimea and Kohala. The remnants of these plantings are still standing and are producing.

An interesting note from the mid-1930s is the effort expended by Arthur Gilroy Greenwell of Kona, brother of Sherwood, who marketed in-shell roasted macadamia nuts (Fig. 18) in appropriately designed bags. Of greater interest is the manner in which Greenwell spelled "MacAdamia," in true Scottish fashion. During these early years, Greenwell cracked nuts with a hammer and sold the roasted nutmeats to Ellen Dye, then the leading candymaker in Honolulu. About the same time, the candy shop in the Alexander Young Hotel made chocolate-coated macadamia nut candies.

Basic Research

Simultaneously with the efforts being expended in the fields, research work on the macadamia nut was initiated at the Hawaii Agricultural Experiment Station, then under the supervision of the United States Department of Agriculture, now under the University of Hawaii; research still continues. The first published report on macadamia nuts in Hawaii was by Alice R. Thompson *(82)* in 1915. She reported on the chemical composition of Hawaiian fruits and nuts, including macadamia. During her time, the crops considered commercially important were mango, avocado, banana, breadfruit, jackfruit, papaya, and the various citrus fruits. Higgins *(22)*, in his 1916 annual report of the Hawaii Agricultural Experiment Station, devoted one paragraph of his 11-page treatise to macadamia nuts. He simply stated that they were introduced prior to 1893, planted at the substation, doing well in spite of crowded growth conditions, and some trees were bearing fruit "highly flavored with 66% fat, but, a serious obstacle to the commercial importance of this nut is its extremely hard shell."

Pope (Fig. 19) published HAES Bulletin 59 *(60)*, culminating the extensive research he had done since the early 1920s. Pope and his co-workers amassed the basic cultural information needed to test the commercial possibilities of macadamia nuts.

Macadamia knowledge reached another milestone in 1937, when W. W. Jones (Fig. 20) and J. H. Beaumont (Fig. 21) reported in *Science (29)* that the causal agent for a successful grafting of macadamia is an accumulation of starch (Fig. 22) above a girdled branch, which serves as reserve food to sustain growth after graft union is completed. Moltzau, in his first grafting demonstration a few years earlier, inadvertently used a branch that had already accumulated starch above the break.

Culminating a variety selection program started in 1936 by Beaumont and Moltzau, W. B. Storey (Fig. 23), in his Progress Notes 51 *(78)* of the Hawaii Agricultural Experiment Station, assigned varietal names to five selections that were considered better on the basis of the following tree and nut growing standards:

1. high yield
2. vigorous growth
3. strong branches

Figure 19. Willis T. Pope, horticulturist with the Hawaii Agricultural Experiment Station, originally came to Hawaii in 1902 to teach at King Kalakaua's School on School Street. He was superintendent of Public Instruction from 1911 to 1914 and became a horticulturist at the Station in the early 1920s. Aside from his scientific contributions, Pope was an enterprising horticulturist at heart. He went completely out of his way on his own time to help Van Tassel in the development of the orchards at Nutridge and Keauhou.

(Courtesy of Horace Pope)

Figure 20. Winston W. Jones, formerly horticulturist with the Hawaii Agricultural Experiment Station and currently with the University of California at Riverside, published several papers on the physiology of oil production in macadamias. Picture taken in 1936.

(Courtesy of Ralph H. Moltzau)

Figure 21. John Herbert Beaumont, horticulturist and chairman of the Department of Horticulture, later became director of the Experiment Station. Picture taken in 1936.
(Courtesy of Ralph H. Moltzau)

Figure 23. William Bicknell Storey, a native of Hawaii, has been through all the macadamia-growing areas in the world and is the world's foremost living authority on macadamia. Picture taken in 1936.
(Courtesy of Ralph H. Moltzau)

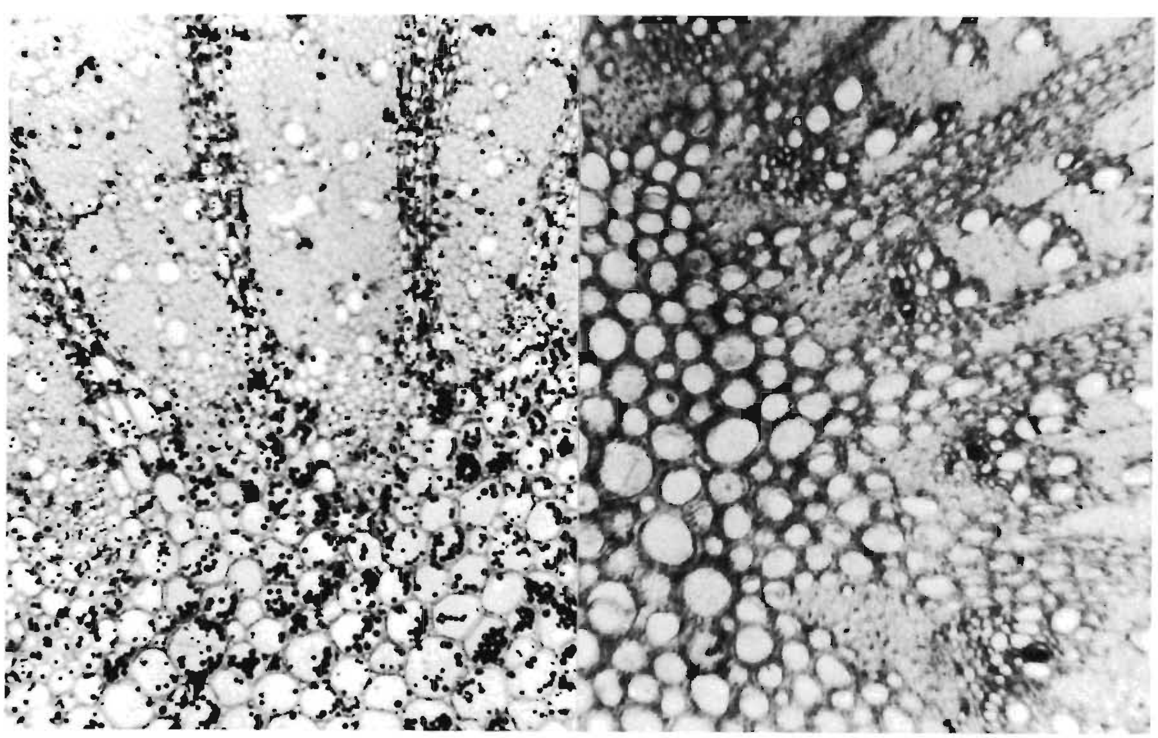


Figure 22. Stem X-sections of macadamia showing starch grains in pith and radial ray cells (left) brought out by iodine staining on girdled stems. The ungirdled stem on the right shows no starch grain depositions. Iodine testing at the stem terminals should be done on all stems before the branch is cut for scion wood. If starch can be detected at the terminals, the whole stem to the girdle will invariably have stored starch.
(Courtesy of Ralph H. Moltzau)

4. round or cone-shaped heads
5. heads neither too open nor too dense
6. nuts uniform in size and shape
7. resistance to diseases and insects
8. high percentage of kernels
9. kernel round and full
10. kernel high in oil content
11. kernel not off-color
12. kernel not bitter or otherwise off-flavor
13. fairly thin shell
14. satisfactory cracking by machinery

Storey assigned names to the following five varieties (cultivars):

1. 'Pahau' (HAES 425). This variety was named in honor of Robert K. Pahau, superintendent of the Kona Branch Station from 1930 to 1947, who assisted Storey in his selection program.
2. 'Keauhou' (HAES 246). 'Keauhou' was named after the locality where Van Tassel had his Kona plantation.
3. 'Nuuanu' (HAES 336). 'Nuuanu' was named after the valley on Oahu where the original Jordan trees were planted.
4. 'Kohala' (HAES 386). 'Kohala' was named after the northern district of the island of Hawaii, where one of the most successful variety-testing orchards was located on land belonging to the Bond Estate, then being operated by Kenneth D. Bond.
5. 'Kakea' (HAES 508). 'Kakea' was named after Puu Kakea, better known as Round Top, where Van Tassel developed his Nutridge Orchard.

Except for 'Kakea', all named varieties were selected at the Keauhou Orchard. Both of these orchards belonged to Van Tassel's Hawaiian Macadamia Nut Company. Although 60,000 trees —over 800 acres—were planted in Hawaii in 1935, Storey's initial selections were made from over 20,000 trees that were then bearing. The varieties were given Hawaiian names to associate them with their Hawaiian origin.

Test plantings of grafted trees in the varietal selection work were begun soon after 1936 and made on all the major islands with private individuals and sugar companies as cooperators. The test sites on Kauai were on Dr. Jay Kuhn's and Robert Eckart's farms, on Oahu at Honolulu Sugar Company at Aiea and Oahu Sugar Company at Waipahu, and on Hawaii at Kenneth Bond's orchard in Iole, Antone Ferreira's orchard at Kalopa, Kiyoshi Takajo's orchard at Kurtistown, and the Experiment Station's Kona Branch Station at Kainaliu, Kona. On Maui the test site was at Makawao Branch Station. Waialua Sugar Company planted a test orchard on the slopes of Mt. Kaala in the late 1940s.

Ripperton (Fig. 24), Moltzau, and Edwards *(62)* described laboratory methods used to evaluate macadamia nut quality to aid in the standardization of factory procedures. They reported a very high negative correlation between specific gravity and oil content in macadamia kernels, and suggested that measuring specific gravity serves as a rapid method of determining the oil content of kernels. They also developed the early concept of quality ratio to determine the weight of kernels produced from one pound of nuts as received at the factory, a concept especially critical in the seedling orchard days. The procedures outlined in the above paper and that published by Moltzau and Ripperton *(45)* in 1939 described the processing procedure that is still basically followed today by industry.

Commercial Expansion

The first major attempt at true commercialization of macadamia nuts was made in 1948 by Castle & Cooke, Ltd., in their venture at Keaau on the island of Hawaii. The most important individual in this period of development and

Figure 24. John C. Ripperton in 1940.
(Courtesy of Mrs. John C. Ripperton)

Figure 25. Harry F. Clements, the single most important individual in the commercialization of macadamia nuts in the state of Hawaii. As consulting plant physiologist at both Castle & Cooke and C. Brewer, he researched, urged, and implemented the initial plantings at Keaau and Ka'u, and their subsequent expansion of acreage in both areas.

expansion was Harry F. Clements (Fig. 25), who convinced the management at Castle & Cooke that macadamia was a good business, led the group in a land search, and finally recommended the land at Keaau. In this search for land, Clements, accompanied by Moltzau and others, surveyed the entire state for land not then in sugarcane or pineapple. The land search included an area in Kapoho in the Puna district of the island of Hawaii, where the Lyman Estate owned huge parcels of land, including abandoned sugarcane land. However, since Kapoho was 30 miles from Hilo and since sugarcane lands are generally very high in soil arsenic due to past use of arsenicals in sugarcane weed control, the search was directed toward forested virgin land nearer Hilo. The search finally ended when Castle & Cooke purchased 1000 acres of forested aa lava land from the W. H. Shipman Estate at Keaau, named the plantation Keaau Orchard, and planted the first grafted macadamia nut tree on January 3, 1949. Later, 2000 adjoining acres were acquired. John F. Cross served as general manager and Gordon T. Shigeura as horticulturist on the plantation. Incidentally, Clements' great enthusiasm for the macadamia nut was engendered at the 1945 meeting where Thevenin gave his talk.

Castle & Cooke copyrighted its brand, Royal Hawaiian, at a small store in Danville, California, in the mid-1950s (Fig. 26), and is credited with popularizing the nuts.

In the early 1960s the Honomalino Agricultural Company, headed by Willis Jennings and W. A. Morriss as general partners and George Schattauer as operational manager, started the 3500-acre nut plantation on aa lava land at Honomalino in South Kona. However, due to some basic errors in earning projection, tree spacing, and variety selection, the venture was not profitable. The orchard, as Mac Farms of Hawaii, Inc., formed under ownership headed by Gary Cadwallader, Dorn Schmidt, and Lonnie Brown, with David Rietow as operational manager for the last three years or so. CSR of Australia purchased the orchard in 1981. With the current management still in control, the outlook continues to be positive. A smaller acreage in the original orchard is operated as Macadamia Nuts of Hawaii, Inc., by W. C. Morriss. Larry Beck also owns an even smaller acreage there.

C. Brewer and Co., Ltd., began its macadamia nut operation as a part of its land utilization experiments in 1956. The commercial macadamia orchard was started in 1960 in the area previously planted to sisal, and has been expanded on both sides of Pahala town to cover over 2000 acres. Harry F. Clements, by then on the staff at C. Brewer, was again the major proponent of this venture. Richard A. Cooke (Fig. 27), project leader, and Gordon T. Shigeura, horticulturist, were in charge of field operations.

Figure 26. Acree's Market in Danville, California, where Castle & Cooke's macadamia nuts were originally sold to establish the Royal Hawaiian label.

With visions of becoming the largest producer of macadamia nuts, C. Brewer and Co., Ltd., purchased Castle & Cooke's operation at Keaau in 1974. With an operation also in Guatemala, and with more than 5000 acres in production, C. Brewer is now the largest producer of macadamia nuts in the world.

In 1974 Paul and Anita DeDomenico, formerly with Ghirardelli Chocolate and Rice-a-Roni, leased the Hawaiian Holiday operations at Haina, Hawaii. The DeDomenicos have developed an excellent marketing system at their factory in Haina with outlets in Waikiki, Maui, and Hong Kong. The DeDomenicos are now financially backing further nut plantings in Kohala on land leased from Castle & Cooke and the Bond Estate.

Mamoru Takitani, president and proprietor of Hawaiian Host Candy and formerly of Maui, who first started his improvised macadamia candy business in the attic at his father's soda works building on Maui about 30 years ago, is now the operator of the largest chocolate-coated macadamia-nut-candy business in Hawaii and California. He purchases his nuts from growers in Hilo and Kona. He processes them in Honolulu and markets them especially as gift items in Hawaii and Japan. Takitani is now establishing a plantation in Brazil to take advantage of the generous aid that country gives to foreign investments. Takitani also recently received approval from the Hawaii Island Planning Commission to construct a nut processing factory in Kona.

Several others who played a prominent part in this period and should be mentioned are Joe Kamigaki of Honaunau, Tatsumi Oue and his brothers of K. Oue, Ltd., in Kealakekua, the late Kenneth Bond of Kohala, Martin Sebastian and the late Fred Erskine of Honokaa, Francis Takahashi of Kauai, factory development expert Harold Tengan from Hilo, and John Cross of Royal Hawaiian's Keaau Orchard.

During this period, the research contributions of the Hawaii Agricultural Experiment Station were tremendous. They covered the range from the earliest stages of macadamia nut cultivation to the ultimate use of the product. Space does not permit a more detailed account of these contributions; suffice to say that the HAES staff has played a major role in the successful development of the macadamia nut industry in Hawaii.

Special recognition, however, must be given to Richard M. Bullock (Fig. 28), formerly assistant

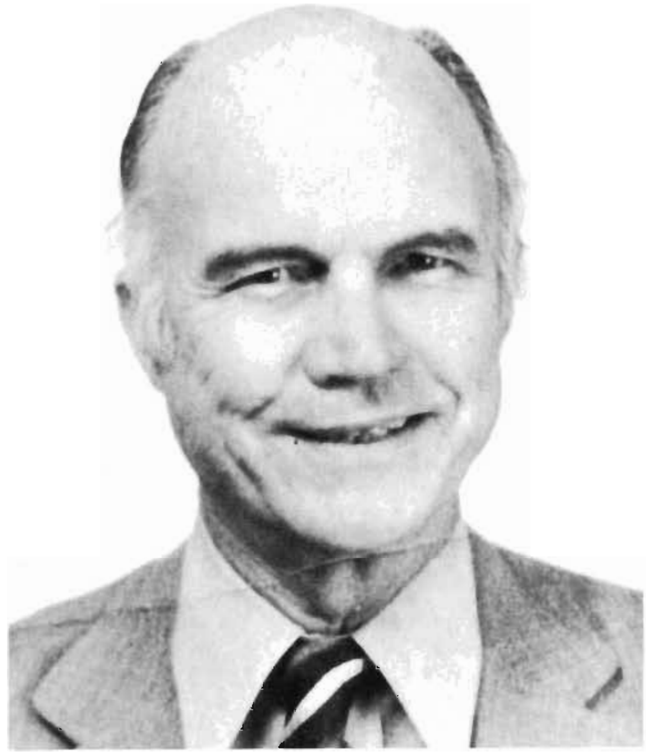


Figure 27. Richard A. Cooke, project leader of C. Brewer's land utilization and Ka'u macadamia nut venture. He also is credited with the organization of the Hawaii Macadamia Producers Association and, as president, led the group for the initial five years to solidify the organization and the industry into a potent unit in Hawaiian agriculture.

Figure 28. Richard M. Bullock, former chairman of the Macadamia Nut Task Force at the College of Tropical Agriculture, who laid the foundation for the industry analysis system now in effect in Hawaiian agriculture.

director of HAES at the College of Tropical Agriculture and chairman of the former Macadamia Nut Task Force. His untiring efforts and leadership kept the University of Hawaii macadamia nut research in proper priority perspective, and assured adequate funding from the University and the Hawaii Macadamia Producers Association. He kept the industry moving in the right direction and on an even keel through the years. The HMPA was represented on the Task Force by Hiroshi Ooka, formerly with Royal Hawaiian Macadamia Company. This unit became the Industry Analysis Group in later years.

Last, but by no means least, the Governor's Agricultural Coordinating Committee, started in Governor John A. Burns' administration with Toshio Serizawa as administrative head, was formed in 1971 to coordinate and monitor all state government involvement in agricultural doings and to report accomplishments to the governor. After a cumbersome start and a period of inactivation, the committee, with proper funding, was reactivated with Richard Matsuura as administrator. Currently, the committee is under the leadership of Tadashi Tojo and Yoshiko Hall, and it is making a tremendous effort in encouraging, developing, and keeping agriculture as a dominant force in Hawaii's economy.

PROFITABILITY OF PRODUCTION

Cost

The production and consumption of macadamia nuts have become increasingly popular and attractive in the last 20 years. Nut production has increased at C. Brewer and Company Orchards at Keaau and Ka'u and at Hawaiian Holiday. Hawaiian Host Candies has made strong efforts in promotion and sales as the many small growers have increased their acreage and production. Although there is now (1981–82) an oversupply of nuts, the nuts have been in short supply historically. The current oversupply is a function of the recession and a supply and demand matter, which should be corrected in time.

On the retail market on the island of Hawaii, when macadamia nuts are sold for about $0.34 an ounce, peanuts are sold for $0.12, almonds for $0.23, and walnuts for $0.15. Although this price differential will obviously vary at different times and places, the relative values are valid. Macadamia nuts still command a premium price whenever they are available. But the fact that nuts are purchased on the retail market, even in Hawaii, predominantly as gift items by Hawaiians and tourists alike indicates that the nuts may be priced too high and, at the same time, may be working their way out of the market. The authors feel this speculation is real, and a matter that must be given serious thought; probably a redirection of efforts is in order.

Investment capital is another matter to consider. In First World areas, capital for production expansion is difficult to obtain, since investors demand a rapid cash return in any enterprise. Macadamia nut production is not a lucrative business in terms of cash flow, since the cost in its early years, or front-end expense, is high, and a positive cash flow does not develop until the seventh to the 10th year, depending on tree care and growth conditions. In the Third World countries where relatively cheap labor and land are still available, the planting and production of macadamia nuts may develop when those governments are supplied with capital from First World countries.

The economics of macadamia nut production is influenced by the varying perspectives or desired production magnitudes of different individuals. A profitable enterprise is possible with one tree, 10 trees, 10 acres, or 1000 acres. The business depends on the effort, time, and money an investor might wish to spend or earn—the net return is basically proportional to the size of the operation.

To illustrate, let us use 100 pounds of in-shell nuts per tree at maturity, at a wholesale price of $0.30 per pound.

100 pounds @ $0.30			$30.00
Cost:	harvesting	$ 7.00	
	husking	5.00	
	handling	4.00	
	fertilizer	6.00	
	weed control	1.00	
	miscellaneous	1.00	
		$24.00	
			24.00
Net profit:			$ 6.00

However, in a one-tree operation at $0.30 per pound, the owner will probably do all of the work, so his total net income may be as high as $20.

This analysis may be an oversimplification of the total problem, but addition, subtraction, or multiplication of cost items considered in this illustration can give anyone an indication of gross profitability. In a larger plantation-type operation, where management and labor costs are high and lost time and inefficiency in operations are inherent, a net profit approaching 40 percent of total gross income for the year is possible. Irrespective of past economic studies on macadamia *(33, 64)*, to quote or illustrate with generalized, hypothetical projections using today's figures and operations is more misleading than otherwise; and further, the values used in the study will be obsolete on the date of publication. Scott *(65)* and Marutani, Hirae, and Yasuda *(41)* basically reported net profit on several operation assumptions approaching 40 percent of yearly cost on matured orchards. Depending on the efficiency of the operation, it is possible to realize $1000 to $2000 net income per acre before depreciation and taxes on the macadamia orchard operation *(73)*. Current expense money is anticipated in the ninth year and amortization in the 17th year. Anyone interested in a more exact profitability study than presented here should retain a reliable, qualified consultant to do a study that fits his own land, finances, wishes, time, and so on.

Yield Potential

The nut yield per acre in Hawaii can vary tremendously by area due to differences in climate, water, soil conditions, and cultural techniques and field practices employed by individual farmers. Total annual rainfall can vary from 10 to 200 inches. Except on one large plantation, irrigation is not practiced in Hawaii. Winter temperatures in the macadamia areas can vary from a high of 60° to 70°F to a low of 40° to 42°F. Elevations, too, can vary from sea level to 3000 feet to markedly influence temperature changes. Also, total sunlight at higher elevations can be drastically reduced by cloud overhang and fog settling in the early afternoon. Consequently, yield predictions and estimates to be used for budget preparation and cost analyses for any area need to be considered in terms of ranges in yield anticipated to reduce miscalculations or misinterpretation. Table 1 gives the yield range now accepted by the industry as indicative and reliable under Hawaii conditions *(33)*.

If this yield logic is accepted, then the lower yield figures in Table 1 can be used for areas where conditions for growth and production are poor, and the higher figures where the conditions are better.

Table 1. Macadamia nut yield in Hawaii

Age of tree (years)	Pounds/tree/year
5	0–10
6	1–20
7	8–40
8	16–60
9	24–80
10	40–90
11	56–100
12	80–100
13	93–100
14	100–107
15	100–115
16	100–122
17	100–130
18	100–137
19	100–147
20	100–150

FUNDAMENTAL REQUIREMENTS

Land (Soil)

Land is the basic structure upon which a tree establishes its root system in the substrate interstices. Soils in Hawaii have been reclassified *(42, 63)* from the Histosols through the various classifications, based on structure, mineral content, moisture content, temperature variation, and the relationships of each to the others. Macadamia nut trees can grow on any soil orders found in Hawaii except in the Waialeale series found only on the top of Mt. Waialeale on Kauai. However, there are reasons to suppose that, were these soils transported to lower elevations, trees would also thrive on them. The authors feel that, except for reasonable differences, the important consideration in growth is not soil, *per se*, but its management, handling, and methods of cultivation before and after the trees are planted in the field.

Consequently, this section will suggest the many ways in which the various soil orders in Hawaii can be handled to best grow macadamia nuts.

Histosols. Most of the macadamia nut trees in Hawaii have been planted on land classified as Tropofolist under the order of Histosols. This class of land is basically lava flows, aa and pahoehoe, with accumulated organic matter deposited on the surface or in the upper horizon.

In clearing Histosols for tree planting, the land has to be ripped and leveled to a grade not to exceed 15 to 20 percent. A good tractor operator can initially "skim" and "store" the top organic layer, bulldoze the lava base thus exposed into a level terrain, and, in the end, cap this lava base with the stored organic-matter soil. Such careful clearing procedures will result in land better suited for crops. Or, the land can be leveled, at reduced cost, without any consideration of the organic top layer. When this is done, however, the organic matter can be buried beyond the reach of roots, and the surface layer of "soil" then may simply become a layer of various-sized rocks. Land cleared in the latter manner will require a preharvest "re-do" with finer materials to facilitate both hand and mechanical harvesting.

Histosols are very porous and do contain organic matter, but the total soil material, including the organic portion, is low; thus water-holding capacity is limited. In areas with 125 inches of normally distributed rainfall, such as the Hilo area, the summer months can be too dry, and drip irrigation may be called for in the dry period. Areas with less than 100 inches of annual rainfall can be considered substandard for lava land. Provision for irrigation is essential. Base saturation is also very low on such soils; therefore, a regular and constant fertilization program is imperative. Phosphate fixation is also very low. The most important problem on lava land is excessive phosphate in the area of the roots *(28, 70)*, so fertilization needs to be monitored very closely to reduce free phosphate accumulation in the soil. Excessive free phosphate will induce the fixation of cations such as calcium, magnesium, manganese, copper, iron, and zinc, thus making these elements less available to the trees. Chemical toxicity from overapplication of fertilizers and herbicides can also do considerable damage to the plants. However, when managed properly, Histosols can be productive. Two examples are the C. Brewer and Company Orchards at Keaau and the Mac Farms Orchard at Honomalino.

Spodosols. Spodosols in Hawaii are found only in the high mountain areas of Waialeale, East Molokai, and West Maui. They are amorphous mixtures of aluminum and organic matter, and may or may not contain iron. Except for pasturing, this land is not good for the usual kind of farming. Theoretically, farming on this soil will call for deep plowing to break through the spodic horizon, judicious fertilization, and an adequate water drainage system. No macadamias are growing on this soil, since temperature is the limiting factor.

Oxisols. The Oxisols are highly cultivated in Hawaii. They are very high in nonsticky clay and oxides of iron and aluminum. They are also low in natural fertility due to the removal of plant nutrients by weathering and leaching, but they have the capacity to fix large amounts of added soluble phosphate fertilizer. However, these phosphates are not held tightly as in many other soils. Oxisols are low in bases; they have a relatively low lime requirement and a low cation-exchange capacity. When Oxisols are managed properly, however, they are among the most productive soils in Hawaii. Two examples are the soils at Kapaa and Wahiawa. Macadamia nuts can be grown on this soil.

Vertisols. Vertisols are soils containing the expanding-contracting type of clay that contracts when it dries and expands with moisture. During dry periods, deep, wide cracks are formed vertically through the soil. Loose clay material may fall and accumulate in these openings. When moisture runs down into these open cracks, the clay will expand to cause land slippages and slides. This characteristic of Vertisols is no problem to a growing crop if water is maintained or irrigation is practiced. Generally, Vertisols are high in bases and with proper crop management should result in very profitable use. An example is Lualualei. With adequate watering, macadamia nuts should grow on this soil type.

Aridisols. Aridisols are soils of the desert and are generally low in organic matter. In Hawaii, where the climate is tropical, the Aridisols contain more organic matter than they do anywhere else in the world. Because of the nature of their formation, Aridisols have a high base saturation in the upper profile. Although soil depth tends to be shallow, they can, with proper water management, be used for crop production. An example is Kawaihae.

Ultisols. Ultisols, usually occurring in close association with Oxisols, are highly weathered soils with a horizon of silicate clays and a low supply of bases. The presence of micas and feldspars indicates they are not as highly weathered as Oxisols. Ultisols have good water infiltration rates, which tend to leach soluble nutrients. Natural fertility is low to moderate. These soils are very responsive to good soil management, and are used quite extensively for crop production. Three examples are Pauwela, Makawao, and Kaneohe. Macadamia nuts should do well here.

Mollisols. Mollisols are dark-colored, base-rich mineral soils that developed under grass vegetation or forest cover. Mollisols have a high base saturation exceeding 50 percent in the subsurface horizon. They are excellent agricultural soils with good natural fertility. Three examples are Hawi, Pulehu, and Kekaha. With proper care, macadamia nuts are doing well on this soil type.

Alfisols. Alfisols have a moderate to high base saturation with an accumulation of clay in the subsurface layer. In Hawaii, the Alfisols are red and found on old land surfaces of Oahu and Lanai. They are highly productive when properly managed, especially with irrigation. An example is Kemoo. Macadamia nuts should do well here.

Inceptisols. The Inceptisols make up the largest soil order in Hawaii, representing about one-fourth of all the land area in the state. They are young soils, but depending on where they are found, they may or may not have an exchange capacity, are high in organic matter and aluminum or iron oxides, but low in natural fertility. In some areas the clay may be irreversibly dried. Inceptisols are used for sugarcane, vegetables, orchard crops, pasture, and forestry. Seven examples are Niulii, Tantalus, Kainaliu, Olaa, Alae, Hilo, and Ahualoa.

Entisols. Entisols are mineral soils that do not fit into any other classification. These soils are formed by continued deposition by river, wind, and rain. They are usually found in floodplains or deltas. The nature of their formation ensures a low fertility state. Use should be adapted with water and fertility requirements in mind. Two examples are Hanalei and Kilauea on Kauai.

Temperature (Radiant Energy, Elevation)

Recorded air temperature at selected weather stations in most areas in Hawaii is often assumed to be and used, agronomically, as an indicator of the radiant energy received from the sun and used by crops in growth. The relationship of temperature and sunlight is obviously not absolute, differing especially with cloud overhang; but it is the easiest to obtain, and sometimes the only record available where no pyronometric records are kept. Also, due to the well-buffered constant trade winds blowing over the Hawaiian Islands, the relationship between elevation and temperature and radiant energy is very highly correlated. Temperatures obtained over a continental land mass, on the other hand, can vary to extremes without any body of water to help in buffering. Thus, in insular Hawaii, as the elevation changes, the temperature and radiant energy are correspondingly lowered or increased. Since physiological activities within plants are affected by temperature and radiant energy obtained at a given elevation, it is then logical to relate tree performance, i.e., growth and yield, to elevation. The exception to this general rule is on lands with southern exposures where cloud and fog overhang are at a much higher altitude, permitting a longer and more intense period of light exposure below. In such areas, macadamia nut trees bear satisfactorily at a high elevation. Consequently, temperature, radiant energy, and elevation will be considered the same and will be used synonymously in this text.

In growth room studies using potted macadamia nut trees kept at four different night temperatures, Nakata *(51)* showed that trees exposed to 21°C (70°F) temperature (Fig. 29) set only 10 racemes during the experimental period; the trees at 18°C (64°F) set 390 racemes, the trees at 15°C (59°F) set 250 racemes, and the trees at 12°C (54°F) set 160 racemes. Apparently at 21°C the temperature was too high and raceme development was

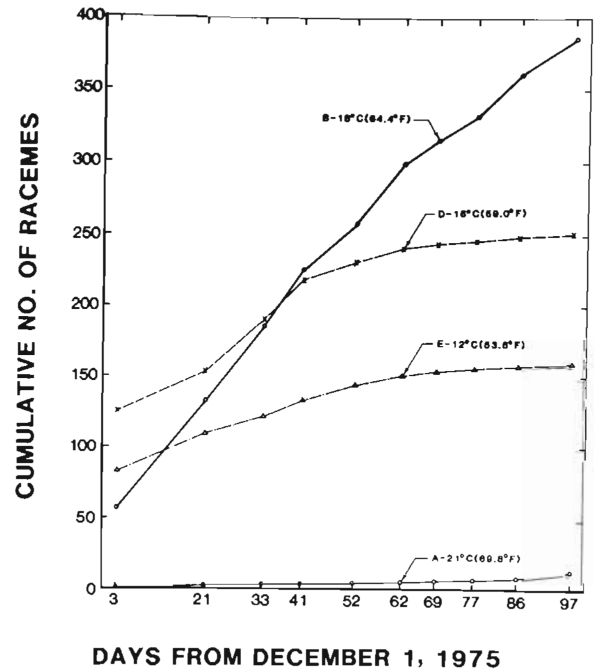


Figure 29. Raceme development in growth room studies by Nakata showing the effect of different temperatures.
(Chart courtesy of Dr. Shigeru Nakata)

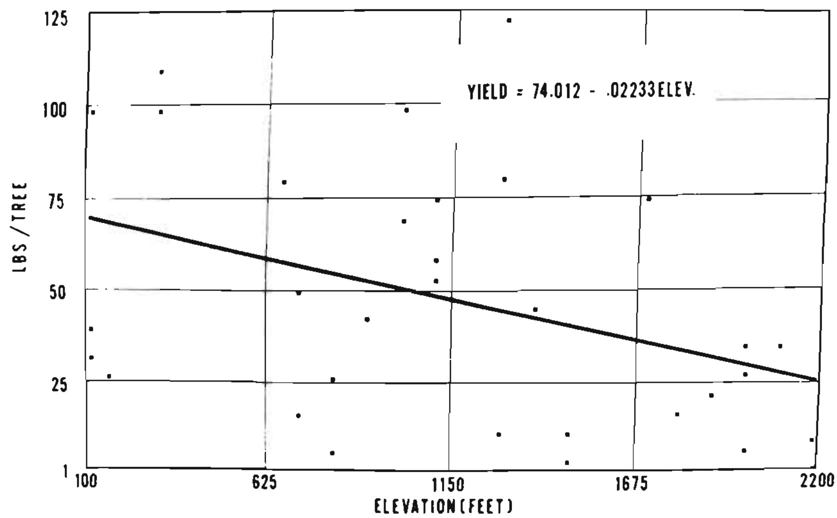


Figure 30. Yield of in-shell nuts as affected by elevation.

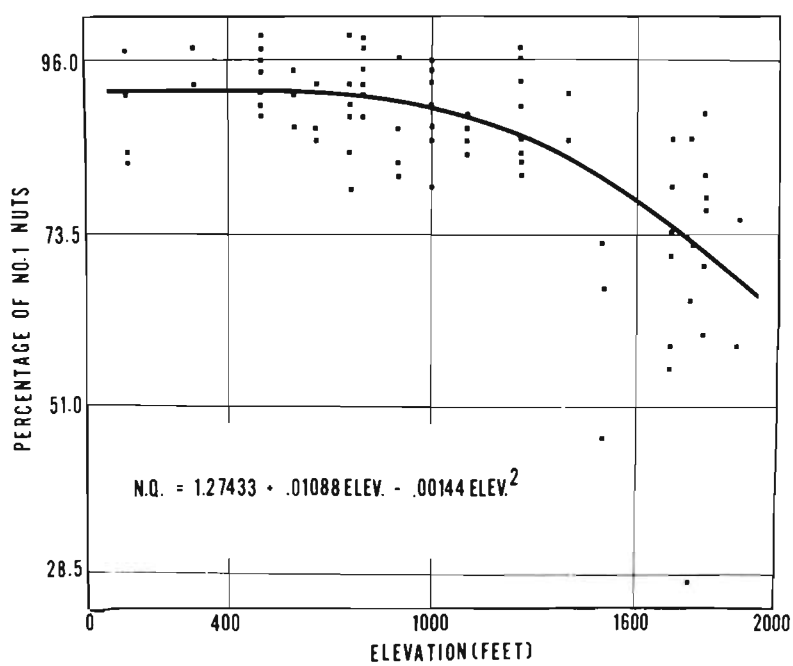


Figure 31. Yield of No. 1 nut kernels as affected by elevation.

inhibited. At the other extreme, 12°C, the trees were subjected to a temperature too low, and thus raceme development was also reduced. Nakata's data seem to suggest an optimum temperature at about 18°C, where raceme formation is encouraged.

Obviously, transposing laboratory data to field conditions can be misleading or erroneous. However, in an independent field study conducted about the same time as Nakata's study, Shigeura et al. *(74)* reported on yield performance of trees *(M. integrifolia)* growing on the island of Hawaii at various elevations, assuming growth and production responses are influenced by elevations (Fig. 30). The regression equation in this study, yield = 74.012 - .02233 elevation, best fitted the distribution of points, and is statistically significant at the 5 percent level. Examination of the chart suggests that the distribution of points from sea level to about 1700 feet (518 meters) was widely scattered from below 5 pounds (2.27 kilograms) to above 100 pounds (45.4 kilograms) irrespective of elevation, indicating that, possibly, factors other than elevation—rainfall, fertilization, weed control, and general field care—affected yield to a larger extent in areas below 1700 feet. Above 1700 feet the points are generally confined to ±25 pounds (11.4 kilograms), suggesting a definite break in the yield pattern. The indication in this study is that the maximum elevation for macadamia nut production is near 1700 feet; at points above, some other factor, maybe minimum temperature, becomes limiting with cloud and fog overcast settling in by midafternoon to reduce air and ground temperatures. In the same study (Fig. 31), Shigeura also reports on the relationship of Grade No. 1 nut quality (No. 1 kernels being those that float in tap water at approximately 1½ percent kernel moisture) to elevation. The regression equation for this relationship is nut quality = 1.27433 + .01088 elevation - .00144 elevation^2, and is statistically significant at 5 percent. Examination of distribution points again shows a general clustering of points near an average of about 90 percent in areas below 1500 feet (457 meters). In areas above 1500 feet, the points are scattered, but seem to average nearer 73 percent, indicating a definite break in nut quality at about 1500 feet. Since nut quality reduction and total yield values break at about the same elevation point, Shigeura suggests that macadamia planting in Hawaii is better suited to areas below 1500 feet (457 meters); toward 1200 feet may be better.

In view of these indicative relationships of elevation to both yield and nut quality, Shigeura *(76)* gathered minimum temperature records from four areas on the island of Hawaii historically known to have either good or poor nut yield. Figure 32 gives the minimum temperature regimes of these areas. The lower set of lines gives minimum temperature regimes at Mealani at 2600 feet (854 meters) and at Kalopa at 1900 feet (640 meters). The upper set of lines is from Kainaliu, Kona, at 1400 feet (450 meters) and from Waiakea at 650 feet (200 meters). The winter temperatures at Kainaliu and Waiakea average about 14° to 17°C (57° to 63°F) and about 11° to 12°C (52° to 54°F) at Kalopa and Mealani. Although the temperature difference in the regimes is only 4° to 5°C, actual production records in these areas indicate that the yield in the lower temperature regime areas is only about half or less than half of that obtained in the warmer areas.

In view of these positive indications in growth room studies relating to raceme counts and subsequent field data, Shigeura *(76)* gives in Table 2, from an expanded study, the comparative tabulation of the average minimum temperatures during the flowering season of several areas where macadamia trees are now growing on the island of Hawaii and in Australia, and of other areas in Australia that may be better suited to macadamia. The temperature ranges of areas in California now in *M. tetraphylla* are also noted to show the trend.

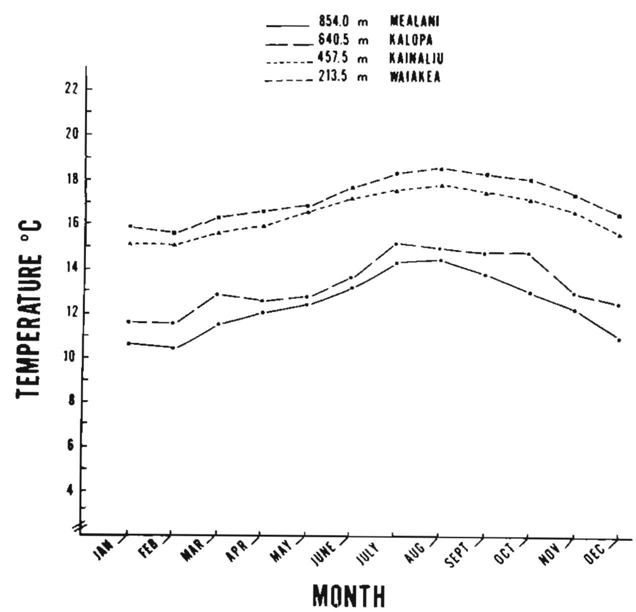


Figure 32. Minimum temperatures for four areas on the island of Hawaii.

Table 2. Minimum temperature regimes of areas in Hawaii, Australia, and California

Area	Average minimum temperature °C (°F)				Remarks
Hawaii	*December*	*January*	*February*		
Kainaliu	13.9(57)	14.4(58)	13.9(57)		Excellent
Waiakea	17.2(63)	15.5(60)	15.8(60)		"
Pahala	17.2(63)	17.8(64)	17.8(64)		"
Kalopa	12.8(55)	11.7(53)	11.8(53)		Poor to bad
Hamakua	12.8(55)	11.1(52)	11.1(52)		"
Mealani	10.6(51)	8.3(47)	10.0(50)		"
Kamuela	12.2(54)	11.1(52)	11.7(53)		"
Australia	*June*	*July*	*August*	*September*	
Alstonville (Lismore)	10.3(51)	9.2(49)	9.9(50)	11.7(52)	Bad; too cold
Nambour	8.0(46)	6.4(44)	7.2(45)	9.7(49)	"
Bandaberg	11.9(53)	10.3(51)	11.4(53)	13.9(57)	"
Atherton Table Land	10.6(51)	9.5(49)	10.4(51)	12.1(52)	"
Bowen	15.7(60)	15.0(59)	16.1(61)	18.2(65)	Should be good
Townsville	14.2(58)	13.4(56)	14.4(58)	17.1(63)	"
Ingham	13.9(57)	13.0(56)	13.8(57)	15.1(59)	"
Innisfal	15.8(60)	14.8(59)	15.0(59)	16.5(62)	"
Cairns	17.6(64)	17.0(63)	17.4(63)	18.6(66)	"
California	*December*	*January*	*February*		
Vista	1.7(35)	1.7(35)	2.2(36)		Subtropical temperature
Escondido	1.1(34)	3.9(39)	3.3(38)		"

Examination of Table 2 and Nakata's raceme count in Fig. 29 indicates that the temperature regimes of Waiakea and Pahala, with their high yield of 6000 pounds per acre, are closer to Nakata's best treatment at 18°C. Kainaliu is slightly lower in temperature than Waiakea or Pahala, but a temperature reversal pattern obtained here results in a dry flowering season with hardly any blossom blight diseases, allowing nut set to be excellent. On the other hand, Kalopa and Hamakua are at Nakata's 12°C, and yields are about 2000 to 3000 pounds of nuts per acre. Whatever trees are growing in the Mealani area are bearing very sparsely; however, the tetraphyllas planted at Kamuela are thriving.

The minimum temperature regimes of the Australian areas now in macadamia production (Table 2) are quite similar to, or lower than, those obtained at Hamakua and Kamuela. In fact, the temperatures from Alstonville to the Atherton Table Land more closely resemble those obtained at Mealani, which is cold and wet, and where the integrifolias do not yield.

The minimum temperature is probably the main cause of the poor yield—both at the higher elevations in Hawaii and in the Australia macadamia areas. These areas in Australia yield only about half of that obtained in the tropical zones in Hawaii. The suggestion is made here that macadamia should not be planted much beyond 1500 feet in elevation in Hawaii. Perhaps in Australia the macadamia nuts would do better on the lowlands between Bowen and Cairns, which have temperatures comparable to Hawaii's tropics. California, on the other hand, gave up on the integrifolia a long time ago, and plants only the tetraphyllas. Allen *(1)*, working on photosynthesis and heat stress of tropical plants in South Africa, suggested the temperature range between 16° and 25°C as best for photosynthesis in macadamia. In a gross sense, his findings support our belief that 12°C during the flowering season may be too cold.

These temperature analyses and yield performances from the fields in Hawaii seem to indicate that Nakata's growth room findings are real and reliable. Until better records are experimentally produced, the minimum temperature regime concept presented here should be used to help in the production of macadamia nuts.

Categorically, the macadamia nut tree can be economically grown at elevations in Hawaii where pineapple, guava, coffee, papaya, mango, and banana are profitably grown. Except for a few areas with definite southern exposure, most of the areas above 1500 feet (457 meters) in Hawaii are not good for macadamias.

Water (Irrigation, Rainfall)

The water requirement of macadamia depends on factors and conditions such as land type, land slope, cloud cover, wind, exposure, and temperature. These factors cannot be controlled or manipulated. Consequently, irrigation recommendations should be qualified and specific, depending on conditions obtained in any given orchard.

On any land where lack of water is a limiting growth factor, irrigation should be practiced. For instance, on aa lava soil (Histosols), with 80 inches (203 centimeters) to 125 inches (317 centimeters) of normally distributed rainfall per year, additional water should be applied during the summer months, or any drought periods. On the other hand, on Mollisols at 1500 feet (457 meters) in Honokaa, 65 inches (165 centimeters) of rain is enough for maximum production. Shigeura *(72)* reported on a 10-year study (1965–1974) on *M. integrifolia* at Honokaa's Circle S Orchard in conjunction with a phosphate availability study (Fig. 33). Except as indicated on Farm "A," located in the middle of Circle S Orchard, rainfall was the

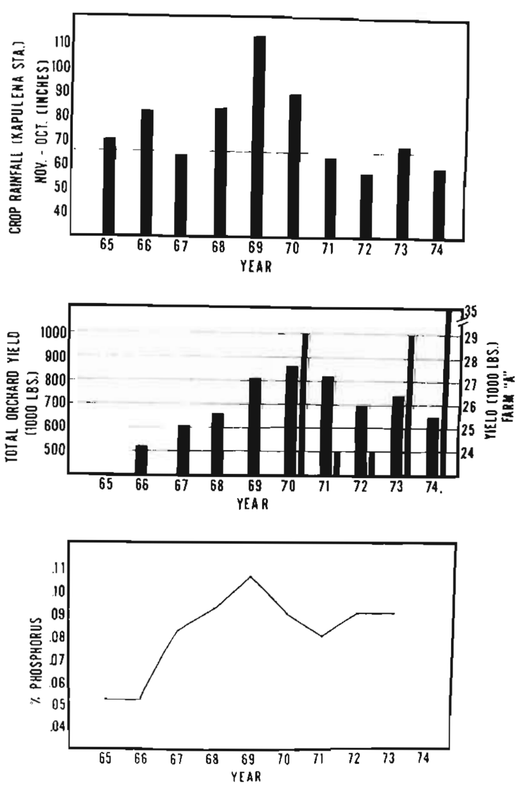


Figure 33. Total yield as affected by moisture and leaf phosphorus.

only source of water for Circle S Orchard. From 1965 to 1970, rainfall was basically above 65 inches (165 centimeters). Phosphorus leaf levels were brought above a minimum of 0.07 by 1967 and maintained adequately throughout the years. Due to response to phosphate fertilization, yearly yield progressively increased through 1970 despite rainfall variations. However, when rainfall dropped below 65 inches (165 centimeters) in 1971, yield also dropped. With continued drought in 1972, yield dropped further. When rainfall went above 65 inches (165 centimeters) in 1973, yield went up slightly. With a drop in rainfall in 1974, yield again dropped, indicating very strongly that the yield pattern of trees in Circle S Orchard responded to rain.

The yield pattern in Farm "A" is shown on the right ordinate of the yield bar graph. With adequate rainfall, the yield on this farm in 1970 was 29,000 pounds (13,166 kilograms); with rainfall below 65 inches (165 centimeters) in 1971, yield dropped to 24,000 pounds (10,896 kilograms). With continued drought in 1972, the yield remained at 24,000 pounds (10,896 kilograms). In 1973 trees were irrigated by overhead sprinklers in the dry summer months. The yield for that year went up to 29,000 pounds (13,166 kilograms). In 1974, when yield at Circle S went down with the drought, yield at Farm "A" went up to 35,000 pounds (15,890 kilograms) with irrigation.

This study suggests that on Mollisols at 1500 feet elevation at Honokaa, 65 inches of rainfall seems to be minimum for optimum production, and that irrigation during drought increases nut yield. Water requirements of specific soils can be worked out with tensiometers and resistance blocks to reach values approaching normal for the area.

Wind

Basically, because of inherently poor root structure and formation, macadamia nut trees are very susceptible to damage by strong winds (Fig. 34). Windstorms of sufficient magnitude to damage trees occur frequently in Hawaii. Figure 35 illustrates the pathways of 13 storm winds and hurricanes in Hawaiian waters from 1954 to 1976, a total of 27 years, or one strong wind every second year. The most damaging of earlier hurricanes was Hurricane Dot in August 1959. The island of Kauai bore the brunt of the high winds and heavy seas as Dot moved up from the south and passed

Figure 34. A "graveyard" of young "fibrous root" trees blown over by a freak whirlwind that went through the Honomalino orchards in February 1971. No anchorage system had developed on these trees, making them very prone to windthrow.

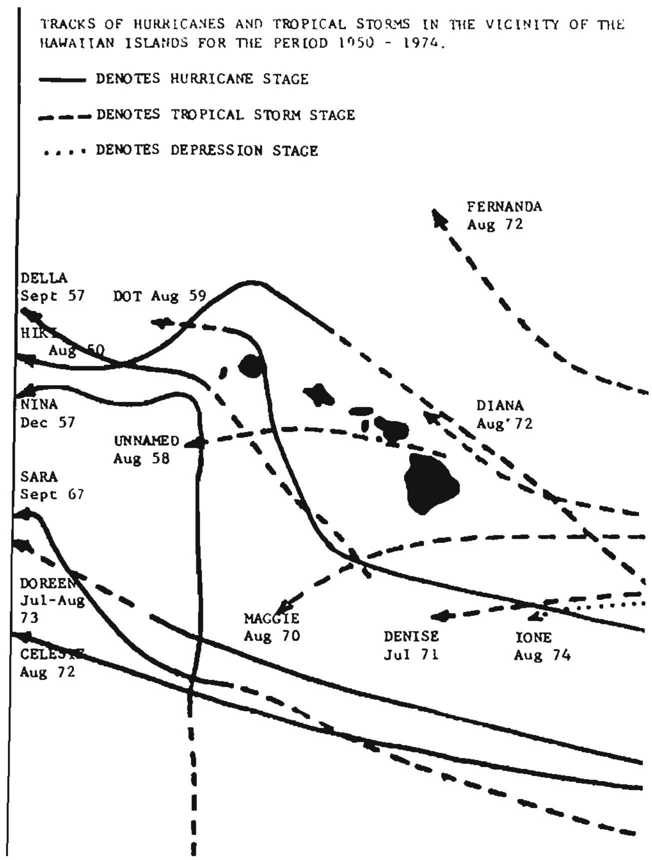


Figure 35. Hurricane and tropical storm tracks in the Hawaiian waters between 1950 and 1974. Notice that all wind disturbances except one occurred between July and September.

(Figure courtesy of National Oceanic and Atmospheric Administration, National Weather Services, Hilo, Hawaii) east of Kauai. Measured wind velocity at Kilauea Point Lighthouse was 103 miles (165 kilometers) per hour. Damage to crops amounted to $5.5 million. In December 1957, Hurricane Nina peaked at 92 miles (148 kilometers) per hour at Kilauea Point Lighthouse. Fortunately, damage was slight at only $50,000. In September 1976, Hurricane Kate, with a wind velocity of 75 miles (120 kilometers) per hour (Fig. 36), came within 350 miles (563 kilometers) of the island of Hawaii before veering away northeastward.

Damage to macadamia nut trees on Kauai from Hurricanes Dot and Nina was extensive. Dr. Jay Kuhn's 10-acre orchard in Wailua, which was in the direct path of both hurricanes, was a total loss. Losses at Francis Takahashi's orchard at Lawai, 12 miles away, were not as severe (Fig. 37).

Hurricane Iwa (Figs. 38, 39, 40, 41, 42, 43, and 44), the most destructive and expensive of hurricanes in recent times in Hawaiian waters, originated in an area 400 miles southwest of the islands of Niihau and Kauai and passed over Niihau at about 7:00 p.m. on November 23, 1982, traveling in a northeasterly direction over Kekaha and Haena on Kauai to leave in its wake severe devastation on the islands of Niihau, Kauai, and as far away as Oahu. Gusts of 110 miles an hour knocked down power and utility lines, ripped roofs off buildings, smashed windows, and uprooted many large trees. High waves along the low-lying coastline destroyed homes, buildings, anchored pleasure boats, and other shoreline facilities. The estimated cost of the destruction will amount to over $200,000,000 when the final total is available.

Iwa, the Hawaiian name of the frigate bird, is the first hurricane given a Hawaiian identity. Due to good and prompt alertness, only one human casualty resulted as the guided missile destroyer *Goldsborough* left Pearl Harbor to ride out the storm at sea.

This time, macadamia nut trees at Francis Takahashi's orchard at Lawai were severely damaged as the eye of the hurricane passed within ten miles of the orchard.

Although macadamia trees cannot be totally protected from winds of hurricane velocities, tall windbreak trees growing on the edges and within the orchard will protect the trees from lesser storms. As a normal practice, one to three rows of windbreak trees should be planted along the perimeter of the field. The distance between windbreak rows should vary depending on anticipated wind velocity and the lay of the land; however, as a rule of thumb, the distance should not be more than 500 feet (150 meters). When the extent of the land is large, a cross windbreak is advisable.

Some species of windbreak trees proven under Hawaiian growing conditions *(71)* are Brisbane boxwood *(Tristanea conferta)*, Java plum *(Eugenia cuminii)*, small cone ironwood *(Casuarina* sp.), paper bark *(Melaleuca leucadendron)*, silver oak *(Grevillea robusta)*, turpentine tree *(Syncarpia laurifolia)*, and Norfolk Island pine *(Araucaria excelsa)* (Fig. 45).

When further protection of young trees from strong prevailing winds is necessary, an in-field windbreak of sugarcane *(Saccharum* hybrid clone *moentai)* can be used. This species grows upright to a height of 10 feet *(68)* and affords excellent protection.

Windbreak tree species *Eugenia cuminii* and *Casuarina* sp. withstood Hurricane Iwa with only limbs torn off the Eugenia; the Casuarina remained undamaged because it was able to "whip" with the wind and stood up exceedingly well. However, some Eugenias growing in the very wet area of Hanalei did go down. Guava trees at Kilauea withstood the gusts well because of their limbs whipping in the wind. *Araucaria excelsa*, as in Hurricane Dot, suffered only lateral-limb breakage with the main bole untouched. These bare boles will regrow in time. *Saccharum* hybrid clone *moentai* took the wind without any damage.

CULTIVATION REQUIREMENTS

Cultivar

Fortunately, both Purvis and the Jordan brothers introduced to Hawaii the tropical species *M. integrifolia* rather than the more subtropical *M. tetraphylla*, and they planted their trees at the lower elevations in Hawaii adapted to the integrifolias. The trees grew and produced well. Again, by chance, the tetraphyllas introduced by the Board of Agriculture about the same time were planted in a forest aboretum on Mt. Tantalus above the city of Honolulu and treated as forest trees. Since the macadamia tree is not good for lumber, as the wood "checks" on drying, the foresters soon lost interest in the trees. It is frightening to think where the Hawaii macadamia nut industry would be had Purvis and the Jordan brothers imported the tetraphyllas instead of the integrifolias.

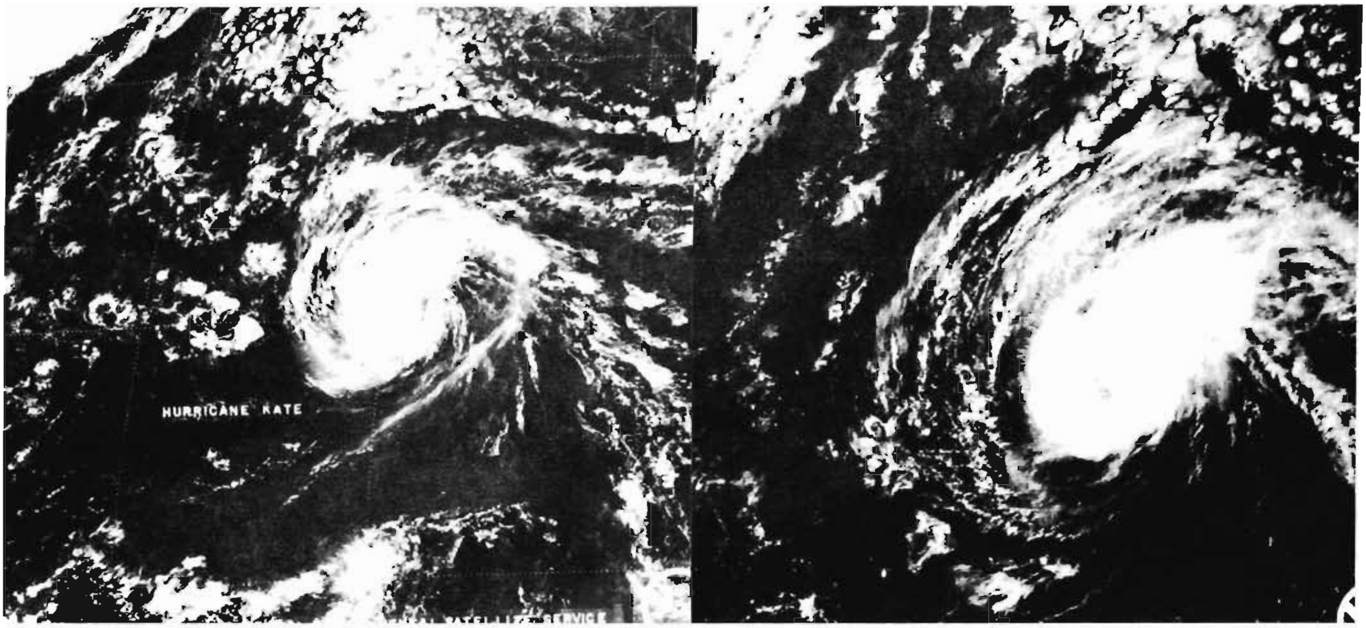


Figure 36. Hurricane Kate approaching Hawaii in September 1976 (left photograph) and turning north a day's distance away from Hawaii (right photograph). The chain of islands is visible to the left of the hurricane.
(Photo courtesy of National Earth Satellite Service, NOAA)

Figure 37. Francis Takahashi's orchard at Lawai, Kauai, after Hurricane Dot in 1959.

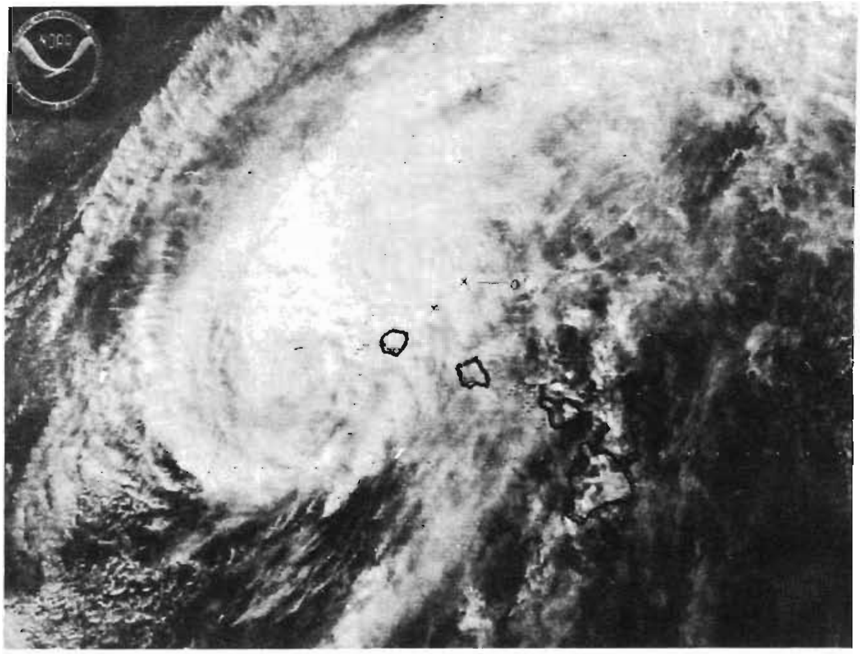


Figure 38. Hurricane Iwa over Kauai and Oahu on the 24th of November, 1982, with the eye of the hurricane to the left of Kauai and the circle extending over much of Oahu.
(Photo courtesy of National Earth Satellite Service, NOAA, Honolulu)

Figure 39. Windswept coconut trees at Waimea, Kauai, survived Hurricane Iwa.
(Courtesy of Jeri Ooka)

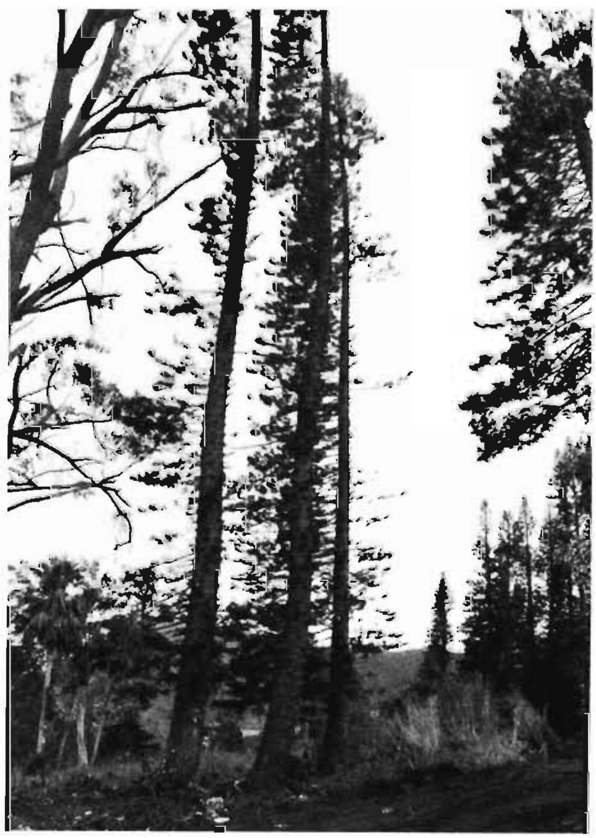


Figure 40. Severely limb-damaged *Araucaria excelsa*, Norfolk Island pine, at Koloa, Kauai, after Hurricane Iwa.
(Courtesy of Jeri Ooka)

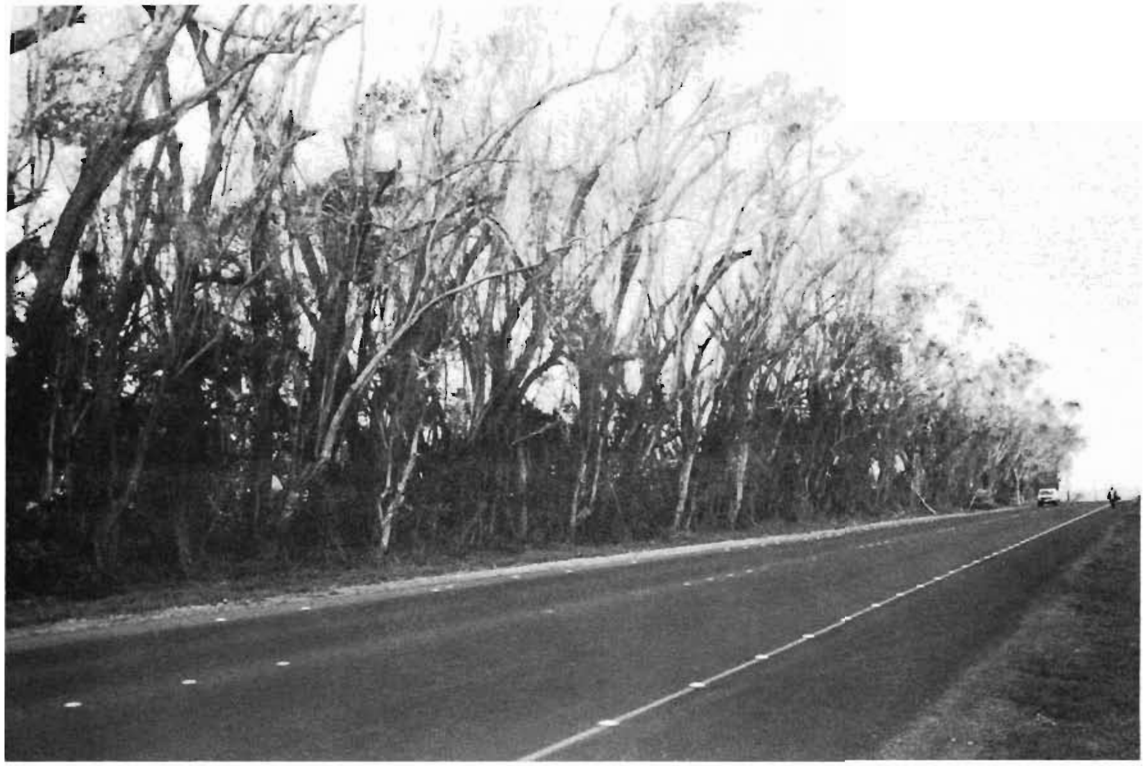


Figure 41. *Eugenia cuminii*, Java plum at Puhi, Kauai, with broken limbs but no windthrow after Hurricane Iwa.
(Courtesy of Jeri Ooka)

Figure 42. Figure 41 trees three months later.
(Courtesy of Jeri Ooka)

Figure 43. *Eucalyptus robusta* trees at Puhi, Kauai, with broken limbs but no windthrow after Hurricane Iwa.
(Courtesy of Jeri Ooka)

Figure 44. Figure 43 trees three months later.
(Courtesy of Jeri Ooka)

Figure 45. Windbreaks in macadamia nut fields: *Syncarpia laurifolia* on the left and *Araucaria excelsa* on the right.

Naquin planted predominantly the integrifolia at Honokaa, presumably because the Purvis integrifolia trees planted nearby were the major seed source. Van Tassel did the same for his orchard at Nutridge. Unfortunately, some of the trees planted in Keauhou, Kona, before Moltzau's time and used as intercrop and shade sources in the coffee fields were tetraphyllas. Moltzau remembers demonstrating the tree topworking technique to Kona farmers by actually topworking hundreds of trees beginning in 1928. Fortunately, he also persuaded the Kona farmers to plant integrifolias.

All five cultivars named by Storey by that time were extensively planted at Keaau Orchard, beginning in 1949. Only two of these, 'Keauhou' and 'Kakea', however, showed good commercial possibilities by 1953. The other cultivars were topworked with 'Keauhou', 'Kakea', and a recently named cultivar, 'Ikaika'.

In 1952 Hamilton and Fukunaga named 'Ikaika' (HAES 333) and 'Wailua' (HAES 475), of which only 'Ikaika' is now cultivated commercially. In 1966 Hamilton and Ooka *(17)*, introduced 'Keaau' (HAES 660), and in 1971 Hamilton and Nakamura *(18)* introduced 'Ka'u' (HAES 344). Hamilton and Ito *(19)* named 'Mauka' (HAES 741) and 'Makai' (HAES 800) in 1977, implying that cultivar 'Mauka' is for the higher elevations above 1800 feet and cultivar 'Makai' is suited to elevations below 1600 feet. In a paper presented at the 1981 annual meeting of the Macadamia Producers Association, Hamilton *(20)* named two new cultivars, 'Purvis' (HAES 294) and 'Pahala' (HAES 788).

As of this date, 13 *M. integrifolia* cultivars in Hawaii have been assigned names. The older orchards are predominantly planted to 'Keauhou', 'Kakea', and 'Ikaika', the cultivars then available. The more consistent cultivar recommendation currently given by most farmers is to plant 'Kakea', 'Ka'u', and 'Keaau'. The nut size of 'Keaau' is somewhat small, but it is a good yielder of both in-shell nuts and quality kernels. It is also a thinner-shelled nut and possibly can be recommended as a seed source. It is also a more confined tree and is, therefore, more economical in terms of space. 'Ka'u', a relatively new variety, is also a confined, upright tree that seems to be more wind tolerant and yields heavily.

Clonal Tree Propagation

Rootstock. The structural formation of the roots on the rootstocks used in grafting macadamia nut trees is one of the most important aspects in tree production. Root structural evidence collected in the last 20 years seems to indicate that the method now employed could be modified to lessen the expensive and eventual loss of trees in a developing orchard.

The desirability in macadamia of using clonal cultivars instead of trees propagated from seeds was recognized by Moltzau in the early 1930s, when it became obvious that there was great variability among trees in terms of their production capabilities and quality of nuts. Even in those early days, efforts were directed toward finding cultivars that grew quickly, yielded well, and produced good quality nuts. Moltzau began by planting seedlings in nursery rows (Fig. 46) for use in grafting to selected better clones.

During this period Moltzau not only selected better clones but also developed and adapted the system of propagation of grafted trees by using nursery rows, a system that was used very effectively until the mid-1950s. The trees in these rows were grafted when the seedling stems were about ½ inch in diameter 6 inches above ground level. The successfully grafted trees were cared for and maintained in the rows until they were about 2 to 3 feet high. The trees were then root pruned by cutting all roots with a long drain spade at 6 to 8 inches around the tree and as deep to form an inverted soil cone with the mass of severed roots. After six to eight weeks these trees, with regrowth of the severed roots, were ready for field planting. Nursery row propagation was tedious and time consuming, but the grafted trees were produced with good root systems.

The use of black polyethylene containers replaced the nursery row system in the mid-1950s. The container sizes varied with the farmers involved but basically were 1 to 1½ gallons in capacity and 8 to 12 inches in diameter and depth. Trees produced in these containers, usually with transplanted seedlings from a seedbed, are not ideal since the roots have a tendency either to bind in the pots or to extend beyond the pots to anchor themselves in the ground. These roots are necessarily severed in transplanting.

Root morphological evidence collected in the fields in the last 20 years indicates that perhaps a critical review and appraisal of shallow poly bags as they affect roots is desirable. Figure 47 suggests that Moltzau, even in the 1930s, recognized the importance of root structure and formation in

Figure 46. The first macadamia nut nursery rows propagated by veneer grafting established in the early 1930s in Kona by Ralph Moltzau. Note the kerosene burner with a paraffin-wax pot being heated.

(Courtesy of Ralph H. Moltzau)

macadamia nuts. Moltzau's illustration shows that when the micropyle and stem-end orientation of the seeds are aligned horizontally, with the suture to the side, the hypocotyl with its shoot and root emerges from the seed in a straight up and down orientation.

On the other hand, Fig. 48 illustrates malformations of seedling root systems when the seeds, at planting, are improperly handled with the micropyle in either an up or down position, or when obstructive materials are in the planting medium. The result can be trees as shown in Fig. 49 with gross embedment of bark as they developed in a twisted fashion. The "creases" are very harmful and can result in total loss of a tree after a profitable period of growth and production.

Figure 50 illustrates another bad situation when the taproots of young seedlings are cut to accommodate the size of containers, or when the taproots instead develop as laterals in structure and in function. Note that the many laterals are emerging on the stem, which is no more than 2 to 3 inches long and, morphologically, has already

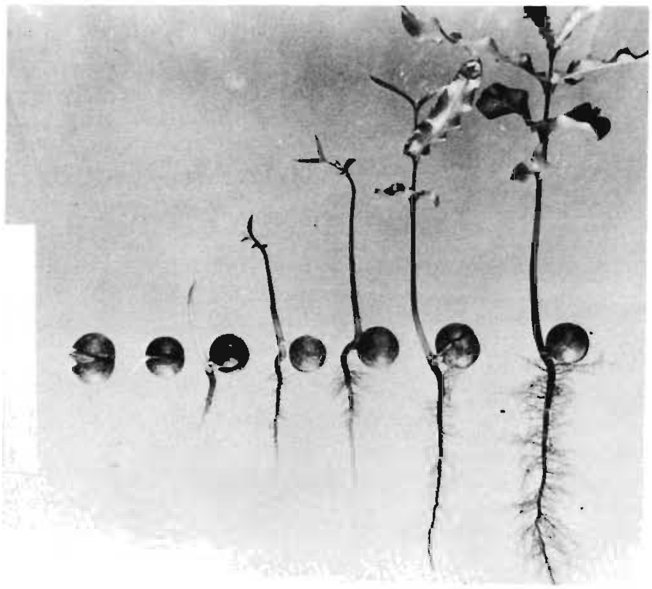


Figure 47. Germinating seeds with micropyle, stem end, and suture to the side, showing the straight-line orientation of stem and roots. The proper orientation can be accomplished by pushing seeds into place on the firm medium before covering with a layer of planting medium.
(Courtesy of Ralph H. Moltzau)

Figure 48. Malformed seedlings. Left to right, (1) roots growing into a half-shell remnant in the planting medium, causing cupping and short upward growth; (2) curved stem growth from seeds with micropyle at the bottom; (3) seedling with micropyle at the top; (4) curved root growth caused by a large obstruction in the seedling root area.

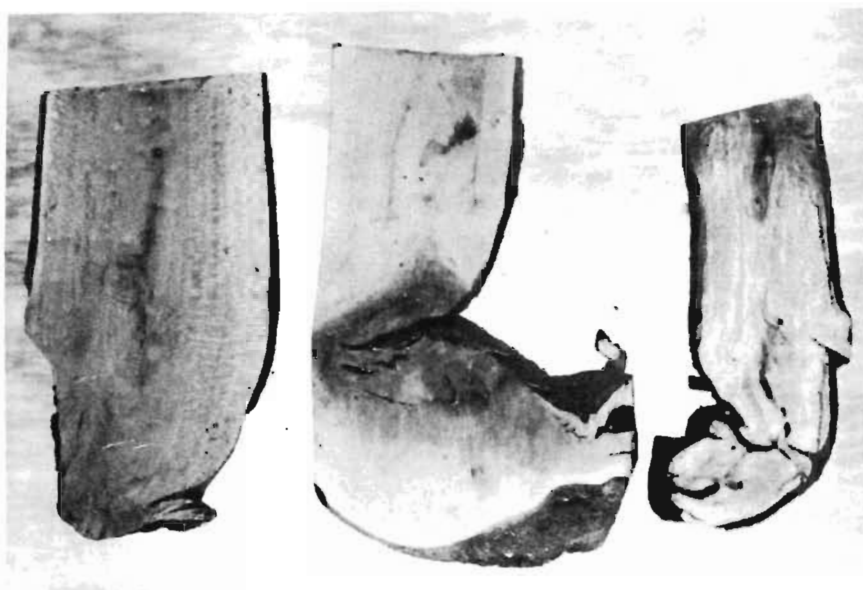


Figure 49. Malformed trees with embedded bark. These trees were wind-thrown. A more careful selection in the seed box or direct planting of seeds would have eliminated these seedlings with "creases."

ceased to grow in the longitudinal axis. The development in Fig. 51 on older material is similar; further growth in the root area is only in the lateral direction and by cambial activity. This tendency embeds the bark, making apparent connections between laterals incomplete, superficial, and at a pinpoint originally formed as in Fig. 50. Figure 52 shows a pinpoint depression due to cambial growth.

Since the formation of these structural weaknesses is initiated at seed planting time, the seeds with the micropyle to stem-end orientation and the suture should be carefully placed horizontally (Fig. 47) in a well-settled medium in a container to reduce shifting. In nursery row propagation, evidence seems to indicate that direct planting in the field or, initially, in a small tube container for immediate transfer to field may be an alternative to planting with seedlings germinated in a seedbed where the roots can be damaged in transplanting. When containers are used, they should be about 8 inches in diameter and 15 inches deep (Fig. 53). Seedlings thus planted produce a tree with a definite taproot with its many laterals placed along the entire system. Some of these laterals will develop, while the other will degenerate and, as likely as not, become buried in the tap structure (Fig. 54). Trees with such massive taproots are not as likely to go down in a windstorm as the trees shown in Fig. 34. Figure 55 compares two grafted trees propagated in small, shallow

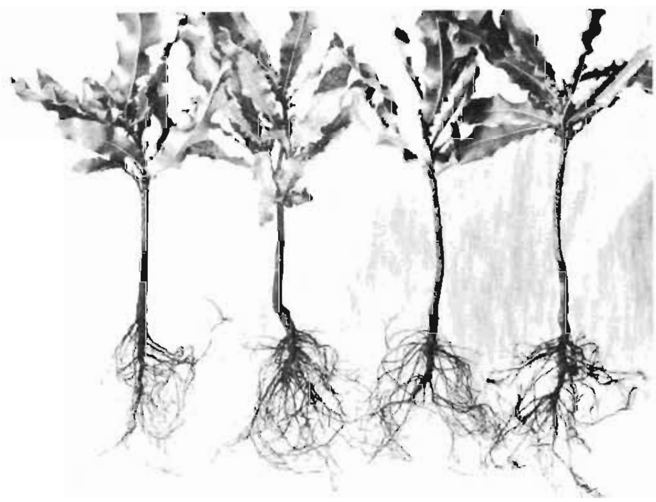


Figure 50. Root systems showing "fibrous root" development much akin to corn and other monocots. Secondary growth on these congested laterals will begin to bury the bark as they grow, leaving the only real transport connection throughout the life of the tree at the pinpoint where the laterals originally met on the seedling taproot.

Figure 51. Lateral root formation in macadamia showing embedded bark. Note that roots gather at the center to indicate that the true and only connections to the main trunk are at the pinpoints where the roots emerge in the seedbed seedling stage. Essentially, nutrient transport in these laterals has to go through these "narrows," greatly restricting efficiency of uptake.

Figure 52. Note a conical depression in the center of the root area forming a pinpoint at the spot where the lateral root was connected to the tap.

Figure 53. Polyethylene containers, 20 inches high, used at Rancho Nuez Nursery in California to permit development of a strong taproot system.

(Courtesy of Tom Cooper, Rancho Nuez Nursery, Fallbrook, California, through Dr. Lois James)

Figure 54. Longitudinal view of cut root showing two strong laterals and a solid tap on a tree approximately 20 years of age. Also, note some apparently ineffective roots embedded at the root-stem junction in the center of picture to the right.

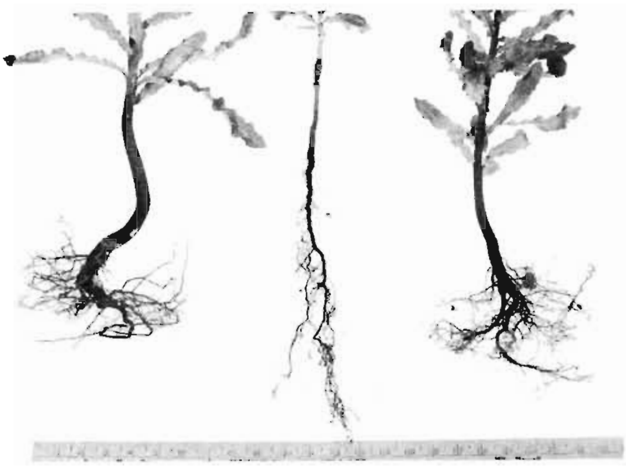


Figure 55. Root system of a tree propagated and grafted early in a deep poly pot (center) showing a developing taproot. The trees to the left and right were propagated in shallow poly pots and have many roots congested in a narrow section.

containers with one that was propagated in a long, narrow tube. Using these narrower tubes and grafting as early as possible by using smaller scion woods are ideas that merit more thought. The use of this sytem should produce field-plantable trees 15 to 18 months after seed placement in containers. In addition to Rancho Nuez Nursery in California, one nurseryman in Hilo is successfully propagating grafted trees in this manner (Fig. 55).

The seedling propagation scheme suggested here is very different from the methods now employed and is based on evidence gathered by the authors in the last 20 years. It is offered here as an alternative to a system that needs improvement.

Preparation for grafting. Macadamia seedlings can be grafted at any time of year, provided that the seedlings are actively growing. Fertilizer applied a month or two before grafting will better insure cambial activity. The scion wood should also be specially prepared to induce long, caney growth (Fig. 56). If this is not possible, succulent growth emerging when trees are pruned, or succulent growth from young trees, is adequate. However, straight succulent sprouts extending vertically on a pruned tree do not make good scion wood since they do not seem to store starch when girdled. These selected limbs should be girdled six to eight weeks prior to grafting to accumulate starch above the girdle (Fig. 22). Girdling is easily done by gripping the stem, using pliers to damage the bark through to the wood to stop the flow of starch past the girdle. The girdle needs to be only about ½ inch (1 centimeter) wide. The girdled stem should be tested for starch before use. This can best be done by snipping the very small terminal of girdled stem and immersing the cut portion in a solution of iodine and potassium iodide. Diluted tincture of iodine from any drugstore can be substituted. Starch deposition, as shown in Fig. 22, indicates that the stem is ready to be used.

Grafting. Macadamia seedlings can be grafted by any of several methods. Moltzau initially used the veneer method with success (Fig. 46). A deep side-wedge, with the seedling stem bent over to permit the scion wood an upright orientation, is now practiced exclusively in Kona. A drawback in wedge grafting is that when the wedge is not cut deeply, the scion wood sometimes slips and separates before the union is completed.

When the graft takes hold and the initial vegetative growth of the scion wood hardens, a vigorous, central upright sprout should be selected and the other sprouts eliminated. The seedling stem at the graft union can then be cut off as close to the scion wood as possible. Pruning paint should be dabbed on the cut surface to prevent decay at the graft union. The trees will be ready for field transplant eight to nine months after grafting.

In Australia, small oval-shaped punches about 1 centimeter long are being used on macadamia to remove buds from ungirdled stems that are fitted into punch-holes similarly created on the stock for a perfect fit *(83)* in budding.

Figure 56. Young, succulent caney growth produced on branches that were "hedged." These limbs are ideal for scion wood when properly girdled for starch storage.

Root pruning. The trees propagated in the nursery rows must be root-pruned two to three months before field transplanting. Root pruning is a technique whereby the seedling roots are severed by stamping a long, narrow, sharp trench shovel angled at about 60° into the root area 6 to 8 inches (15 to 20 centimeters) from the base and about 12 inches (30 centimeters) deep completely around the grafted trees. The pruned roots within the inverted soil cone thus created will then develop a new confined system of feeder roots, and will reduce transplanting shock and losses. To further encourage proper root development, it is advisable to cut some weaker root laterals at the time the trees are lifted for field transplant to permit only two or three strong laterals to develop.

Grafting of in-field planted seedlings. Citrus and some other temperate-zone tree crops propagated in containers or nursery rows produce root systems that take to the field and develop structural root systems in the field that are apparently strong, healthy, and able to withstand windthrow. However, macadamia trees similarly propagated respond somewhat differently after field planting. The reason for this difference is that macadamia laterals and taproots extend well beyond the seedling trees in the nursery rows, and these necessarily are severed in root pruning to confine the root system to a manageable size for field transplanting. In container-propagated trees the same problem exists since the structural laterals, as well as the taproot system, grow out and beyond the containers and again need to be severed before field planting. In either method, the root system of grafted trees of macadamia for field transplant is greatly reduced; these trees do not redevelop as well in the field, or are delayed. As a direct result of this delay or underdevelopment, the young trees in the field are highly susceptible to windthrow even in a mild wind. Some trees are so weak at transplanting that they begin to lean during the first year in the ground and need to be staked. This vulnerability after transplanting extends to about 10 years of age in the field. However, after this initial period, the tendency to windthrow is very much reduced.

To lessen this disproportionate redevelopment of roots in the field after the roots are necessarily severed in the nursery, perhaps small, container-propagated nursery seedlings (Fig. 53) with *unsevered* roots should be planted in the field *before* grafting. In this manner the roots will be permitted to extend and develop in the field as strong laterals and a taproot that need not be severed. The roots may then be more than 10 feet long before grafting, and very strong.

In a test of this method carried out at Keaau Orchard in the 1950s, the trees stood up very well in windstorms, with only broken limbs and no windthrow. Perhaps larger trials of this method are in order. Obviously, pregrafting field maintenance and grafting-in-the-field costs will be higher, but the compensation in sturdier trees that will not be susceptible to windthrow may be worth the effort. Or, perhaps these small seedlings should be grafted in the mist chamber, much akin to the practice now developing in Australia, and planted in the field as soon as possible.

Spacing of Planting

One of the more important considerations in profitability of field operations is spacing of planting. The initial cost of establishing an orchard and the maintenance cost until a positive cash flow develops at about the eighth year is very high. The first commercial harvest begins about the fifth year after the grafted trees are set out in the field. Since there is no income during this early period, a critical decision on developing this cash flow as soon as possible is necessary. A good way to do this is to plant some fast-growing cash crops in the inter-row areas during the first few years. Corn, sweet potatoes, and some other vegetable crops can be planted profitably. However, sometimes the care and maintenance of the immediate crop becomes more important, and the macadamias can be neglected; this may negatively affect overall profitability. Instead of using interplanted crops, the orchardist can use a system of denser planting of macadamias with the intention of eliminating trees as they begin to close in. This is basically a system of intercropping with macadamias, and there is no doubt that the trees will get all the cultural attention they deserve.

Most of the commercial orchards in Hawaii today have been planted in a square pattern, 25 feet (6.4 meters) by 25 feet (6.4 meters), to give 70 trees per acre. Castle & Cooke planted Keaau Orchard in the 1950s at 70 trees per acre with the intention of *thinning out alternate trees* slowly as the permanent trees extended into the space occupied by these trees. The final, permanent orchard would then have 35 trees per acre with a spacing of 35 feet between trees on the diagonal. After 30 years, the original 70 trees are still in production. In view of this demonstration, Castle & Cooke planted an additional 1000 acres (405 hectares) in squares 30 feet (9.2 meters) by 30 feet (9.2 meters), with an additional tree planted in the center of the square for a total of 96 trees per acre. The additional trees are to be eliminated in 20 years or so, to result in a square orchard with 50 trees, 30 feet apart, per acre.

The original trees at C. Brewer in Ka'u were planted in the 1960s in a 25-foot-square pattern to give 70 trees per acre. Beginning in the late 1970s planting has been in rows spaced at 25 feet and trees in the row spaced at 18 feet, giving each planting area a square footage of 450, or 97 trees per acre. When the closely planted trees are alternately eliminated as they close in and begin to shade each other, the ultimate diagonal distance between trees will be an adequate 30.8 feet, which should be the permanent distance between trees in a mature orchard at 48.4 trees per acre.

Dense planting to advance development of an early cash flow, and subsequent alternate-tree elimination as the orchard trees begin to close in, is economically very sound; it should be practiced universally. In an orchard operated under a corporate structure, where the operations are done on a relatively large scale and very impersonally, the design of planting and subsequent tree elimination are agreed upon prior to planting. Consequently, tree elimination can be done without any second thought when the orchard closes in. However, on a smaller farm where the owner also operates the farm, tree elimination can become a difficult issue since it can temporarily reduce yield when done drastically. This becomes a problem especially when the tree to be eliminated happens to be healthier and better than the permanent trees next to it.

Anticipating a difficult decision at a later date, the permanent orchard can be completely laid out initially in an equilateral (quincunx) design to make the best use of the spaces between trees. This decision is a compromise at the start, which enables the orchardist to know exactly where he is at the beginning. Figure 57 graphically illustrates the loss in land area utilization when the trees are planted in a square rather than in an equilateral triangle. A reasonable assumption is that a tree with branches emerging in all directions will grow in a more or less circular, rather than triangular or square, pattern. If this assumption is correct, the large "dead" area among four trees in a square can be expensively underutilized. This "dead" area can be much reduced by using the equilateral planting scheme. For example, in a 30-foot-square pattern, each tree is allocated 900 square feet of land area. On the other hand, with the same distance between trees, 30 feet, in an equilateral triangular pattern, the distance between the rows of trees will be 26 feet. Trees in this pattern will then be allocated 780 square feet. Expressing this gain in number of trees, a 30-foot by 30-foot square will allow only 48 trees per acre, while the 30-foot equilateral triangular pattern will allow 56 trees per acre, an increase of eight trees, or 17 percent. Perhaps this is a better way to increase early and continued production.

Another essential factor in tree spacing is the growth habits of the trees. Some of the selected clones are more dome shaped, and some more

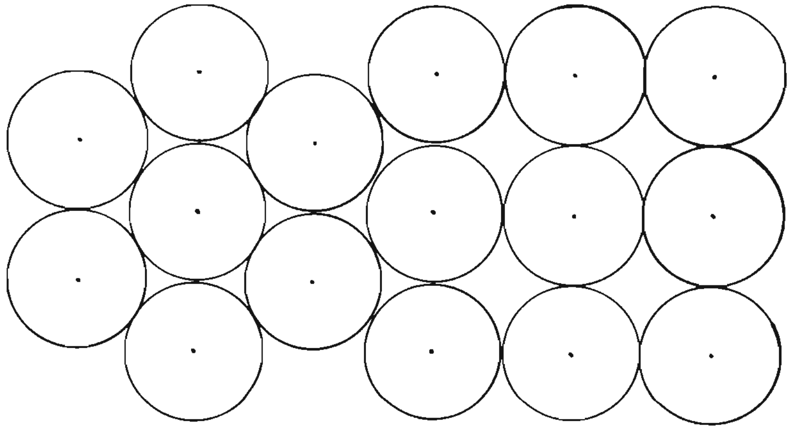


Figure 57. Graphic representation of planting design to illustrate space loss in a square planting compared to the equilateral triangular (quincunx) system.

columnar, with others falling in between. 'Keauhou' (HAES 246) and 'Ikaika' (HAES 333) are basically dome shaped, 'Keaau' (HAES 660) and 'Ka'u' (HAES 344) are columnar, and 'Kakea' (HAES 508) can be either domed or columnar. These trees need to be pruned somewhat differently when planted together. However, to reduce the ills of tree shape and yet permit cross-pollination, the varieties are better planted in alternate rows instead of alternate trees.

Planting

The planting holes to receive the trees in the field should be laid out and completely prepared before planting operations begin. This is very important since the delicate grafted trees, especially when bare rooted, should not be left in the field unplanted in the hot summer. The tree holes can be dug with hand tools, posthole diggers (Fig. 58), or a backhoe. The holes should be hand cleared, if necessary.

Planting method is an individual matter and can vary depending on individual preference and the situation. However, a few general words of caution may bring the more common problems into better focus. The grafted trees are living entities with established root systems that need to be handled very carefully and placed in their proper orientation. When using bare-rooted trees propagated in nursery rows, the taproot should be placed in a straight up-and-down position with all obstructions removed. The laterals should be aligned to spread from the main root-stem axis like wheel spokes attached to a hub, and thinned, if necessary, to reduce congestion and permit the remaining laterals to radiate more strongly as definite laterals. The roots thus placed should be tamped in gently, to permit a firm foundation.

Grafted trees propagated in containers have to be treated somewhat differently prior to field planting. By the nature of root growth and extension in a container, as often as not, some roots will assume dominancy in growth extension and will begin to circle the side of the enclosing container. Some others might extend downward or vertically onto the table holding the containers, or into the soil if placed on the ground. Whichever the case, before planting, sever the circling extension to permit a radial extension, and sever the downward or vertical extensions, if necessary, at a point to permit further development in the field. Some trees do neither of the above, but the roots will

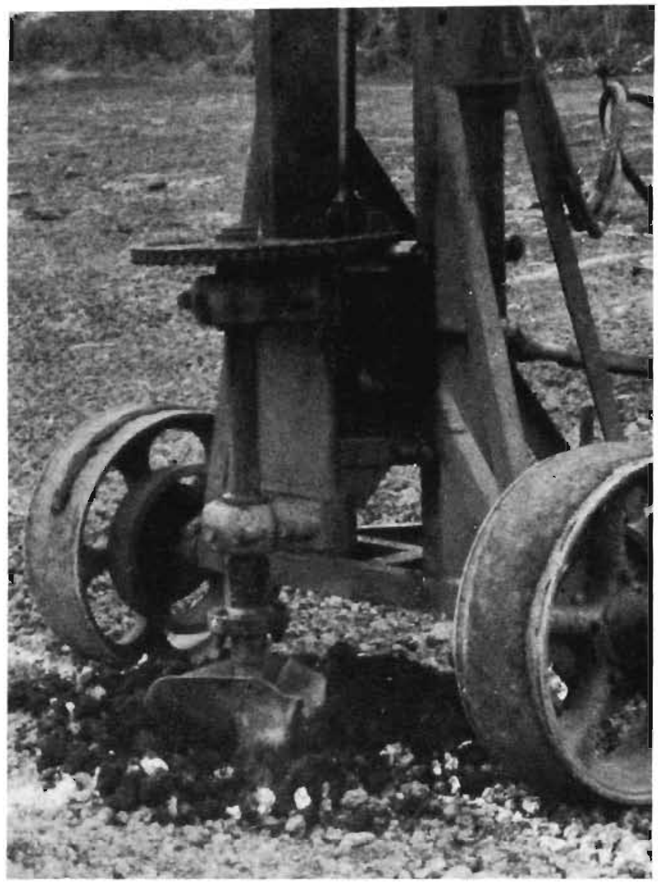


Figure 58. The original posthole digger fabricated by Stubenberg and Company in Hilo for use at Keaau Orchard in the early 1950s. Note the wide auger especially designed for macadamia on aa lava land. This unit derived its power from the power takeoff on a tractor. In recent years, a backhoe has been used to further reduce cost.

appear as pinpoints at the container surface. In such cases, since no root system has assumed dominancy in extension, these trees should be planted undisturbed, in the hope that some of these points will assume dominancy in the field to grow and extend into structural laterals.

To enable the trees to develop as soon as possible, fertilizers should be applied soon after planting. In areas where phosphate is a problem, about 1 pound of rock phosphate can be placed at the bottom of the tree hole or superphosphate can be sprinkled among the roots. Slow-release fertilizers in tablets or granules may also be applied.

Where lack of water can become a problem, irrigation water should be available; if it is not, the trees should be planted only when rainfall is expected. In planting the trees on lava land at

Figure 59. The planting trailer is being loaded with water-saturated soil in planting at Keaau Orchard in the early 1950s. This trailer was drawn between two rows of tree holes, with two men each planting a tree in each row.

Figure 60. A total loss of tree caused by development and retention of two or more equally strong branches after tree planting in the field. The dark portion at the break is bark embedment at the upper end and mold growth at the lower. This destruction could have been prevented by limb selection to a single stem during the first year after field transplanting.

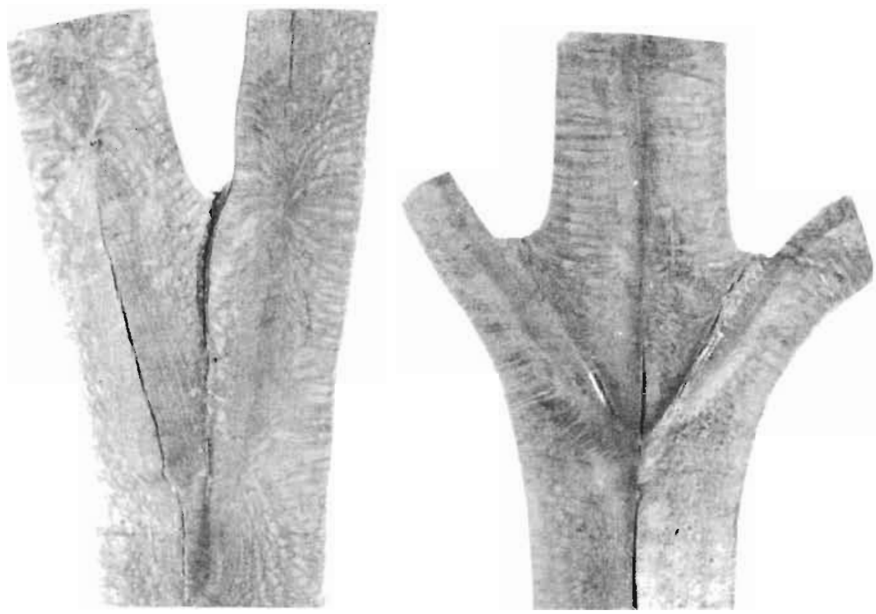


Figure 61. Bark being embedded by equally strong branches originating at one point on the left; on the right, cambial activity between the terminal and the weaker or subordinate laterals has started to "join" these branches together by laying down cambial wood. Note on the left that bark was being embedded when the branch was still very small.

Keaau Orchard, the planting soil that was hauled in for packing around the bare tree roots was watered to saturation as it was unloaded from the dump truck (Fig. 59).

Tree Training

Leader tree. The development of a single-leader top growth in the tree is essential. A neglected and untrained macadamia nut tree can develop into a tree that is multiply branched with branches originating from points at the base of the tree. This type of branching grows into a congested system with large and equally strong limbs akin to the arrangement of ribs in a common fan. This arrangement is poor because each branch without any space for lateral expansion will grow into and crowd the others for growth space, a state that, when continued, will drastically reduce yield. The elimination or reduction of this undesirable development is one of the objectives of tree training. For good yield, a macadamia nut tree should have a leader growth, a central main axis of growth. The leader should have lateral branches spaced strategically, regularly, and loosely to permit air and sunlight penetration into the crown to allow flowers to develop. To accomplish this desired end, the trees in the field should be pruned and trained as soon as possible.

The usual practice in transplanting in the field is to snip-cut the top of the tree to reduce transplanting shock. When this is done, the next vegetative growth on the stem is usually in two parts, or dichotomous. If this dichotomous situation is allowed to develop, losses as shown in Fig. 60 will develop because of bark embedment in the crotch of the two terminals. Rather, these terminals should have been permitted to develop and grow for about one year to put on more growth. After this period, *all but one* growth should have been eliminated, the one remaining to become the main axis of the new tree. After this initial pruning, new lateral branches developing at the pruned point will be *subordinate* in development to the leader, and thus will make excellent lateral branches.

Dominant laterals, and thus bark embedment, can become very serious, as shown in Fig. 61. The branch section on the left shows equally strong branches with bark embedded at the crotch, while the one on the right shows a reduced bark embedment because the laterals are smaller and subordinate in development to the leader. Figure 62 shows the gross external view of bark being embedded down the line in the tree crotch to the left, while on the tree to the right, the total bark is being "pushed out" by cambial activity at the crotch. Essentially, then, the embedded bark concept must be the prime thought in training throughout the life of the tree. Subordination of lateral growth is very important. If, however, embedded bark laterals have been missed, errors can be corrrected by bolting or wiring the limbs together (Fig. 63).

Thus, in training the foliage portion of a macadamia nut tree, keep all lateral branches subordinate in development to the upright leader. This can be accomplished by heading back the laterals or bending them over to develop axillary buds that will reduce dominant growth. To prevent bark from being embedded, allow only one weak branch to originate at one point on the main axis.

Fruiting twigs. Another concern in pruning is the development of fruiting twigs whenever possible. Small branches within the crown of the tree and developing off a structural lateral will not become strong; instead, these branches will remain small and subordinate in development. These are the fruiting twigs—they should be nurtured by thinning out other small branches in the area, if necessary. These are older woods and, if permitted to go vegetative even very weakly, these new tiny branches will continue to flower and fruit for a long time.

Hedging. Hedging as a method of tree manipulation was used experimentally to keep the trees confined to permit machine movement in the inter-row areas. When done improperly, hedging is counterproductive in total yield since it disrupts the apical dominancy of stems thus pruned. Growth occurring subsequently at the hedged surface will be vigorous, dense, and multibranched into the void formerly occupied by the severed branches. This method will cause yield to go down eventually because old wood will not be created to set flowers, and sunlight penetration into the tree crown will be drastically reduced by this heavy

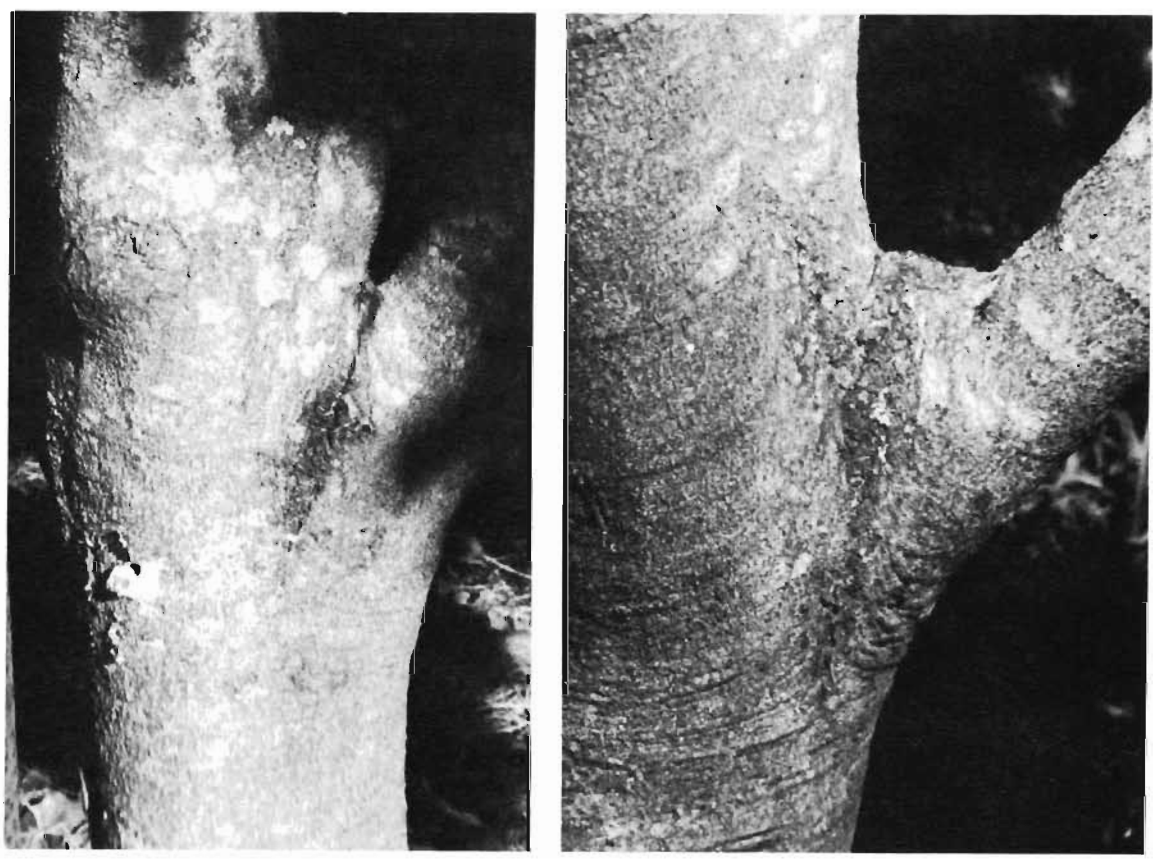


Figure 62. Gross external view of limbs, showing embedded bark on the left. Note deep furrow where bark is still being embedded. In the limb on the right, bark is being pushed out by cambial growth. Note bark pieces and "bark wave" formation as the development is pushed out by cambial activity.

Figure 63. The use of bolts to save an embedded-bark limb, practiced by Ralph Moltzau in the 1930s.
(Courtesy of Ralph H. Moltzau)

canopy of small branches.

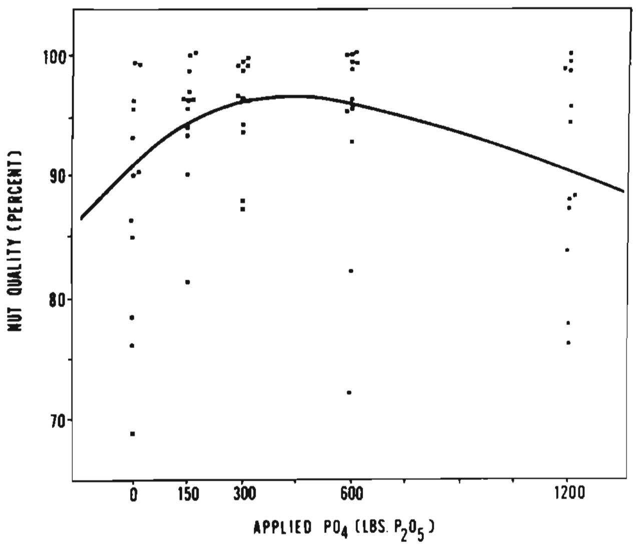
To sustain yield by pruning, when necessary, limbs or large branches should be pruned and eliminated at the point of their attachment to another branch to permit more light to go through the void thus created. In this manner the remaining older branches will set flowers and thus increase yield. This system of branch pruning will also extend yield by forcing top growth in the proper direction and will enable trees to maintain total productivity over a longer period of time by better utilization of airspace.

Fertilization

Fertility requirements of macadamia have been studied and reported over the years by Cooil and his co-workers *(9, 10, 11)*, Shigeura et al. *(69, 70, 72, 74)*, and Warner and Fox *(86)*, suggesting leaf analyses values that can be used in a more objective fertilization program. Cooil and his co-workers, working on *M. integrifolia* at Keaau Orchard on the island of Hawaii in the early 1950s, established leaf analyses values for nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) using leaves at the time the major flush of growth is beginning, generally in March. In this sampling procedure, a mature leaf is taken from the second whorl below the newly emerging flush. A total of 10 leaves is suggested for each sample. Cooil's values for N, P, K, and Mg have been found to be accurate and useful in predicting nutritional needs of trees growing on the many soil types found in the state. This sampling procedure has now been extended and applied to leaf sampling throughout the year.

Shigeura et al., using Cooil's leaf values, developed a system using the leaves from the most recently matured terminal, which is distinct and identifiable since new terminals continue to develop on macadamia throughout the year, and the new leaves are glossier green than older leaves. The overriding advantage of using recently matured terminals is that the sampled leaves will be of the same vegetative age irrespective of the time of sampling, and represent the nutritional status of the tree at that time. Values thus obtained can be reasonably compared with leaves sampled at any time during the year. On the other hand, the age of leaves in Cooil's method cannot be accurately determined since the leaves may be of recent origin or may be more than a year old at sampling time. Consequently, leaf calcium (Ca) values on Cooil's "prior to flushing" samples are erratic and seem to be affected by the difference in the age of leaves. Cooil's difficulty in determining a critical leaf Ca value lends support to this statement.

Fortunately, the value differences in N, P, K, and Mg between "March sampling" and "recently matured terminal" samplings are not discernible. Calcium, however, differs very strongly. Data gathered by Shigeura et al. *(72)* in Kohala, Hawaii, suggest that leaf phosphate can be 0.07 percent to 0.08 percent (Cooil, 0.08 percent) to obtain maximum nut quality (Fig. 64) and yield (Fig. 65). The difference in P noted here is hardly anything and not important by itself; but it should be monitored closely because phosphate approaching 0.10 percent in leaves becomes a problem, since high leaf P indicates an accumulation of phosphate in the substrate as soluble phosphate. Jones et al. *(28)* report work done with the electron microprobe showing that there is actually a depletion of iron (Fe) and an accumulation of P in the vicinity of the roots on Fe-chlorotic trees growing on aa lava land. Shigeura et al. *(70)* showed that under this condition the strong, healthy leaves at the very terminals of branches will begin to yellow



$$QUALITY = 65.22 + 2.52ZN + 308.88MG^2 + 36.52\sqrt{CA} - 0.1543CU^2 - 0.0081FE^2 - 0.02PO_4{}^2 + 1.91\sqrt{PO_4}$$

Figure 64. The effect of applied phosphate on nut quality. Note the best quality is attained between 300 and 600 pounds of applied P_2O_5, which corresponded to 0.07 percent to 0.08 percent leaf P.

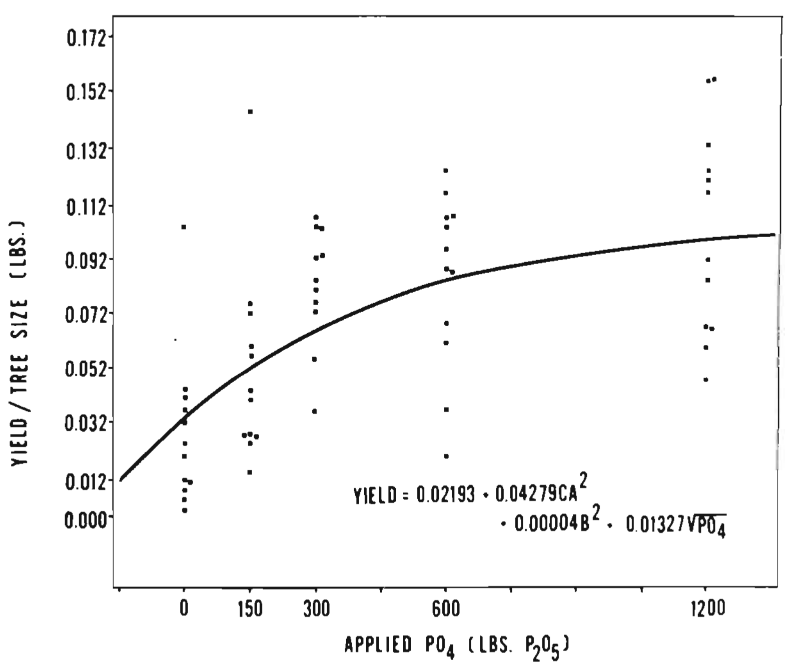


Figure 65. Nut yield corrected to tree size as affected by phosphate application. Yield increase beyond 600 pounds of P_2O_5 applied (0.07 percent P) was not statistically significant.

due to lack of chlorophyll formation, a complete yellowing at the terminals indicating Fe deficiency. In recent tests yet unreported, Shigeura *(73)*, using leaves and stems as index tissues, has been able to show that manganese (Mn) can also become a problem on lava land where excessive phosphate has been applied. In another test on soil order Inceptisols (suborder Andepts) at Honokaa *(72)*, Shigeura demonstrated that a reduction in leaf concentrations of Mn, Ca, and Mg is associated with an increase in P concentration beyond 0.10 percent in the leaf index tissue, suggesting three possibilities: (1) that phosphate causes a big flush of growth and "dilutes" other nutrients; (2) that phosphate increases soil cation exchange capacity and thus leads to lower solubility of other nutrients; or (3) that cation fixation by phosphate in the soil occurs with macadamia in Hawaiian soils.

On the basis of a "recently matured terminal" sampling, Shigeura et al. *(74)* presented data suggesting the optimum Ca level is 0.55 percent (Fig. 66). This value is not applicable using Cooil's physiologically older leaves since older leaves analyze at a higher level of Ca.

Workers in Hawaii on sugarcane, papaya, and pineapple used recently matured leaves in their foliar diagnostic work. Jones *(31)* and Jones and Embleton *(32)*, in their work on *M. integrifolia* in California, used "matured spring growth" leaves, which are essentially comparable to "recently matured terminal" in Hawaii. Although the advantage of the "recently matured terminal" sampling is very real, one danger with this method is that sampling done by an inexperienced person can include terminals not yet fully matured. Immature leaves are distinctly softer to the touch. However, with proper training and care in sampling, this procedure is very easy to learn.

Boron (B) deficiency *(24)* is quite prevalent in the Islands. On macadamia it manifests itself in terminal dieback as in P deficiency; but unlike P, B-deficiency symptoms show clusters of small, leafy heads on the dying terminals. When a B-deficient tree is sprayed with soluble B, regrowth takes place throughout the defoliated area and at the very terminal branches (Fig. 67); regrowth terminals appear lighter in color. Further work on minor elements such as zinc, manganese, copper, and iron is indicated.

The suggested leaf analyses values by the various workers are given in Table 3.

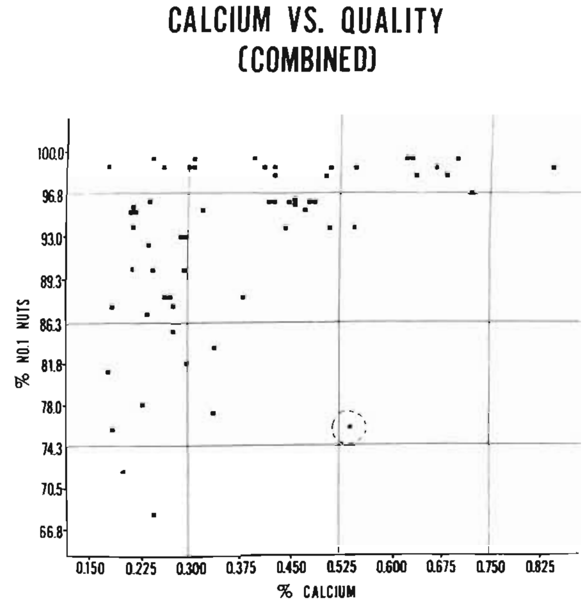


Figure 66. No. 1 nuts as affected by percentage of leaf Ca. Except for the stray point, the chart shows a widespread distribution of points for No. 1 nuts below 0.4 percent Ca, and a relatively confined distribution above 0.4 percent, becoming better confined at points above 0.55 percent.

Figure 67. Boron-deficiency symptoms showing regrowth (lighter colored) on defoliated branches after B application.

Figure 68. Tree showing early P deficiency symptoms: a declining terminal growth with defoliation in the stems of these branches and normal-appearing branches at the lower third of the tree.

Figure 69. A P-deficient tree with dead, dry twigs at the terminal.

Table 3. Suggested leaf analyses values for macadamia on oven-dried leaf tissue

Nutrient	Cooil	Shigeura	Warner, Fox
N, %	1.50	-	-
P, %	0.08	0.07-0.08	-
K, %	0.45	-	-
Ca, %	-	0.55	-
Mg, %	0.095	-	0.10
S, %	-	-	0.24
Mn, ppm	-	-	100.00
Zn, ppm	-	-	15.00
B, ppm	-	-	75.00
Cu, ppm	-	-	4.50

A fertilization program based on leaf analysis is the more exact and desirable procedure to follow. However, the farmer may not be able to have his leaves analyzed to meet his needs. In these situations, although it is not as reliable as leaf analysis, visual examination of trees for symptoms may be used for some needs or deficiencies.

Nitrogen. Trees deficient in N are yellow-green throughout, with decidedly smaller leaves. Occasionally, in severe cases, trees may appear burnt.

Phosphorus. When P is deficient, trees respond with smaller leaves at the apex of the tree and mild to major defoliation of leaves on these branches. At the same time, the branches on the lower third of the tree have larger and healthier leaves (Fig. 68). These trees invariably have leaf P values of 0.05 percent or below, and definitely need immediate phosphate fertilization. Figure 69 shows trees becoming progressively worse due to phosphate deficiency. Figure 70 shows a tree recovering after phosphate fertilization.

Potassium. Symptoms of K deficiency are seen only in older leaves as marginal necrosis and are usually more confined to the margins of leaves. Field experience indicates that Hawaiian soils are high in available K for macadamia nutrition, and the K requirement for macadamia is low, with 0.5 percent being adequate for good production *(9)*.

Magnesium. When the older leaves become generally yellow with green veinal tissues and yellow to orange interveinal tissues, Mg is deficient. This latter symptom is especially pronounced in 'Kakea' (HAES 508), becoming especially bad with heavy phosphate fertilization. In this situation, a Mg fertilizer such as magnesium sulfate (Epsom salt) should be applied immediately to correct the deficiency. Within a year, trees should respond by greening. When

Figure 70. A badly P-deficient tree recovering with healthy regrowth after P fertilization. Picture was taken nine months after application of fertilizer.

symptoms are not severe, the less expensive magnesium oxide or dolomite may be used. Leaf analyses should be made to monitor the change.

Leaf analysis values for tetraphyllas can be developed by using integrifolia values at the beginning and relating these to production and nut quality. Changes in the integrifolia values can be made upwards or downwards for the tetraphyllas, depending on tree responses.

Weed Control

Weed control continues to be one of the more important and expensive cultivation cost items. A persistent and continuous effort needs to be maintained in cultivation to reduce the competition from weeds for moisture and nutrients so vital in tree growth and production. Further losses through poor weed control can be expected during the harvest season when some nuts on the ground are lost among the weeds and are not picked up regularly. Unharvested nuts left too long on the ground can become unacceptably moldy or can be eaten by rats. In either case, losses to total production can be substantial and very expensive.

During the past 50 years, as farm labor has become increasingly scarce and, when available, expensive, weed control using chemical herbicides has become the standard practice. In spite of the continued increase in cost, the use of herbicides, with the continuing development of more specifically effective chemicals, is now the cheapest and most effective method of weed control.

One of the early problems in weed control was the lack of effective, selective, and cheap herbicides approved for use on macadamia by the U.S. Food and Drug Administration and the Hawaii State Department of Agriculture. Some of the uncleared herbicides used in the past were the many forms of arsenicals, sodium chlorate, trichloroacetic acid, pentachlorophenols, and aromatic oil. Due to the lack of effective and approved herbicides in the early 1960s, H. Ooka *(59)* experimentally used flame weed control with butane and propane gases at Keaau Orchard (Fig. 71). It was particularly effective on small weeds and left no chemical residues on the nuts or on the ground. The practice was discontinued, however, after more herbicides were cleared, particularly because fire risk and insurance considerations were too high.

Weed control by mowing or beating with chain segments or steel blades has been used extensively

Figure 71. Flamethrower experimentally used at Keaau Orchard in the early 1960s.

and effectively in the past. This method is still practiced today in the prebearing period in orchards on steep terrain where soil erosion can be a problem and in open areas away from and between trees. However, since weed control throughout the orchard becomes especially critical at harvest time, adequate control should be extended so that the nuts are not lost or hidden in the weed growth. When nuts are harvested by tree shaking and caught with a catchment frame, weed control need not be very extensive.

Royal Hawaiian Macadamia Nut Company at Keaau Orchard pioneered in the clearance of effective herbicides as early as 1959 *(55)*. Label clearance of dalapon for use in the macadamia orchard was received in 1961, followed by simazine, atrazine, diuron, and paraquat *(56, 57)*. Roundup herbicide was cleared for use in 1978 *(54, 58)*. The use of herbicides is now regulated by the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Hawaii Pesticide Law *(48)*. The state and federal agencies classify each herbicide for restricted or for general use, and all users of restricted herbicides must be certified by the Hawaii State Department of Agriculture. A person qualifies by taking a course in the safe use and handling of pesticides from the University of Hawaii's Cooperative Extension Service and must pass a written test before a use permit is issued.

Herbicides registered *(49)* for use in macadamia orchards under the law are as follows:

Herbicide	Rate/acre	Directions and limitations
		Restricted use
paraquat (Paraquat CL)	1 to 2 qt plus a non-ionic surfactant in 50–100 gal of water	Directed spray. Postemergence. Do not contact foliage, fruit, or stem. Do not graze livestock on treated areas.
		General use
atrazine (Aatrex 80W)	2½ to 5 lb in 50 gal of water	For preemergence control of many broadleaf and grass weeds including crabgrass, foxtail, wiregrass, flora's paintbrush, spanish needle, and fireweed. Apply after harvest and just before weeds emerge. Repeat as necessary. Do not spray when nuts are on ground during the harvest period. Do not apply by air.
dalapon (Dowpon M)	5 to 10 lb per acre	To control crabgrass, bermudagrass, kikuyugrass, paragrass (California grass), dallisgrass. In macadamia orchards in Hawaii use Dowpon M in concentrations of ½ to 1 pound per gallon of water. Spray the grass to wet without runoff, but not to exceed 100 gallons per acre. Make first application before harvest and respray at intervals as regrowth warrants. Do not exceed 24 pounds of Dowpon M per acre per year. Caution: During harvest period, spray only immediately after gleaning nuts from the ground. Do not spray directly on fallen nuts.
simazine (Princep 80W)	2½ to 5 lb in 50 gal of water	Apply after harvest and just prior to weed emergence. Repeat application as necessary. Do not apply when nuts are on the ground during the harvest season.
diuron (Karmex)	2½ to 6 lb in 50 gal of water	Use only on trees established for at least 1 year. Repeat as necessary. Do not exceed 10 pounds per acre per year.
glyphosate (Roundup)	2 to 4 qt in 50 gal of water	Recommended for weed control in established groves or for site preparation prior to transplanting.

Before using any herbicide, read the entire label carefully and follow the directions exactly.

Animal grazing is not recommended because of nut contamination by animal refuse.

Pest Control

Insects. Although in its indigenous area of Australia the macadamia does have many economically serious insect pests *(44)*, Hawaii has only a few that need to be attended to.

The larvae of the koa seed worm, *Cryptophlebia illepida* (Butler), and those of the litchi fruit moth, *C. ombrodelta* (Lower), feed upon the nut husks, and, if the shells are soft, will bore through and damage the kernel *(52, 53)*. *C. illepida*, an insect native to Hawaii, is parasitized by several natural enemies, whereas *C. ombrodelta*, being an immigrant species, has only a few enemies. Since chemical control of these insects is difficult and not economically feasible, field sanitation and the elimination of alternate hosts, such as acacia, are recommended.

The southern green stink bug, *Nezara viridula* (Linnaeus) *(43)*, was a major pest in the 1960s, but, with the introduction of several predators and parasites, it has been brought under reasonable control, and chemical control of this insect is not recommended.

The red-banded thrips, *Selenothrips rubrocinctus* (Giard), and the Hawaiian thrips, *Taeniothrips hawaiiensis* (Morgan), periodically develop into epidemic proportions. Damage to flowers reduces yield substantially. Leaves may also be damaged, causing yellowing. The insects do not normally attack young nuts, but older nuts may be spotted with the silvery dried excrement of thrips. This damage is of no significance. Wettable malathion can be applied at 2 to 4 pounds per acre or to a drip-wet state in which spray quantity is difficult to judge. With the emulsifiable concentrate, 1 to 2 pints per acre is allowed with no time limitation on its use. However, since malathion is toxic to honeybees, application should be made early in the morning when bee activity is low. Phosalone (Zolane), an organic phosphate insecticide-acaricide, has been registered in Hawaii for use in mite and aphid control, and is applied at 4 to 8 pints per acre per year.

Other insects such as ants, beetles, mealybugs, and scales are of minor economic importance. Stored macadamia nuts, sometimes infested by beetles, can be treated with methyl bromide when necessary.

Mites. Two species of mites, the broad mite, *Polyphagotarsonemus latus* (Banks), and the red and black flat mite, *Brevipalpus phoencis* (Geijskes), cause damage to flowers with some symptomatic tanning of husks and leaves *(21)*. Wettable sulfur has been found to effectively control the mites. One large grower has been applying wettable sulfur at 10 pounds per acre by air and ground once or twice a year during the flowering season to reduce the buildup of the mite population. Morestan miticide has been cleared for use in macadamia at the rate of 1 to 8 pounds per acre. Three applications per season may be made, up to the day of harvest. Plictran 50W miticide was given a supplemental label to meet a special need in Hawaii to control broad mites affecting macadamia nuts. Four to 6 ounces of Plictran 50W per 100 gallons of water are used. It is applied as 200 to 400 gallons of spray mixture using conventional spray equipment. The miticide should be applied when the broad mites appear and repeated as necessary. The use restrictions on the label specifically say not to apply more than 6 pounds of Plictran 50W per acre per season, or more than four applications per season, and not to apply it within 14 days before harvest.

The mite predators *Metaseiulus occidentalis* (Nesbitt) and *Amblyseius californicus* (McGregor) were released in two large orchards in 1978. As of 1982, these predators have not been recovered.

Diseases. Currently, only three economically important diseases affect macadamia. These are the two flower blights, caused by *Botrytis cinerea* *(25, 26, 38, 39, 84)* and *Phytophthora capsici* *(40)*, and a root rot organism, *Kretzschmaria clavus* *(34, 35, 37)*, especially prevalent in and associated with the wet areas of Hilo and Pahoa.

1. *Botrytis cinerea* is a blossom blight that establishes itself only on senescent floral tissues of macadamia; affected flowers do not develop into mature fruits (Fig. 72). This disease is especially prevalent in Hawaii during the winter months, when the humidity approaches 95 percent and the temperature is between 61° and 72°F in the flowering season.
2. *Phytophthora capsici* is especially prevalent during a prolonged wet period. It is a water mold fungus that infests the immature raceme even before the floral structures are

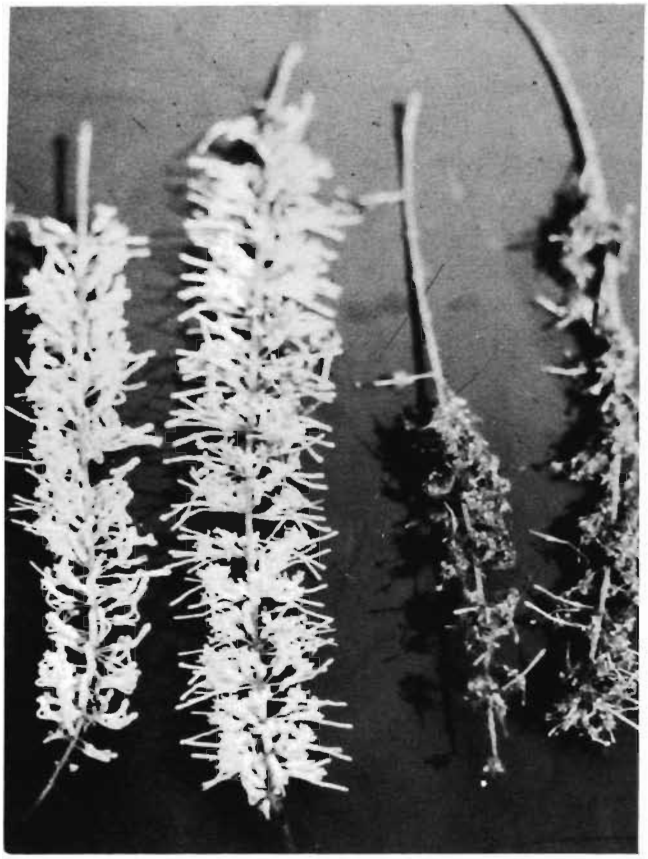


Figure 72. Macadamia racemes showing effects of ***Botrytis cinerea*** infestation (right) compared with normal racemes (left).

Figure 73. Macadamia racemes showing ***Phytophthora capsici*** infestation. (Normal racemes are shown in Fig. 72.)

formed (Fig. 73). The infestation first appears as minute necrotic spots on the racemes, but it very rapidly develops to encompass the total structure. Flowers and fruits do not develop normally.

3. The *Kretzschmaria clavus (34, 35, 37)* root and trunk rot symptom is especially noticeable when the trees are about 15 to 25 years old (Fig. 74). Its ecology has not been completely established and further studies are needed, but at this time, young trees planted in the same spot where a tree has previously succumbed seem to grow normally, probably indicating that this organism develops very slowly. The *Kretzschmaria* root rot is again more prevalent in the wet areas of Hilo and Pahoa. More work on this fungus has been funded by the Governor's Agricultural Coordinating Committee through the Hawaii Macadamia Producers Association.

Phytophthora cinnamomi has been associated with trunk canker in macadamia. However, this infestation is rarely found and apparently does not affect production *(23, 36, 87)*. It probably exists only as a harmless member of the microbial community *(36)*.

Figure 75 shows a nut-set picture of a tree in the leeward area of Kona, where the high mountain brings about a temperature reversal for most of Kona, resulting in a dry winter when the flowers are developing. This temperature situation in Kona is very unlike the wet condition in Hilo and the windward sides of the Islands, where the flowering season is wet and cold. Under this dry condition in Kona, *Botrytis cinerea* and *Phytophthora capsici* develop slowly; nut set is consequently very good.

With the advantage of hindsight after 30 years of active macadamia production, the evidence now on disease manifestation and control indicates that a better alternative on land is the use of areas that are cool and dry in the winter months. This will reduce the bad effect of flower blights. If economic considerations can be resolved, macadamia planted in dry areas where irrigation water is available and is applied will lend itself further to better control of its serious diseases, including *Kretzschmaria* root rot. Such a rethinking is a better alternative and worth considering as a first step in macadamia disease control and macadamia production.

Rats. Without a thorough rat eradication pro-

Figure 74. ***Kretzschmaria clavus*** **is a root and trunk fungus that can eventually kill a tree.**
(Photo contributed by W. H. Ko)

Figure 75. Nuts set in Kona, where blossom diseases *Botrytis* and *Phytophthora* do not develop too readily with low relative humidity and low rainfall during the flowering season.

gram, nut losses will greatly reduce profitability. In orchards where the nuts are not harvested regularly, or under some trees where weeds are overgrown, losses can approach 100 percent. Areas along field edges or where the rat population has inadvertently been permitted to increase can be bad (Fig. 76). The urgency of proper rat control cannot be overemphasized, and all methods of eradication need to be exercised.

Presently, Phospho-grits, a commercial preparation of zinc phosphide, is approved by the Environmental Protection Agency (EPA) for use in macadamia fields. Since the zinc phosphide in the preparation becomes inactive with moisture, the bait needs to be wrapped in waterproof packaging or placed in waterproof bait stations (Fig. 77).

Since the problem of rat control is basically the use of a good attractant, many bait materials such as macadamia culls, raw sugar, various grains, and cookie crumbs have been used with varying success. Anticoagulant baits are also available and have been used with much success at the field edges and in windbreaks. To be more effective, bait should be dropped into rat holes or nests; if container stations are used, these should be placed close to the source of infestation. An experienced grower will begin spotting and baiting only badly infested areas where the rat population is high.

Among the species of rats found in Hawaii, the black rat, *Rattus rattus*, does the most damage to macadamia nuts. The polynesian rat, *Rattus exulans*, can become a problem when there is nothing besides macadamia nuts to feed on. The Norway brown or sewer rat, *Rattus norvegicus*, which lives near dwellings, is seldom found in macadamia fields and hence does not do much damage. The house mouse, *Mus musculus*, is a minor consideration, since its habitation is generally near shelters.

NUT PRODUCTION

Pollination

The pollination requirement of macadamia nuts has been reported in several papers. Based on experimental evidence collected, a statistically significant increase in nut set is attainable *(27, 66, 67)*. When this increase is translated into dollars it can become a substantial item in cash flow. Although there seems to be some indication of self-incompatibility *(85)*, most of the major varieties

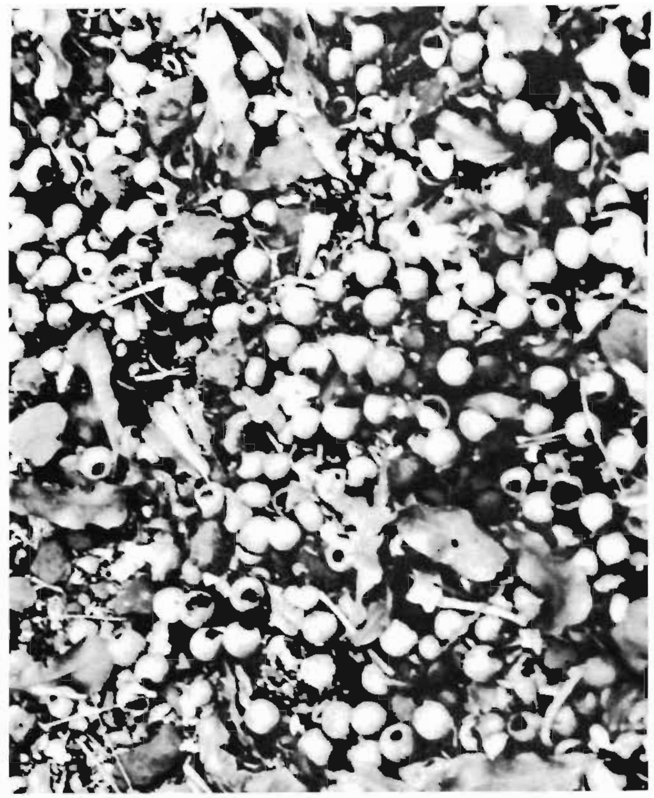


Figure 76. Rat-damaged nuts under a tree that was isolated and poorly maintained. Rats gnaw through the outer hard shell, creating an opening through which they are able to reach the nutmeat.

Figure 77. Rat bait stations made of cans with a lip bent up on the lower opening to reduce rainwater falling on the bait.

are self- or cross-compatible. Although honeybees do help in pollination, evidence indicates that bee population from a given apiary rapidly declines with distance from the hive *(15)*. However, no suggestions as to the distance between apiaries in an orchard or the number of hives necessary per acre can be given at this time. Until reliable data on the macadamia nut becomes available, the beehives in the orchards should be clustered to make placement easier, at the rate of about one hive per acre. The density of hives can then be changed as further information becomes available. Syrphid flies and other insects also aid in pollination *(85)*. Consequently, any insecticidal spray program should be closely monitored during the flowering season.

Honey from macadamia blossoms is considered excellent.

Flowering and Nut Set

The macadamia flower cluster is a raceme *(16)* with 200 or more perfect flowers, each on its own pedicel, arranged along the sides of a common flower stalk. Each raceme extends to its fullest development before the buds begin to open at random throughout the cluster. The flowers stay open for a few days, during which time most of the pollination takes place. Some flowers have their own pollen capsules attached to the stigmatic surface, and are self-pollinated. Although no data have been collected, visual indications are that only about 10 percent or fewer of the racemes formed on the tree will eventually produce harvestable nuts. Initial fruit set on these racemes is generally heavy, but for causes not yet determined, some young fruits up to ¼ inch (0.5 centimeter) in diameter will drop very early, leaving only a few nuts to mature on a setting raceme. When the nuts are much larger, "June drop" occurs during the summer months, further reducing the harvestable nut set. Experiments on the effect of the growth regulator succinic acid 2,2-dimethylhydrazide (SADH) have been conducted *(50, 59)*. Results of these trials using 10-ppm solutions have shown a 10 percent nut set increase without affecting nut quality, growth, or mineral nutrition of leaves. However, more research in this area is needed.

Flowering normally occurs during the period from November through February in Hawaii; the nut harvest period starts about August of the following year and continues until about February or March. In older trees, however, flowering can take place throughout the year, and nut season is year-round. 'Kakea' (HAES 508) especially shows this characteristic. Depending on the variety and climatic conditions, Jones and Shaw *(30)* report that nuts on the tree are mature approximately 215 days after anthesis (flowering). Although the nuts are mature on the trees, field experience has shown that they do not begin dropping until eight or nine months after anthesis. Further maturity research is indicated here.

Harvesting

Harvesting can be the single most expensive operation, since large losses, especially in nut quality reduction, can result from improper harvesting method or scheduling. Except in mechanical tree shaking, mature nuts drop off the tree and remain on the ground until picked up by machine or by hand. While on the ground, the nuts can be eaten by rats, or they can become moldy through minute cracks in the nutshell or a faulty formation at the nut micropyle. Either way the losses can be substantial. Consequently, the nut harvesting schedule has to be rigidly maintained and followed in any given area. The rat population, leaves and other debris under the tree, periodic rainfall pattern, air movement through the field, sunlight penetration under the tree, and the general humidity in the orchard should be considered in determining intervals of harvest. Generally, an interval approaching four weeks is a good point to start from to work toward shortening or lengthening the period to suit the conditions of the area.

In hand harvesting, nuts are picked up in buckets, temporarily stored in bags, and loaded on trailers or trucks to be hauled to the husking stations. The bulk of hand harvesting is done by hired labor or by contract labor on a per-bag cost basis.

Mechanical harvesting off the ground is practiced by large growers using three separate machines: a leaf blower (Fig. 78), a nut sweeper (Fig. 79), and a harvester (Fig. 80). In mechanical harvesting, after the area is blown clear of leaves and debris, the sweeper brushes the nuts into windrows between two rows of trees for the pickup harvester, which is a machine with rubber finger scrolls to kick the nuts onto a cross conveyor belt, which, in turn, empties the nuts onto a lift conveyor to be elevated and finally dumped into a towed trailer. A new model of this harvester uses two synchronized high-velocity rotation reels to eliminate twig and leaf uptake.

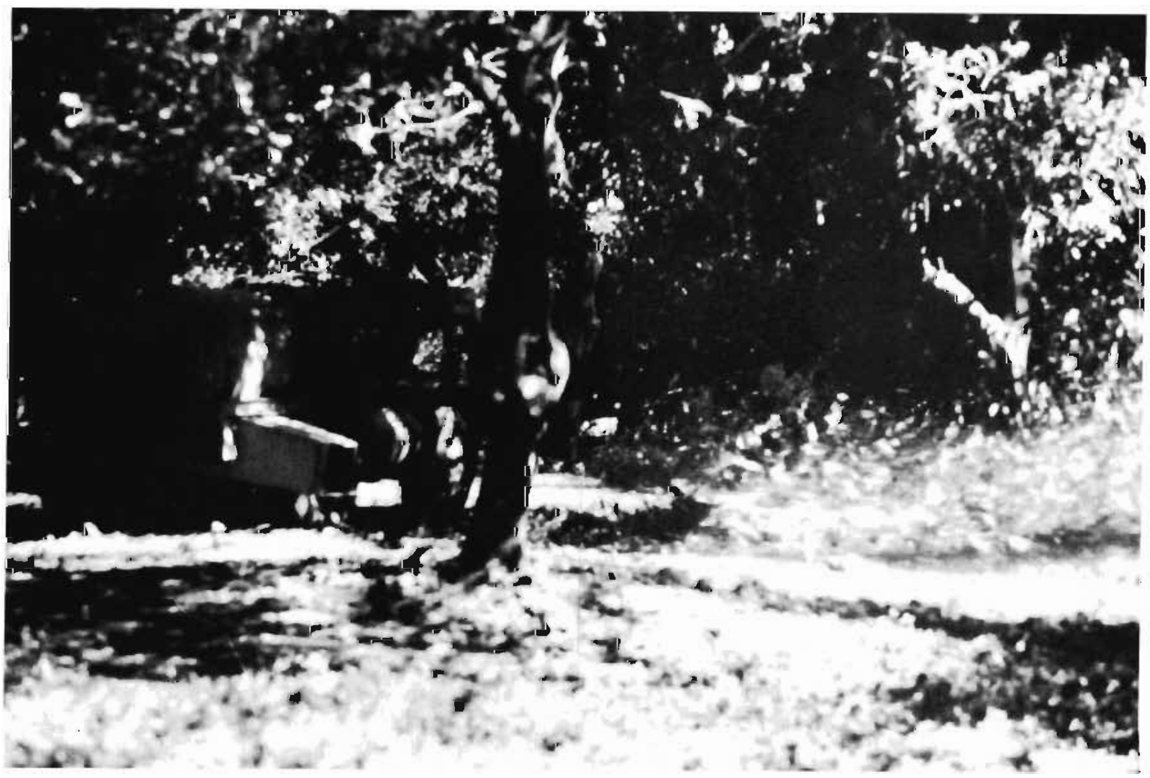


Figure 78. Self-propelled blower to rid the field of leaves before sweep harvesting.

Figure 79. Sweeper used to windrow nuts in the center of the tree rows for mechanical pickup.

Figure 80. Pickup harvester with trailer nut bins to the rear.

Figure 81. Shake harvester with catchment frames on two separate units working together.

Many types of harvesting machines presently on the market can be adapted to macadamia nuts. However, in the use of this method on lava land, the orchard floor terrain must be improved with fill materials (e.g., sand, quarry waste), making the surface crevice-free to enable easier and more efficient pickup of nuts. On a better type of soil, such treatment is not necessary. The area under the tree must also be kept free of weeds and leaves so the nuts are not lost.

Prior to harvesting, small growers remove leaves under the tree by blowing with a knapsack-type blower. The leaves are easily separated from the nuts in blowing since their light weight and flat shape enable them to be blown further away. The nuts thus exposed can be picked up by hand. Leaves can also be eliminated in the orchard by burning them in open areas among the trees, by shredding and using them for mulch, or by baling them for use as a biomass energy source.

Tree harvesting using vibratory machines is being done by two large growers. One grower uses a unit with two self-propelled machines with catchment frames mounted on each unit and a grabshaker on one (Fig. 81). This harvester has a shaker clamp that hydraulically grips the tree trunk about 2 feet above the ground and vibrates the tree for a few seconds to shake the nuts onto its deflectors and the catchment frame. The nuts are then conveyed to a bin. When filled, each bin is removed by a high-lift tractor and replaced by an empty bin. A shaker with its own catchment frame is now being used with increased efficiency (Fig. 82).

Although tree harvesting has definite advantages, the effects of this method on nut maturity *(7)*, quality, and yield *(47)* for all the cultivars now being used in industry have not been fully demonstrated. But labor availability and cost dictate the adoption and perfection of this method as soon as possible. Basically, the issue is whether the business loss is greater when harvestable nuts are left on the ground to become moldy or eaten by rats prior to harvest, or when immature nuts are tree harvested, thus lowering nut quality. These business alternatives may have to be decided on a plantation-by-plantation basis rather than an industrywide basis.

Several other methods of harvesting have been tried experimentally through the years but discarded because of some bad features in the methods. A modified golf ball picker with spring-loaded rollers about 2 feet in diameter was used and discarded because it was too flimsy in construction, and improvements appeared remote. A nut sweeper with many brush units operating on the main axis, so that each unit could follow its own land terrain, worked well, but the project was abandoned because of a drop in interest. Harvesting using the vacuum principle has not been too successful on aa lava land since the suction created by the machine picked up all materials on the ground, including nuts, smaller rocks, and

Figure 82. A shock wave harvester with its own catchment frame.

Figure 83. Net harvesting system used at Brewer Orchards with the leaf stripper ready to receive the gathered nuts and leaves.

Figure 84. Leaf stripper showing the counter-rotating scrolls to separate the nuts from the leaves.

pebbles. On lava land this method created cavities throughout the harvest areas. To compound the problem, the pebbles and fines that were picked up and dropped from the machine in mounds needed to be placed under the trees again. Considerable work on vacuum harvesting needs to be done before this method can be used on macadamia nuts.

Net harvesting (Fig. 83) has been tried in orchards where the terrain was too difficult and costly to improve to permit sweep harvesting *(59)*. In this method ½-inch polypropylene net was stretch-suspended on wires nailed to limbs of trees in a "V" design under the total canopy of trees. At gathering time, the flaps at the bottom of the "V" were opened, and the nuts, leaves, and small twigs were dropped on polyethylene sheeting to be lifted onto a leaf stripper (Fig. 84). The nuts were then dumped into a trailer bin to be hauled to the husking station. This system of harvesting was abandoned because of the high initial cost of netting and the high cost of maintaining the nets damaged by large-branch breakage.

Husking

The in-husk harvested nuts are transported to a husking station by various means. Small farmers usually use bags for storage and hauling; large growers use bottom-dump trailers (Fig. 85). The fleshy husk on the nuts as received from the fields needs to be stripped and removed as soon as possible to minimize loss in nut quality. Husking is usually done at a centralized station. The accumulated loose husks are then disposed of by whatever manner the grower chooses. They can be used for composting in nursery operations or as an organic material source for anthurium culture.

The principles and methods of husking currently used were developed in earlier years when the economic potential of the macadamia nut was first recognized. The first attempt, obviously, was by hand; this evolved into a crude system of using a rubber-tire-section doormat to hold the nuts steady and a hammer to break and tear the husk. The next innovation was the use of a spinning rear tire of a jacked-up car formfitted into a metal abrading plate (Fig. 86). In this method, the nuts were dropped into the trough created by the abrading plate and the spinning tire, and husked by the forces thus created—much akin to pebbles being strewn off the road by a rapidly turning tire on a car. With the continued growth of the industry, the jacked-up-tire husker was further improved as a permanent stationary system using electricity. One small grower still uses this system and has used the same tire for the last 25 years (Fig. 87). Another husker now popular is based on counter-rotating scrolls (Fig. 88). Although this method has been patented, the true credit for its invention is obscure.

A new husking machine (Fig. 89) has been invented by Quentin F. Gandall of Hilo and is

Figure 85. Bulk trailers for hauling nuts.

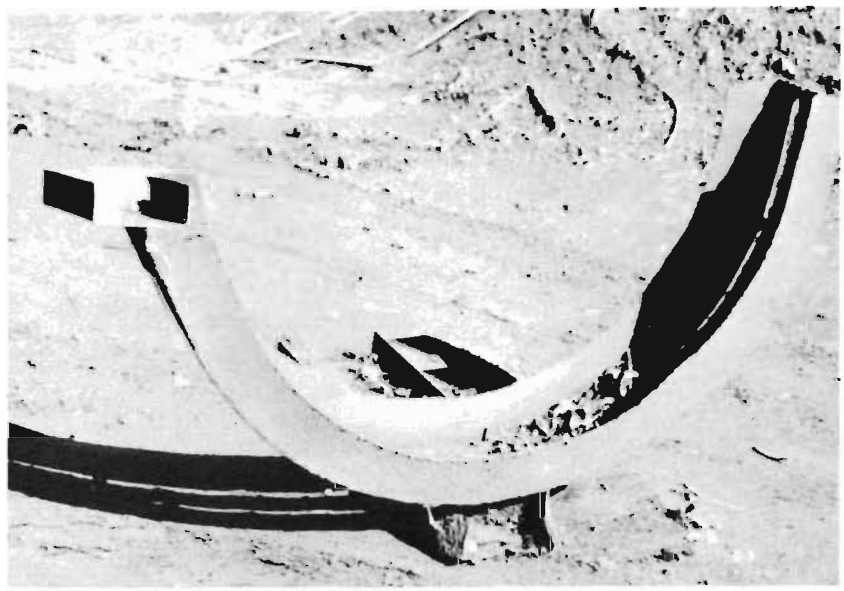


Figure 86. Hoaeae husker, 1930. Probably the first husker using the jacked-up rear tire of a car.

Figure 87. Rubber-tire husker with its power source an electric motor, still used by Francis Takahashi on Kauai.

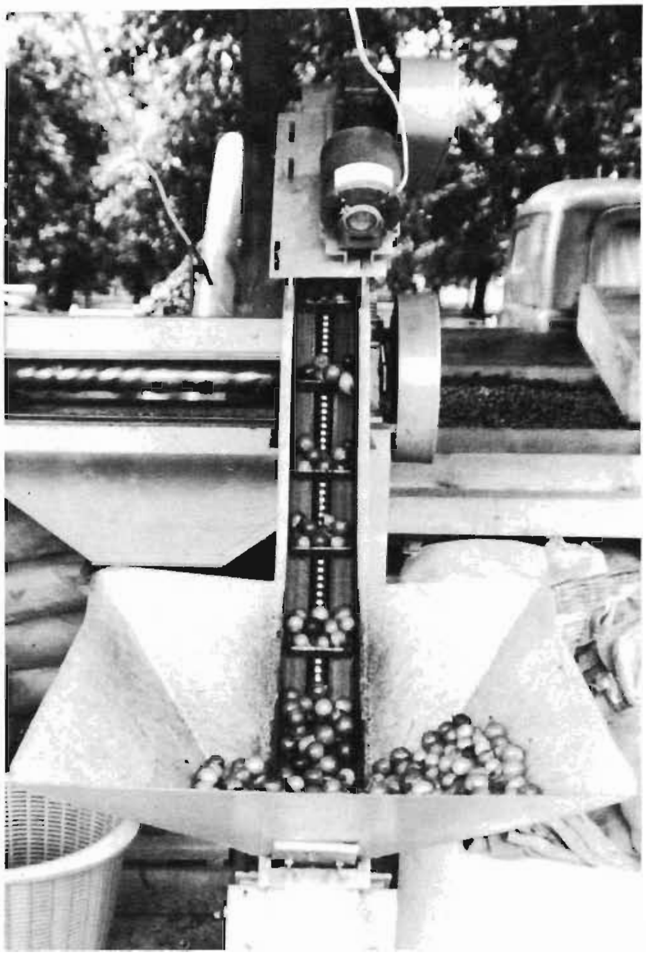


Figure 88. Husking at M. Uchida Farm using the counter-rotating double scrolls, 1979.

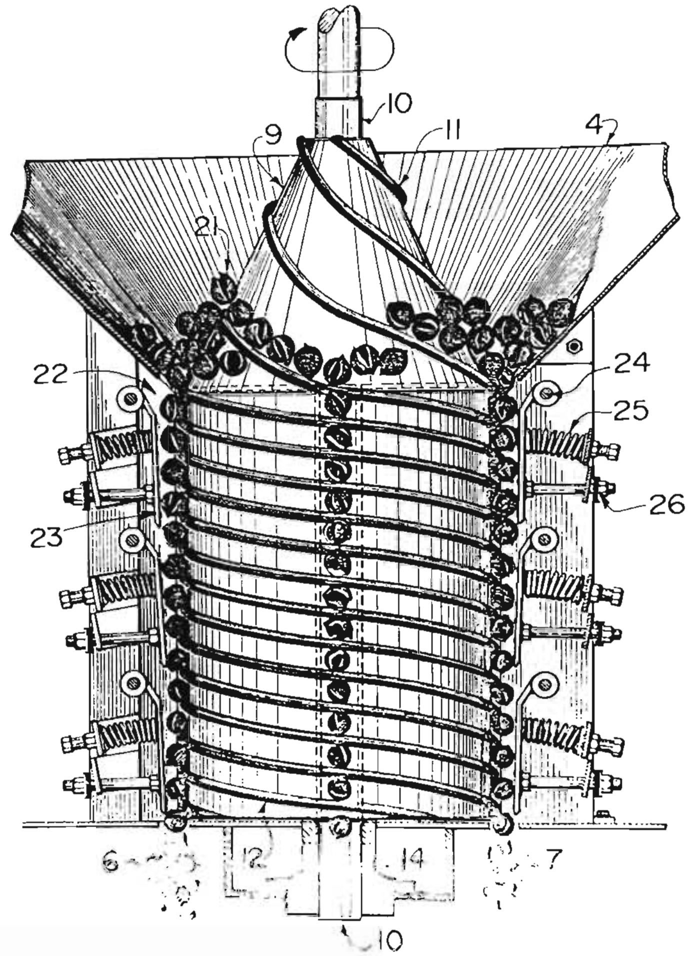


Figure 89. The Gandall husking machine positively feeds the nuts at "21" through "22" against the adjustable-pressure shoes at "23."

now being used in production on several farms. The apparent advantage of this machine is that the nuts are positively fed into the machine at "22" from a holding bin at "4" and moved against adjustable-pressure shoes at "23" to insure complete husking.

The Uniwai in-field husker (Fig. 90), using the counter-rotating double scrolls and a tractor PTO as its power source, was fabricated *(75)* for use where electricity is not available or for rocky land where the husks can be used for mulching in the field. This machine eliminated the hauling of husks back to the field from a centralized husking station.

NUT PROCESSING

In-shell macadamia nuts, as they are received at the factory, are finally ready to be processed for the consumer market into the many forms and concoctions in which the nuts are now being sold. Whatever form the final nut product takes, the overriding issue that has to be met and maintained in the factory is *quality*. Obviously, the word has different connotations for the many different people involved in the production of macadamia nuts *(8)*. All the handlers of the nuts, beginning with the plant breeder, through the growers, and on to the processors, contribute to the realization of a perfect, high quality nut. However, to keep quality in a better perspective, subsequent discussions will be confined to quality as it is affected or controlled as the nut goes through the factory and is finally packaged in consumer containers.

Drying

Immediately after the husked nuts are received at the factory, they are dropped into drying bins, a series of large containers arranged to allow the

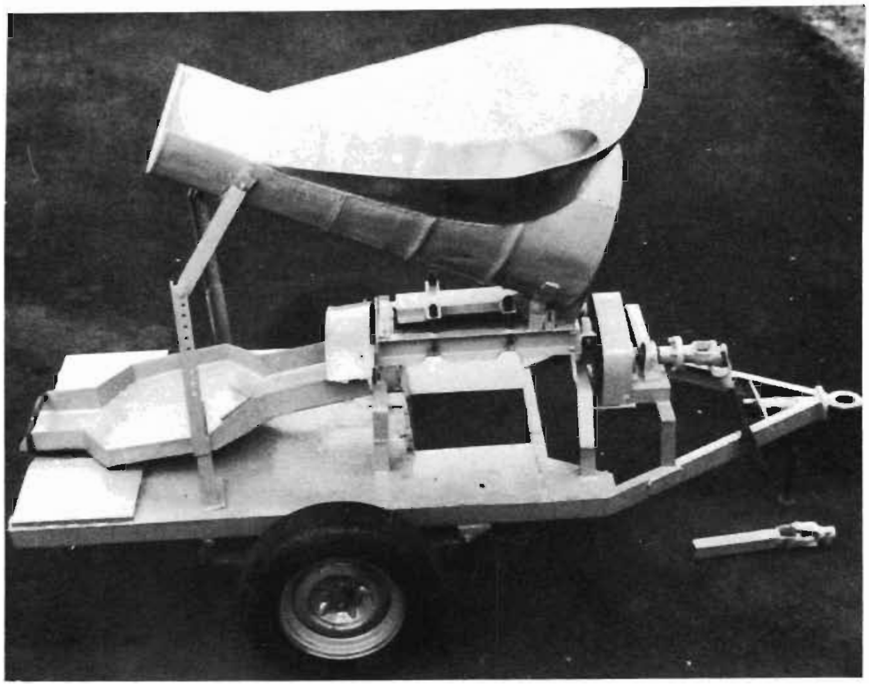


Figure 90. The Uniwai in-field husker.

nuts to be dried in batches. Quality control begins here. In this filling process the nuts, by necessity, are dropped from the top onto the metal surface at the bottom of the bins. With this severe impact, the kernels can be damaged even though the shells may appear normal *(8)*. A rubberized baffle system or a "let down spiral" can be used in the initial filling to divert or shorten the distance of nut fall against the steel bottoms of the bins.

The bins are tall, large containers, round or rectangular, conveniently placed so that the filling and discharge of nuts can be controlled, and drying heat from the boilers does not have to travel too great a distance. Since hot air rises, heat is introduced to the bins from the bottom, and the escape hatch is at the top. An innovation in bin construction at Mac Farms is the air escape holes constructed in the sides of the bins to shorten the distance of air travel from an air duct built in the center of each. This innovation increased efficiency in drying.

As soon as the bins are filled to the top with 3 to 5 tons of in-shell nuts, drying can begin. However, due to the varying field-drying conditions on the farms and the length of time the nuts are on the ground drying in the fields, nuts as received at the factory can be anywhere from 15 to 27 percent in kernel moisture content. The lower-moisture nuts have actually been air dried in the field as they lay on the ground, and nuts at 27 percent were on the ground for a short time or were from a very wet area. Thus, because nuts in a single lot may vary widely in moisture content, they should be dried initially with ambient air for two or three days. After this period in ambient air *(45)*, the temperature can then be raised to 100°F (38°C) until the kernel moisture is approximately 8 percent *(61)*. The temperature is then finally raised to and maintained at 125°F (52°C) until the kernel moisture comes down to 1.5 percent. It is possible to use a final drying temperature of 140°F (60°C), but only after kernel moisture has been reduced to 6 percent. The nuts are then ready to be cracked. Some processors prefer to crack at 3.5 to 5 percent kernel moisture. These kernels then need to be dried to 1.5 percent moisture before cooking.

The nut drying regime suggested by Prichavudhi and Yamamoto *(61)* is very important since the negative effects of excessively high drying temperature become apparent only after the kernels are roasted. The use of high initial drying temperatures on nuts with high kernel moisture results in roasted nuts with brown centers. This tendency is further increased since the non-reducing sugars in the nuts are enzymatically converted to more reducing sugars.

When necessary, in-shell nuts at 1.5 percent kernel moisture can be stored for a year at ambient temperature, provided they are kept dry. Roasting quality and shelf life of roasted nuts are not affected *(5)* by this storage treatment.

Cracking

The nuts dried to 1.5 percent kernel moisture are cracked using any of a number of machines now available. All of the cracking machines now use compression force to release the kernels with as little damage as possible. The crackers now being used by the industry in Hawaii are the Mauna Loa (Fig. 91), which is used by Mauna Loa Macadamia Nut Corp., the Shaw cracker made in California, and the Tengan cracker made in Hawaii. A new cracker designed by Quentin F. Gandall of Hilo, Hawaii, is now being used by one processor and looks promising. Ultimately, whatever machine is used should result in kernels with little scarring and a high percentage of whole kernels. Total earnings are correspondingly increased with the recovery of more whole, unscarred kernels, since chips and fines are generally downgraded and used for baking, ice cream topping, butter making, and such lower return products.

The shells can be used as a fuel source in the boilers to replace imported oil, and they also can be used in the fields or nursery.

Sorting

Immediately after cracking, the large kernels are separated through proper-sized screens and the remainder pneumatically separated from the remaining small pieces of shell. The flow is then put through a series of electronic color sorters to further eliminate shell pieces and the low-grade darker nuts. A final inspection can be made by trained personnel before the kernels are roasted.

When necessary, dry raw kernels can be stored for 16 months at 35°F *(3)*. Kernels stored in this way can be used later in delayed processing to meet market demands as they arise, and in developing new markets for unroasted kernels for immediate consumption by the consumers. A small test of the latter alternative has indicated that another positive development is very likely in this direction *(73)*.

Roasting

Kernels dried to 1.5 percent moisture can be roasted by cooking in oil, by dry heat in an oven, or on a conveyer belt where heat is applied.

The recommended method of oil roasting *(45)* is to immerse the nuts in vats with constantly agitated coconut oil or hydrated vegetable oil maintained at 275°F for 12 to 15 minutes until the nuts develop the desired state of brownness. When cooking is complete the kernels are lifted out of the oil and allowed to drain. They are then placed in a centrifuge to further remove excess oil. After a period of rapid drying using a fan, when the nuts are still lukewarm to cool, they are coated with an adhesive and salted. The adhesive solidifies on the

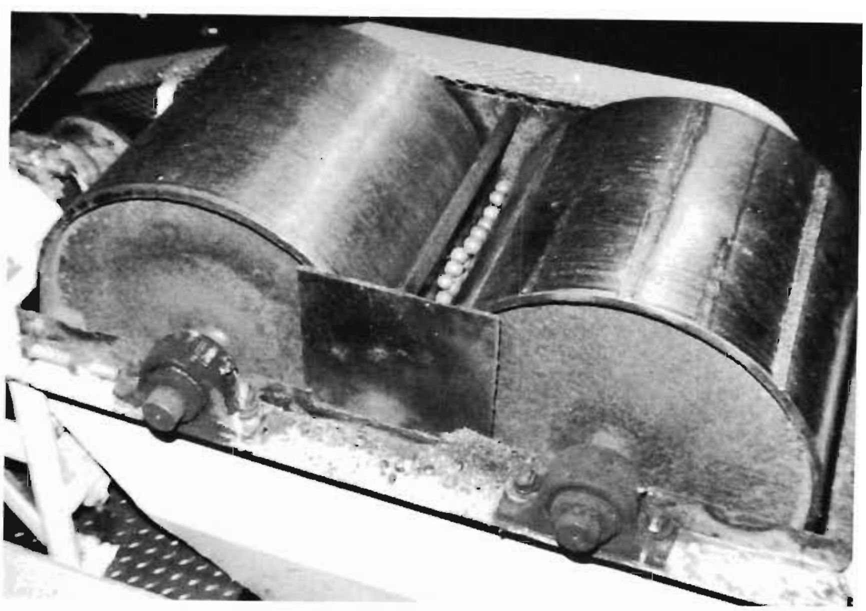


Figure 91. The Mauna Loa nut cracker, which has gone through many modifications.

nut surface at room temperature to hold the salt.

In roasting, unevenly applied heat causes the surface of the kernel to brown rapidly while the inner portion remains unroasted. Frequent stirring or agitation of nuts in oil roasting, with an air blast in dry roasting, is necessary to produce a uniform product. In spite of roasting nuts as recommended, browning defects will appear on some kernels that appeared normal prior to roasting. These are sorted into lower grades. Good quality macadamia nuts, after roasting, are light brown to tan. Kernel moisture content prior to cooking is critical for the desired texture and stability. It has been shown that kernels with 1.4 percent moisture or lower produce nuts with good stability and only a slight decrease in quality after 16 months of storage at temperatures up to 100°F. It has been also shown that kernels with moisture content exceeding 2 percent are not satisfactory for roasting *(3, 12)*, much less storage.

The oil used in roasting goes through considerable chemical and physical changes with repeated use. Evidence gathered by Cavaletto and Yamamoto *(6)* indicated that the changes in oil quality over a period of 13 weeks' use did not affect flavor or shelf life appreciably. However, if desired, stability of nuts can be increased by adding the antioxidants butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) to the salt adhesive.

Stainless steel is recommended for the construction of vats, baskets, and any containers used in roasting. Hot oil introduces a corrosion problem with the use of other metal.

Packaging

Premium grade roasted kernels are usually packed in cans, glass jars, or foil pouches, while commercial grade kernels are used for candies, brittles, chocolate-covered nuts, bakery products, ice cream, and so on *(4)*. One enterprising manufacturer in Hawaii makes over 100 consumer products with macadamia nuts. More use of nuts in the confectionery trade is needed.

MARKETING AND DISTRIBUTION

The marketing and distribution of nuts to the consumer seem to be matters of sales philosophy, conceptual differences in marketing, and availability of funds to promote and sell products. This statement is especially true with large growers who see the total picture from growing and on through to the grocery shelves, but must confine operations to a limited area because of their immediate and current money status. Except for one completely integrated company, the industry in Hawaii is made up of specialized companies and individuals who concentrate on the growing and production of in-shell nuts, the processing to produce raw kernels, the processing of roasted kernels for the grocery shelves, and the distribution. In time, depending on the size of operation and the inclination of the individuals involved, the companies may expand into the next category very easily. As the specialized companies become larger, no doubt the integration of the various production phases into larger companies by merging or by expansion will happen. This tendency in growth is universal and very easily attained when capital monies become available, or when the added production phase is simply an addition to an ongoing procedure.

The distribution of consumer products to the grocery shelves, on the other hand, is quite easy when the total volume is low, and possibly can be done by the processors themselves. But as the volume becomes larger, distribution becomes a specialized matter that might be handled more efficiently by brokers and distributors. This is especially true when a large distributor is equipped to serve the whole country, with many items to sell at the same time to spread the distribution cost.

THE FUTURE

The Hawaii Agricultural Reporting Service in the State of Hawaii released its annual summary sheet on macadamia nuts on January 19, 1982, partially reprinted here as Table 4 *(14)*. The summary indicates that the 1981 in-shell nut production on farms was 36,000,000 pounds, compared with 20,980,000 pounds in 1978, for a 72 percent increase in production during this period. The farm price during this same period increased by 23.2¢, or 43 percent, over that of 1978. During the same period, the wholesale price for the dried raw kernels from the factory increased from $3.25 to $4.75, or 46 percent, over that of 1978.

Although inflation obviously had a part in these price changes, a big real change in total production has taken place, indicating that the marketability of the nuts will undoubtedly become the next problem in Hawaii.

The Foreign Agricultural Service of the USDA reported on the production of macadamia nuts in

Table 4. Acreage, production, and value of macadamia nuts in 1972-1981

Crop year[1]	Number of farms	Acreage[2] In crop	Acreage[2] Bearing	Yield per acre	Marketing[3] (in-shell)	Farm price	Value of sales
		———*Acres*———		——*1000 pounds*——		*Cents per pound*	*1000 dollars*
1972	326	9,250	5,000	2.6	13,110	23.3	3,055
1973	343	10,450	5,080	2.4	12,124	22.5	3,092
1974	400	9,890	5,760	2.8	16,370	32.0	5,238
1975	444	10,400	6,080	3.0	18,210	31.6	5,754
1976	455	10,250	6,300	3.0	18,990	36.9	7,007
1977	456	9,895	6,300	3.1	19,680	40.8	8,030
1978	464	10,200	9,200	2.3	20,980	53.8	11,287
1979	464	11,400	9,600	2.8	26,660	62.9	16,769
1980	465	13,200	10,000	3.3	33,390	72.4	24,174
1981	465	13,700	10,000	3.6	36,000	77.0	27,720

[1]Year ends June 30 of following year.
[2]At end of year.
[3]Includes home use.
Source: Hawaii Agricultural Reporting Service, January 19, 1982.

some foreign countries (Table 5) in comparison with production in the United States.

Table 5. Production of in-shell macadamia nuts by major foreign producers, 1979-81

Country	Production in metric tons 1979	1980	1981
Australia	1,140.8	1,205.2	1,500.0
Costa Rica	5.0	22.0	68.0
Guatemala	33.6	53.8	74.6
South Africa	—[1]	200.0	600.0
United States	12,065.8	15,145.7	16,680.0

[1]Data not available prior to 1980.
Source: Foreign Agricultural Service, USDA, 1982.

Although most of the acreage in Australia is not bearing, in time Australia can compete with Hawaii for the macadamia market. However speculative his records are, Shigeura *(76)* reports that all the areas in Australia that are planted in macadamia nuts are subtropical in temperature, and not the best for our smooth-shelled macadamias. Areas in the same temperature regime in Hawaii are yielding only 2000 to 3000 pounds per acre, compared with the tropical areas in Hawaii, which are producing anywhere from 4000 to 8000 pounds. Shigeura speculates, therefore, that the cost of production in Australia may be prohibitive and profitability may be low. If correct, this tendency will help Hawaii.

On the other hand, Costa Rica, Guatemala, and Malawi in South Africa may become competitive in the future because they are in the tropics. South Africa, as such, is subtropical.

Those who are contemplating investments in macadamia nuts now should look upon this enterprise as a strict business venture and consider its potential profitability. After his personal financial position is considered, the investor may find that macadamia is not his best bet because of its long-term nature.

However, depending on the efficiency of the operation, it is possible to realize anywhere between $1000 and $2000 net income per acre before depreciation and taxes on a macadamia orchard operation *(73)*. Those who are interested in planting or processing macadamia should consult experts in economic planning for a closer study of the financial aspects. The long-term investors who are willing to take this risk will find that there is still a great deal of money to be made from the popular and versatile macadamia nut.

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Figure 92. Monument to Dr. John Macadam on his grave in the Presbyterian section of the Melbourne General Cemetery in Melbourne, Australia. Picture taken by the senior author on one of several trips to Australia to study macadamia culture.

Figure 93. Very closely planted trees at Bond's orchard at Iole, Kohala, where the fine nut seed tree, 'Bond 23', originated.

Figure 94. The Keauhou warehouse in Kona, built in the early 1930s, was already in bad condition when the authors saw it in the early 1950s.
(Courtesy of Ralph H. Moltzau)

Figure 95. Ralph H. Moltzau with the first macadamia tree that he grafted using Pope's twig while still a high school student working part-time at the Experiment Station in 1928.
(Courtesy of Ralph H. Moltzau)

Figure 96. Moltzau's topworking of macadamia nut trees at Nutridge in the late 1930s with selected strains of trees. Note entrance to Honolulu Harbor in the distance.
(Courtesy of Ralph H. Moltzau)

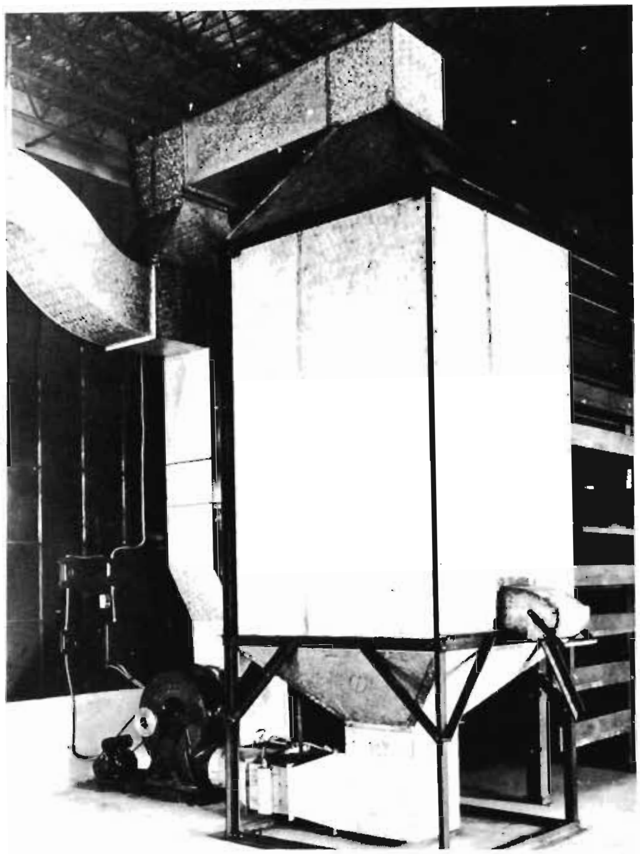

Figure 98. In-shell nut drying bin at the Hawaiian Macadamia Nut Company factory on Pohukaina Street in Honolulu in the 1930s.
(Courtesy of Ralph H. Moltzau)

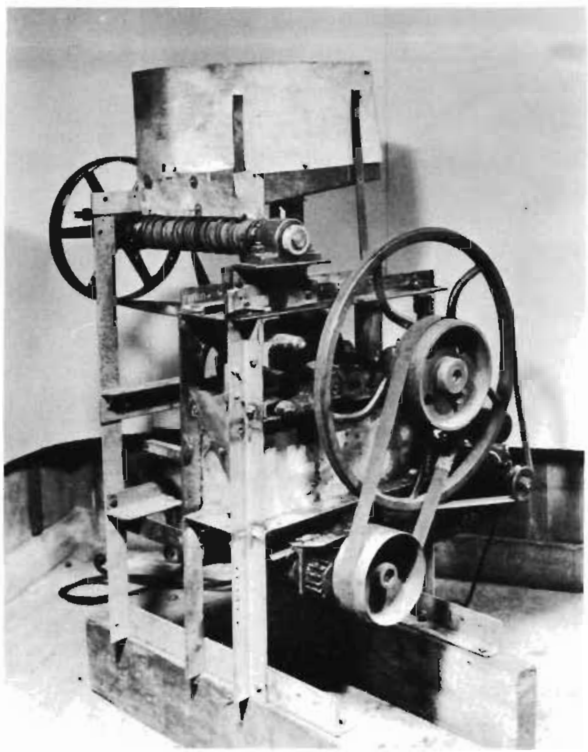

Figure 97. A macadamia nut husker developed by W. P. Naquin and Otto Hermann and used in the industry at the Honokaa Sugar Plantation in the late 1930s.
(Courtesy of Ralph H. Moltzau)

Figure 99. In-shell air-drying nut trays at the Hawaiian Macadamia Nut Company factory on Pohukaina Street in Honolulu in the 1930s.
(Courtesy of Ralph H. Moltzau)

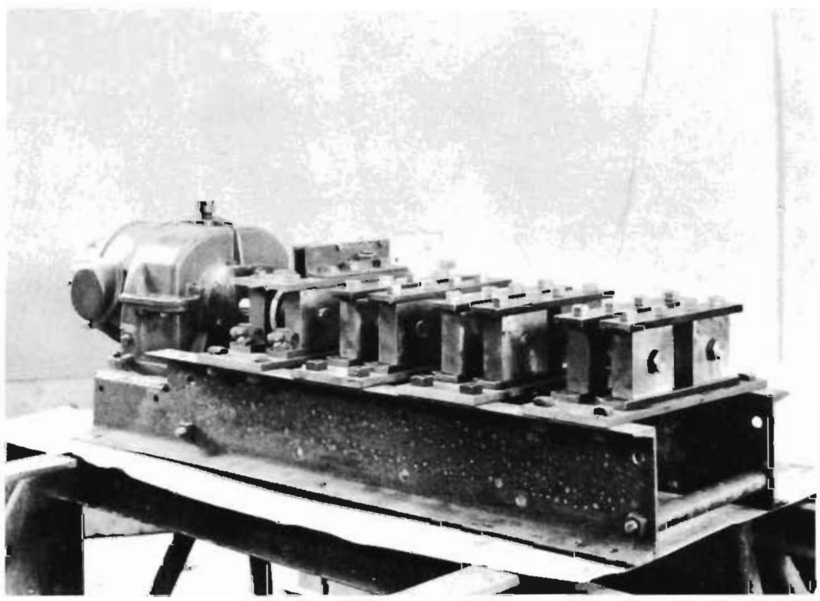

Figure 100. Probably the first nut cracker used in the industry at Honokaa Sugar Plantation to crack macadamia nuts at Honokaa in the 1930s. This machine was designed and built by Otto Hermann.
(Courtesy of Ralph H. Moltzau)

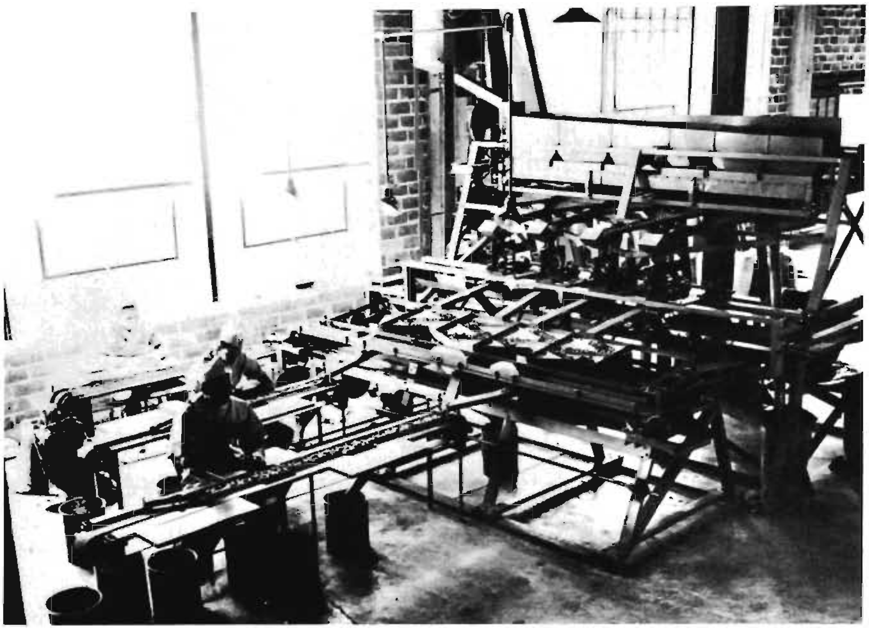

Figure 101. The first macadamia nut "assembly line" set up in Hawaii at the Hawaii Macadamia Nut Company factory on Pohukaina Street in Honolulu in the 1930s.
(Courtesy of Ralph H. Moltzau)

Figure 102. A corner of the Hawaiian Macadamia Nut Company factory on Pohukaina Street in Honolulu in the 1930s where the nuts were cooked, centrifuged, salted, and bottled.
(Courtesy of Ralph H. Moltzau)

Figure 103. Clearing forest vegetation on aa lava land at Keaau, Hawaii, to establish the first commercially planted macadamia nut orchard in Hawaii, December 1949.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 104. Solid pahoehoe outcropping at Keaau Orchard being blasted with dynamite charges to establish orchard at Keaau, Hawaii, December 1949.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 105. Leveling cleared land and pushing vegetation into huge piles to burn at Keaau Orchard, 1949.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 106. Macadamia nut tree planted on aa lava. Rocks and boulders of all sizes necessitated land improvement to fill in crevices where nuts could be lost.

Figure 107. The use of fines and waste from the quarry in Hilo to give lava land a smooth finish without any deep crevices, 1950.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 108. A test to crush large pieces of lava rock to create filler materials that would aid in water and nutrient retention in macadamia orchards, 1953. The experiment proved too costly at Keaau.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 109. Land rolling at Keaau Orchard with a reclaimed steamroller, 1950. Note decided improvement in land surface.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 110. Mulching recently planted macadamia nut trees at Keaau Orchard with waste vanda orchids obtained from an export packing house at Olaa, 1950. Mainland publicity hurt orchid sales.

(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 111. A view of snow-covered Mauna Kea through macadamia nut flowers in Section B, Keaau Orchard, 1953.

Figure 112. First tree at Keaau Orchard, planted as tree no. A-1-1-1, shown with G. Shigeura in 1950.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 113. A high knoll in Section G, Budge Vista, named in honor of then-president of Castle & Cooke, Alexander G. Budge, 1954.

Figure 114. William Hale, John F. Cross, and "Porky" Ooka at Budge Vista, 1960.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 115. **"Porky" Ooka standing alongside the test variety 660, which was named 'Keaau', 1958.**
(Courtesy of Mauna Loa Macadamia Nut Corp.)

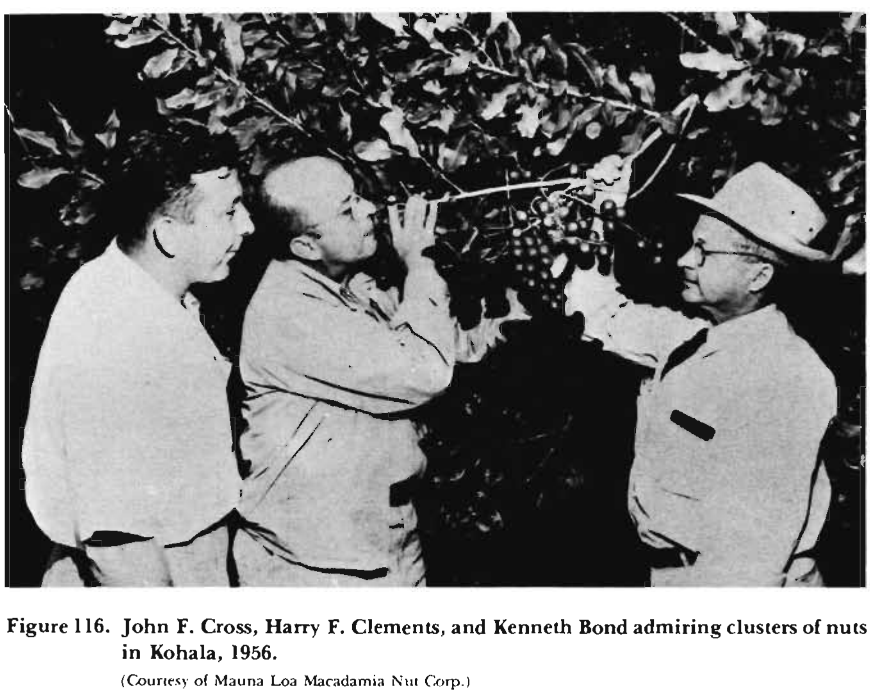

Figure 116. **John F. Cross, Harry F. Clements, and Kenneth Bond admiring clusters of nuts in Kohala, 1956.**
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 117. Alexander "Zander" G. Budge and John F. Cross at the "factory" open house at Keaau Orchard, sampling nuts in 1955.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 118. Keaau Orchard about 1955. Left to right, John F. Cross; Clarence Lyman, University of Hawaii Extension Service; Fred Simpich, Castle & Cooke; Gordon Shigeura; Leon Thevenin, Honokaa Sugar Co.; John H. Beaumont, director of the Experiment Station; and Donald Mahaffey, factory superintendent, Keaau Orchard.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 119. Carefully root-pruned tree with a mass of fine roots formed on small laterals. Yoshio Ogomori (right) and Hipolito Dela Cruz (left) with trees, 1955.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 120. Five-year-old trees windblown at Ka'u by storm wind, 1955. Macadamia trees are highly susceptible to windthrow up to about 10 years of age.

Figure 121. A macadamia tree that went through a twister wind at Honomalino in 1962 had snapped limbs but no windthrow, apparently because it had a taproot system that held well. Hurricane Iwa, which went through Francis Takahashi's orchard on November 23–24, 1982, left in its wake similarly damaged trees.

Figure 122. Portable weed-burning torch unit at Keaau Orchard, 1960.

(Courtesy of Mauna Loa Macadamia Nut Corp.)

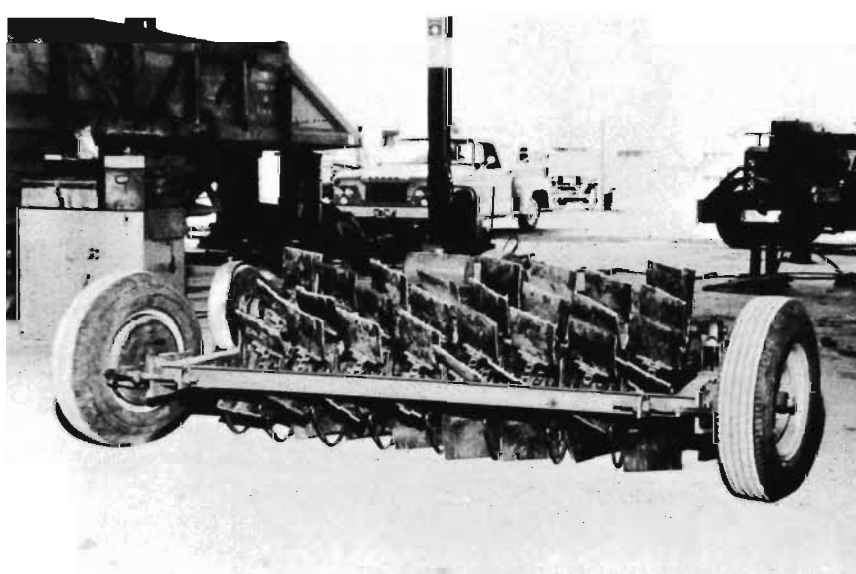

Figure 123. Individually suspended and rotating nut-sweeper unit about 9 inches wide, constructed to permit each unit to follow its own terrain over uneven land, C. Brewer, 1960.

(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 124. Experimental shake harvesting of nuts at Honomalino by George Schattauer, 1970.

Figure 125. Experimental vacuum harvesting of macadamia nuts placed on ground at Keaau Orchard, 1953. Note quarry waste spread on ground to fill crevices.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

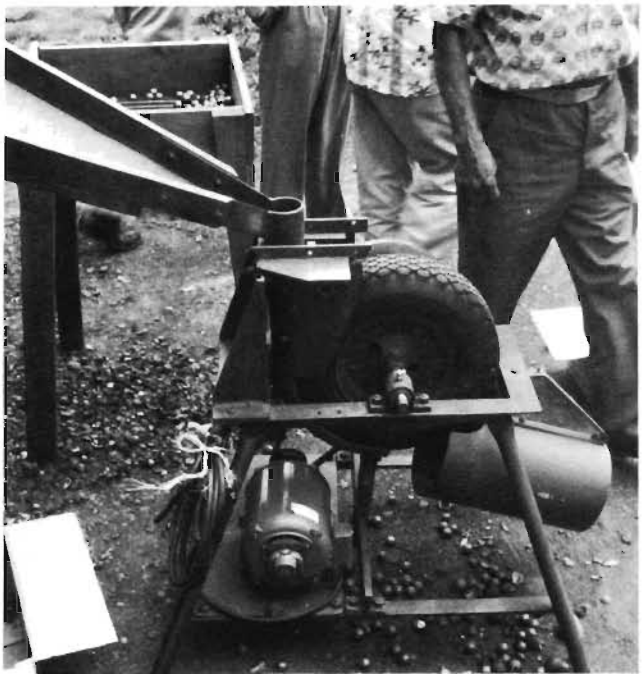

Figure 126. Made by a grower in the Kohala area, this portable nut husker uses a small wheelbarrow tire.

Figure 127. Herbicide tank used at Keaau Orchard in the early 1950s. Isamu Yamauchi, operator, filling the tank, 1954.
(Courtesy of Mauna Loa Macadamia Nut Corp.)

Figure 128. Rat guard placed at the base of the Purvis tree at Kapulena, Hawaii, in the early times.

Figure 129. Honeybee hives placed in the orchard at Martin Sebastian's Circle S Ranch, 1975.

Figure 130. Separation of kernels from shells was accomplished in a rotating drum by having the shells, which are lighter in weight than the kernels, spill over the edge. The remaining shells were hand separated. The smaller pieces and fines were separated through screened portholes in the lower portion of the drum. This machine was used by Mamoru Takitani of Hawaiian Host Candy in his original candy factory in the attic of his father's soda-water-bottling building in Wailuku, Maui, about 1955.

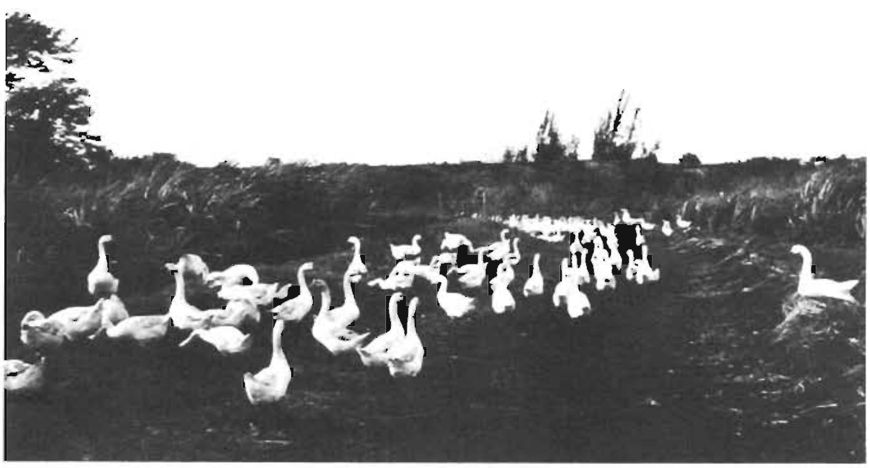

Figure 131. Geese were used for weed control in the 1950s by letting the flock forage in sugarcane and macadamia fields to keep them practically weed free. The geese especially liked nut grass tubers, and they had to "till" the land to reach the tubers growing in the ground.

NOTE: As part of a structural reorganization, the Hawaii Agricultural Experiment Station and the Hawaii Cooperative Extension Service have been merged administratively under the name HAWAII INSTITUTE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES, College of Tropical Agriculture and Human Resources, University of Hawaii.

Hawaii Institute of Tropical Agriculture and Human Resources
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