Corn Production in the Tropics

The Hawaii Experience

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Written and revised 1996–2003 by
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Note on measurement

Corn biomass and silage yields are expressed in tons/acre. Grain yields are expressed in bushels/acre (bu/A).

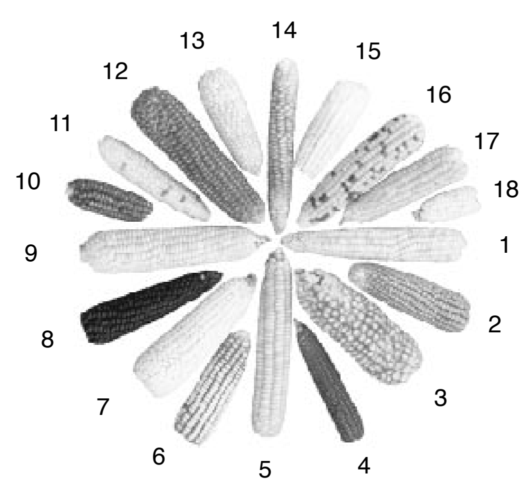
1 acre (A) = 0.4 hectare (ha)
1 bu holds 55 lb of "No. 2 flats" dry corn grain, thus the weight of a bushel varies with the type of corn; therefore, 1 bu dry grain weighs approximately 55 lb
1 ton/ha = 15.9 bu/A
1 ton per acre (t/A) = 2000 pounds per acre (lb/A) = 35.7 bushels per acre (bu/A) = 2.25 metric tons per hectare (MT/ha)
1 MT = 1000 kg = 2200 pounds (lb) = 1.1 ton
100 bu/A = 2.8 t/A = 6.3 MT/ha

Cover photo

Corn ears from trials in Waimanalo, Hawaii, display some of corn's impressive genetic diversity (photo courtesy of Sarah Nourse Styan).

Key to corn ears shown

1 Reventador (Mexican Highland popcorn)
2 Chocolate (mutant with bronze pericarp)
3 Coastal tropical flint (W. Indies)
4 Argentine popcorn (with red aleurone)
5 Coroico (Bolivian flint)
6 Floury (mutant floury-2, high lysine)
7 Chandelle (Venezuela, white flint)
8 Mishca negrito (Colombia, blue dent)
9 Canario de Ocho (Brazil, yellow floury)
10 Pagaladroga (Peru, red floury)
11 Nal-Tel (Guatemala, Maya Indian corn)
12 Alazan (Peru, red floury)
13 San Marceno (Guatemala, yellow flint)
14 Chapalote (Anazasi Indian corn, bronze)
15 Teopod (mutant with husk on each seed)
16 Yellow:red in 13:3 ratio (CI/C R/r self)
17 Yellow flint
18 Araguito (Venezuela, popcorn)



Preface and Acknowledgments

When the project of creating this production manual was begun (around 1975), the document owed much to Sam Aldrich's excellent but Corn Belt–based *Modern Corn Production*. Today it owes as much to Web sites (see *References*), but in general it is patterned on the treatment of the subject by Aldrich.

Tropical islands have an annoying way of providing a suitable climate to grow any plant without providing the market conditions to make it economically viable. This is certainly true of corn production in Hawaii. Perhaps the most exciting market for our field corn was for shipment to California during World War I! Since 1970, however, corn has become a significant winter seed industry for Hawaii, and Hawaiian supersweets have become firmly established as a vegetable crop.

Corn is no newcomer to Hawaii. The Royal Hawaiian Agricultural Society was encouraging research on "Indian corn" in the 1850s. They recognized that pest resistance was the principal problem in adapting corn from the Mainland states to Hawaii. Only in the early 1900s did corn flourish, but production was restricted to Hawaii's highlands due to a major tropical plant virus disease.

Economic production of corn in Hawaii, as in the rest of the world, rests firmly on the availability of superior adapted varieties, excellent crop land, competent farmers, and a reliable market. Only in recent years have these elements begun to come together in Hawaii, although farmers continue to be plagued by high costs, infrastructure problems, and a poor business climate.

Seed corn has become one of Hawaii's significant agricultural industries. Hawaii's seed industry has grown since 1966 to involve most of the seed companies and many of the corn research institutions in the United States. It has an enlarging international role in relation to many crops.

Supersweet vegetable corns have become a burgeoning market for Hawaii's farmers, and University of Hawaii (UH) varieties and hybrids undergird this industry. They are grown increasingly throughout the world, while Hawaii's markets often seem hopelessly naive about the superb quality of this product (given a little tender loving postharvest care).

Field corn production for silage or grain in Hawaii has been limited by lack of suitable land, presence of tropical plant diseases, and poor market conditions. The first of these problems has diminished through the decline of sugarcane production. The second has diminished greatly due to the release of pest- and disease-resistant UH hybrids. The third factor, markets, can vary wildly in Hawaii, as animal producers have varying interests in locally grown corn grain and silage for improved production of milk and finished beef, or for swine and poultry feeding.

Problems still abound; for example, Hawaii's corn farmers have expenses for land, water, inter-island transportation, and equipment that are an order of magnitude above those of the Corn Belt. Tropical weeds, insects, pheasants, feral pigs, and even escaped pet parrots take their toll. Good corn farmers are hard to find. Even Hawaii's generous climate fails by providing too little light and too much wind. I write this manual, however, with an optimism that Hawaii's corn production and its role in international corn improvement have exciting futures.

The present edition of this book owes much to the editorial skills of Dale Evans, Publications and Information Office, UH College of Tropical Agriculture and Human Resources.

No publication of this magnitude is the product of a single person, particularly when it has developed over more than a quarter-century. I owe great thanks to my students and colleagues for their inputs, criticisms, and suggestions. Fellow authors include

Dr. Jay H. Chung (until recently, administrator with Asian Development Bank, Manila, Philippines)

Dr. Hyeun Gui Moon, corn breeder, Office of Rural Development, Suwon, Korea
Dr. Soon Kwon Kim, director general, International Agricultural Research Institute, Kyungpook National University, Taegu, Korea
Dr. John Thompson, retired professor of agronomy, University of Hawaii (deceased).

Graduate students in CTAHR's Department of Tropical Plant and Soil Sciences (which combines the former Department of Horticulture and Department of Agro-nomy and Soil Science) have figured prominently in my corn research over the years. Among those who have helped in preparing and editing this manual are
Dr. Sarah Nourse (Styan), with MS from Wageningen, Netherlands
Dr. Xiaowu Lu, with MS from Beijing University, Beijing, ROC
Dr. Myoung Hoon Lee, professor, Dongguk University, Seoul, Korea
Mr. Yoonsup So, graduate student.

James L. Brewbaker
Honolulu, Hawaii, 2003

About the Author

James Lynn Brewbaker ("Dr. B." to his students) has been associated with corn since his birth in 1926, the year his father (Harvey E.) completed a PhD in plant breeding at the University of Minnesota. Harvey's mentor, Dr. Herbert Kendall Hayes, had been a student at Harvard of Professor Edward M. East, one of the co-discoverers of Gregor Mendel's definitive research establishing the science of genetics. The names East and Hayes, together with their students (e.g., Emerson, Mangelsdorf, Jones, Burnham, Brink, Rinke, Warner, Wortman) are associated with every major finding about the genetics of corn in the 20th century. Their discoveries and applications of hybrid vigor in corn alone are worth billions of dollars annually throughout the world.

Harvey Brewbaker served as an assistant professor in the corn program at St. Paul until 1930, when he moved the family to Colorado to assume a position on sugarbeet improvement. Naturally, he grew corn in his backyard in Ft. Collins, where his son got his first experience pollinating, standing on a box that he carried through the field. They later moved to a farm near Longmont.

In 1953, following his PhD under Dr. Sanford S. Atwood at Cornell and a postdoctoral position with Professor Arne Muntzing at University of Lund, Sweden, the author went to Southeast Asia. There he worked on a corn and rice project with Dr. Hayes (then "retired") and Dr. Dioscoro Umali at the University of the Philippines. Two years later he joined the U.S. Atomic Energy Commission in radiation genetics. In 1961, he joined the faculty of the new Department of Horticulture in the College of Tropical Agriculture and Human Resources of the University of Hawaii.

He soon initiated a program of regular corn plantings throughout the year at the Waimanalo Research Station. In a widely quoted speech to the American Seed Trade Association in 1974, he reported that his staff harvested year-round every Tuesday morning. Using no pesticides, a continuing evolution occurred between diseases, pests, and Hawaii's home-bred corn. Today, Waimanalo-bred corns effectively can be grown without pesticides, having high levels of resistance to a host of diseases, pests, and stresses peculiar to the Hawaiian Islands. During these years, experiments led to the founding of Hawaii's corn seed industry and of the Hawaii Crop Improvement Association (1969). An estimated 1200 trials of corn have been planted at Waimanalo through these years. Some of Dr. B's inbreds and varieties have over 70 generations of breeding.

Dr. B's students to the MS and PhD degrees number over 50 and are among his proudest accomplishments. His publications number over 250 and include four books, ranging from *Agricultural Genetics* in 1963 to *Quantitative Genetics on a Spreadsheet* in 1994. His corn inbreds, varieties, conversions, and hybrids are used throughout the tropics. The journal MAYDICA honored him in 1999 with a commemorative issue, "Bringing Maize Genetics to the Mid-Pacific," v. 44, issue 3, pp. 263–384.

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Chapter 1

Corn and Its Environment

Corn evolved in the American tropics, where it became a staple food of all early civilizations of native Americans. It was named “mais” in Spanish, or “maize,” from which Linnaeus coined its Latin name, *Zea mays*. Modern corns never grow wild but survive only through man’s care. Thus corn’s history is completely interwoven with the histories of the Olmec, Maya, Teotihuacan, Zapotec, Aztec, Nazca, Iroquois, Inca, and other peoples under whose guidance it evolved (Brewbaker 1979, Mangelsdorf 1974).

In the 500 years since Columbus arrived in the New World, corn has spread beyond the Americas to become the world’s most widely distributed crop. It is grown on about 300,000,000 acres of land, and more than 70 countries have 200,000 acres or more in corn. About a quarter of this acreage—and over half the world’s total production—is in the USA.

Few crops are found in such diverse forms as corn: sweet and supersweet corns eaten as vegetables, popcorns, dent and flint feed corns, corn as an energy crop, floury and high-lysine and waxy (glutinous) and high-amylose corns. Corn products occur in about one of every five items in a supermarket, ranging from sodapop to plastics. The increasingly economical uses of high-fructose corn sugar and of alcohols, starches, and oils from corn ensure that the list of products containing corn will continue to expand.

The demand for corn increases in proportion to world population growth—an awesome 2 percent annually. Production has not been able to keep pace with this demand, except in a very few countries. The USA is the world’s major exporter—about a third of its crop. Despite the origin of maize in the tropics, much of the world’s present corn production is in temperate zones, using corn varieties developed for temperate climates and latitudes. These highly productive temperate-zone varieties are based on only a fraction (less than 5 percent) of corn’s germplasm.

Corn production around the world

Corn is one of the world’s three major crops, along with rice and wheat. The major corn-producing countries in year 2000 were led by the USA and China (Table 1.1). As intimated by the table, corn is found in every country in the world and occupies more acreage than any other crop except wheat. While rice is grown mainly in the tropics and wheat is largely a temperate crop, corn is grown commercially from Alaska to the equator and from sea level to elevations over 10,000 feet.

Production in Asia has increased greatly as use of meat in the diets increases. Korea, for example, imports millions of tons of corn as feed and also produces corn on extensive acreage for food (even to make corn noodles) and feed. World production of corn has increased steadily since 1950, from about 150 million to 550 million tons in industrialized countries, and from about 50 million to over 200 million tons in developing countries. The real price trend in international markets has been downward, from about 10 cents/lb in 1950 to 5 cents/lb in 1990.

Corn production in the USA has been based on about 75 million production acres. Yields have increased steadily since the 1960s and greatly exceed all other cereal crops at present. Figure 1.1 shows that this is a linear increase, averaging almost 3 percent gain per year. Scientists attribute over half of this increase to plant breeding, or an annual return on investment in corn breeding of about $300 million.

A large international market is developing for American corn, including tropical hybrids bred in Hawaii, as tropical nations achieve demographic transition. The limited public investment in the USA toward improving tropical agriculture restricts corn self-sufficiency abroad.

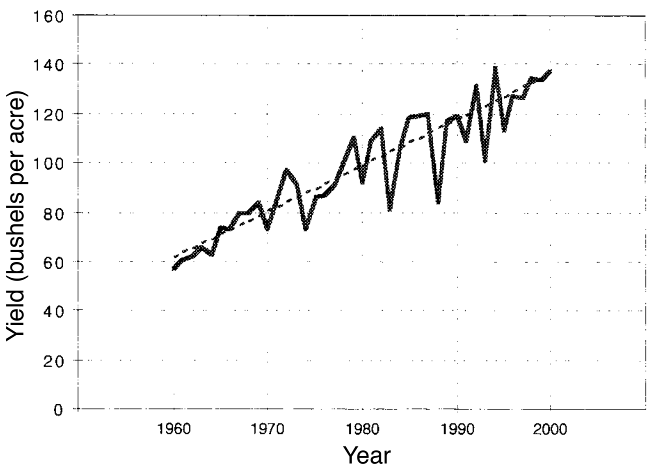
Yields of silage corn grown in the USA, for use primarily by dairies, average about 15 tons/acre. Similar yields are obtained in countries like Australia, Korea, and Italy, where yields are about double the world average.

The U.S. corn grain yield of approximately 4 tons per acre (145 bushels per acre) is about ten times that of most developing countries, which are largely tropical.

Essentially all corn grown in the USA is hybrid corn. The yield increase since 1960 shown in Figure 1.1 is based almost entirely on single-cross hybrids. These succeeded open-pollinated varieties (to 1940) and later double-cross hybrids (to 1960), types still common in the tropics. The development of superior single-cross hybrids for Hawaii can contribute to major increases in corn production in the state—if and when the hybrids are adopted and produced by growers.

Corn-grower contests are held annually in the United States, using high intensity production systems involving high plant densities, superb hybrids, and high inputs. Yields since 2000 have exceeded 440 bushels of grain per acre, equal to more than 12 tons/acre. These values continue to increase, indicating a significant exploitable yield gap for farmers and scientists.

Figure 1.1. Corn yields in the USA, 1960–1998.



Hawaii's corn production

Corn production worldwide is presented in Table 1.2 in terms of the number of people per acre of corn. The United States has only 3 people per corn acre, as it produces about a quarter of the world production but has less than 4% of its people, The world has about 20 people per acre of corn, while Hawaii has almost 300 people per acre. Corn production in Hawaii thus falls far short of meeting the state's market demand for any type of corn—whether for sweet corn, popcorn, silage corn, or grain.

Hawaii cannot grow U.S. Corn Belt corn varieties commercially without high inputs for disease and pest control. We must rely instead on hybrids derived from germplasm adapted to tropical conditions. There is great scope for increasing the diversity, yield, quality, and pest resistance of corn varieties for the tropics and subtropics, as the author's work at the University of Hawaii has demonstrated over the years. This publication focuses on the production and uses of corn in the state of Hawaii, but its information is applicable to many of the world's warm regions. Hawaii, at about 20°N latitude, has a subtropical climate and a representative range of the

Figure 1.2. Cash value of corn production in Hawaii.

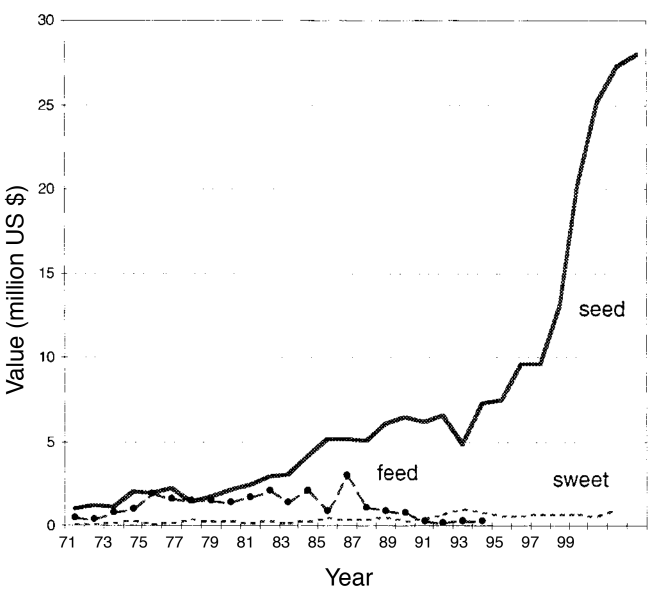


Figure 1.3. Acreage of corn production in Hawaii.

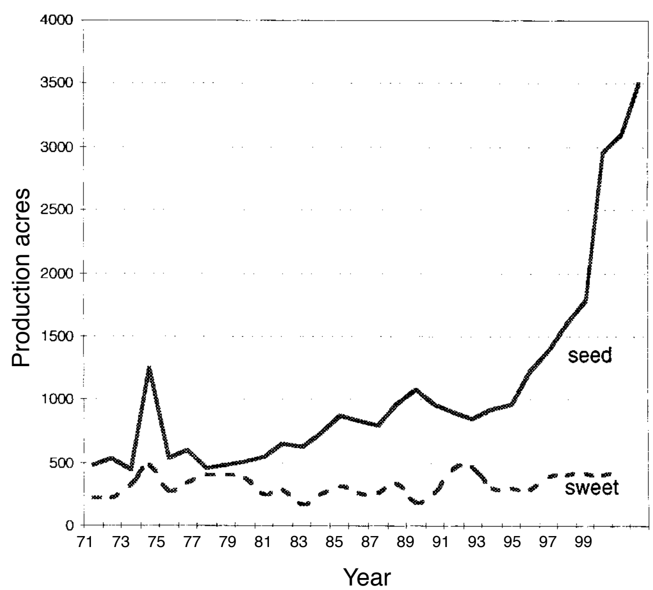


Table 1.1. World corn production in the major producing countries.

Country	Production (million tons)	Yield (tons/acre)
USA	177.3	3.6
China	81.8	1.9
Brazil	21.8	0.8
Mexico	11.8	0.8
France	10.9	3.0
Russia	10.2	1.2
S. Africa	8.8	1.2
India	8.2	0.7
Yugoslavia	7.7	1.6
Romania	7.3	1.4
Canada	6.4	3.0
Indonesia	5.9	0.9
Hungary	5.8	2.5
Italy	5.5	3.4
Argentina	5.5	1.5
Philippines	4.4	0.6
Thailand	3.6	1.1
Spain	2.9	2.9
Kenya	2.4	0.8
Tanzania	2.4	0.6
Nigeria	1.8	0.6
Zimbabwe	1.6	0.7
World	total 434	average 1.6

Table 1.2. Corn production and the human population.

Locale	Population in 1995	Annual corn production (acres)	People per acre of corn
Hawaii	1,100,000	4000	275.0
USA	240,000,000	75,000,000	3.2

environmental stresses, plant diseases, insect and weed pests to which corn is subject throughout the world.

The cash value of Hawaii's corn crops since 1971 is summarized in Figure 1.2. Seed corn has risen in recent years to dominate these numbers; there has been an upward trend in sweet corn but no progress in field corn. Overall, the corn-based industry contributes around $40 million annually to the state. The high value of the seed-corn industry inflates the apparent value of Hawaii's corn crop, but high costs of labor, land, water, supplies, and services reduce net profitability.

Crop acreage for seed and sweet corns in Hawaii is summarized in Figure 1.3. Commercial production has ranged from 1000 to 3000 acres. These are "crop-acres," because Hawaii's corn lands can produce more than one crop per acre per year. The decline in acreage of sugarcane and pineapple has afforded great opportunity for expanded corn production.

The seed corn industry (see Chapter 10) was established in Hawaii in 1966 and grew rapidly, stabilizing in value by the mid-1980s. As new lands became available in the 1990s, this industry continued to expand. Sweet corn production has increased since the introduction of Hawaii-bred hybrids such as the Hawaiian supersweet varieties. Sweet corn has been called "America's favorite vegetable," but Hawaii's production still falls far short of local demand.

Field corn grown for grain or silage ("green chop") has been variously successful since World War II in Hawaii. Failures were attributed largely to high production costs, questionable management practices, and a difficult local market in the dairy and poultry industries. Since 2000 there have been major expansions in production of silage corn for dairies and of sweet corn.

Corn's environmental requirements

Soil

Corn is grown in nearly all types of soil, but major efforts may be required to make production feasible. Corn grows best with good drainage and soil aeration. Croplands of the northeastern USA had to be lined with drainage systems to improve corn yields over those obtained by the native Americans. In corn fields with clayey soils, patterns of poor growth due to compaction from heavy equipment may be visible for years. Liming of soils to pH 5.5 and above is required in much of the world.

For optimum corn yields, the addition of nutrients is essential on most soils. Growth is best between soil pH 5.5 and 7.3, with pH 6.0–6.5 preferred. In this range, calcium and magnesium are optimally available, as are the applied phosphates. A good corn soil will have a cation exchange capacity around 20 (milliequivalents per 100 g of soil) and a water-holding capacity of 2 inches per foot of soil. In some acidic tropical soils, aluminum or manganese can become toxic if soil pH is less than 5.5. On crushed coral soils and other alkaline soils, pH-induced deficiencies of minor elements such as iron and zinc can reduce yields.

Temperature

Corn is a fast growing crop in the tropics. In Hawaii's lowlands, sweet corn is ripe in 70 days, field corn for green chop (silage) is ready in 95 days, and dry grain is harvested after 110 days of growth. Temperatures in these areas range between 70 and 85°F. Below 50°F, corn makes little or no growth. This limitation is recognized in the "growing degree day" (GDD) formulas for corn, which sum the differences between ambient temperature and 50°F (see Chapter 3). For example, if average daily temperature is 75°F for 10 days, there have been 250 GDDs. Accurate prediction of the time of flowering is important to corn seed producers, and GDD calculations can allow this.

Crop physiologists recognize corn to be a highly efficient type of plant that conserves loss of water by respiring not in daylight but only in the dark. Respiration is the "living combustion" in which sugars created in photosynthesis are converted to more complex products to support plant growth. Respiration's primary waste product, oxygen, needs to be released from the plant as carbon dioxide and water. The valves in the plant's exhaust system, called stomata, are in the leaf surfaces, and they need to be open during respiration. In most temperate-zone plants, including wheat and rice, respiration occurs in the daytime, but in corn and other tropical plants with the "C-4" metabolism, it occurs at night, when temperatures are cooler. By keeping stomata closed in the daytime, losses of water are limited, and C-4 plants are thus "adapted" to warm climates.

Nevertheless, at high temperatures, corn may not take up soil moisture rapidly enough to compensate for plant water loss through the leaves, and wilting can occur. Plants are most susceptible to drought-induced wilt during the "grand growth" phase and at the time of pollen dispersal. Hawaii's temperatures are relatively constant, however, and drought stress is rare under irrigation as it is normally practiced.

Elevation

The speed with which corn reaches maturity is related directly to the temperature during crop growth, which for a given region is related to elevation. Corn is grown at elevations in excess of 10,000 feet in some locations within the tropics. Under such cool conditions, varieties such as 'Cuzco' are grown, which develop very large seeds ("corn-nuts") and take up to 250 days to mature. Corn production in Hawaii has ranged widely from sea level to 6000 feet. Corn flourished on the slopes of Haleakala crater on Maui in the early part of the century.

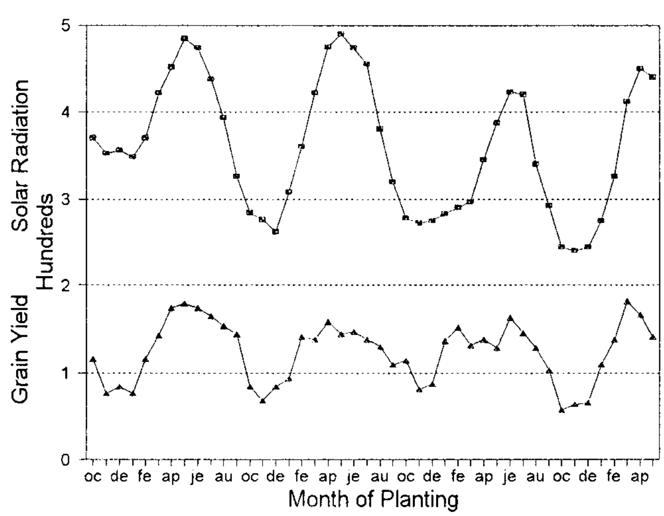
Tropical corn yields generally increase with the elevation at which they are planted. The lower temperatures delay maturity and permit longer development. Plants become larger, with more leaves and bigger ears and kernels. While higher yields can be obtained at higher elevations, the growing season is longer. Thus any yield advantage of highland production generally is lost when yields are calculated on a per-day basis. Other factors can also favor lowland production: Hawaii's highlands are often too wet, with soils that are too acidic or too poor in nutrient status to be suitable for corn production.

Light

Corn and other tropical plants with the C-4 metabolism are considered to be highly efficient in harvesting the sun's energy and converting it to growth products. Despite this metabolic advantage, light is one of the major constraints to maximizing corn yields in the tropics. Tropical days are short! In Hawaii they range from 11 hours 16 minutes to 13 hours 50 minutes (including twilight). Rainy periods that involve cloudy, overcast skies further reduce incident light. This is especially true of windward areas during the winter in Hawaii.

The relationship of corn yield to light in Hawaii is illustrated in Figure 1.4. Data were taken at Waimanalo,

Figure 1.4. Grain yields (bu/A) at Waimanalo from monthly plantings over a four-year period, with data on solar radiation (cal/cm²/day) for the four months following planting.



in windward Oahu, from monthly plantings made over a four-year period. Grain yields were reduced over half by the poor light of winter. A close relationship of this yield decline was shown to exist with incident light during grain-filling period, in the first month after flowering.

The immediate effects of reduced light in a corn field are shorter plants and ears that fill poorly at the tip (Figure 1.5). In the tropics generally it is uncommon to see ears filled fully to the tip, and in Hawaii this condition is especially typical of the short-day, rainy winter months.

Because corn plants and ears tend to be smaller in the winter, should fertilization be increased to keep yields high? Should field populations be increased, or the reverse? We do not have good answers to these questions. If a choice is possible for the farmer, lands with maximal light should always be reserved for growing corn. Alternatively, plantings can be confined to the high-light months and timed to ensure that the maximal light comes after pollination, during grain filling.

Figure 1.5. Field corn ears fail to fill to the tip, even in Hawaii's summer days, due to limited receipt of daylight in the tropics.

Trees and hills can shade corn fields for many hours of the day in Hawaii. Windbreaks must be oriented carefully to minimize yield loss from shade. With Hawaii's northeast trade winds, the preferred orientation for windbreaks is SE–NW, but light interruption is minimized with an E–W orientation.

Daylength

Corn evolved at tropical latitudes and has a sensitivity to long days, causing it to delay flowering when grown in temperate latitudes where the days are longer. This daylength sensitivity still characterizes most tropical plants, and it had to be bred out of the corns that were moved into temperate latitudes. A 14-hour day can be considered a dividing line; when daylength exceeds 14 hours, many tropical corns will be delayed in pollination from 10 to 40 days. Thus most hybrids bred for Hawaii appear to have normal maturity here, but they will be very late in maturing if grown in the U.S. Corn Belt or other temperate regions.

It is possible to grow almost all of the world's corn types in Hawaii, although they are not all well adapted. Corn from the highland tropics, with soft, floury kernels susceptible to rot, is often ill-adapted in Hawaii. Corn selected for the latitudes of Canada or northern France are often dwarfed and unable to gather enough light from Hawaii's short days to achieve grain-fill.

Water

The water requirements for corn are commonly met in Hawaii by irrigation (see Chapter 6). If rain-fed, corn requires at least 18 inches of rain per crop, preferably distributed uniformly—about 2 inches per week. However, Hawaii's rains rarely come that way!

Other climatic factors affect crop water relations. Strong winds, such as Hawaii's trade winds, accelerate water loss from plants. At high elevations, fog drip can supplement rain water. Soil drainage is usually adequate to prevent waterlogging in most of Hawaii's soils, but on heavy soils, standing water in the field is deadly to young corn.

Wind

Corn in windward areas of Hawaii often suffers yield loss from trade winds. Plants on the windward edge of a field often show reduced heights and irregular grain-fill. Windbreaks are advisable for the very windy agricultural areas of the state, including the Hoolehua plain of Molokai, the slopes of Haleakala on Maui, and the Kohala coast on Hawaii. Prolonged heavy winds can induce plant lodging (falling over) and loss of grain. Lodging is less common in Hawaii because storms are infrequent, and we lack the stalk borers that so severely weaken corn stalks elsewhere in the world.

Corn's many uses and markets

Hawaii's uses for its corn harvest are presently only a fraction of those possible (Fig. 1.6). The principal markets for Hawaii-grown corn in the past decade were seed corn for the corn-breeding industry and supersweet corn for roadside stands and local supermarkets; a very small amount of corn for silage or feed grain for dairies. Corn imported to Hawaii represents the production of about 5000 acres in Hawaii, with three crops per year. The major importation is of feed grains that have averaged over 30,000 tons per year in the past two decades. This includes mixed feeds that can be of poor quality, including cracked and processed corn. About 75 percent of Hawaii's sweet corn is imported. Even the popcorn eaten in Hawaii could support 400 production acres at the U.S. average annual consumption of 2 pounds per person.

Alternative uses for corn in Hawaii include many possibilities. International markets are developing for foundation seed grown in Hawaii. Much interest is in corn-based ethanol as a gasoline supplement. Mainland and Asian marketing of Hawaii-grown supersweet corn is an option, as is local processing and freezing. Other possibilities are evident from the following list of common uses and products of corn:

- alcohol—from fermented grain—as fuel, beverage, and for industrial use
- starch—from wet-milled grain—as starch or a source of corn syrups
- high-fructose corn sugar—from enzyme-digested starch
- oil—from wet-milled grain—for industrial use and margarine
- flour, meal, and grits—from dry-milled grain—for use in feeds and foods.

The list of uses of corn is virtually unlimited and is expanding to include new "specialty corns," genotypes offering unique value-added starch products. Corn can be parched, boiled, and popped. It can be ground for whole corn-meal breads or tortilla flours, grits, and breakfast cereals. It is the basis of an array of alcoholic beverages. It is used as an ornamental, eaten as baby ears, and made into products such as cornnuts, hominy grits, and masa harina. The by-products of processing are feedstuffs whose co-product values often undergird the economics of processing.

The use of corn in the USA is about half for feed, 30 percent for export, and 20 percent for food, alcohol, and manufacturing. The feed corn goes to poultry (20%), dairy (15%), hogs (10%), and beef cattle and other animals (5%). The food-alcohol use goes either via wet or dry milling. Wet-milled products include high-fructose corn sugar (40%), ethanol (25%), other sugars (20%), and corn starch (15%). Products from dry-milling include breakfast cereals and foods (20%), alcohol (45%), animal feeds (15%), brewing (12%), and manufacturing (8%). Nearly all of these uses reflect the fact that corn is one of the cheapest sources of starch. A Web site listing over 600 products of corn is *www.ncga.com* (see *References*).

Figure 1.6. Of all its uses, corn is at its best as "Hawaiian Supersweet," fresh from the field about 18 days after pollination (bite-test by Peter Kamanakai Brewbaker).

Chapter 2

The Corn Plant

Origin and evolution of corn

Corn became a cultivated crop as a result of human selection. Its major center of origin and evolution was in Mexico and Central America, at about the same latitude as Hawaii. The Swedish taxonomist Linnaeus named it *Zea mays*. Although it is called "corn" in the USA, in much of the rest of the world it is known as "maize," from the Spanish *mais*. Maize cultivation began in Mexico 5000 to 7000 years ago, and it soon spread into the Andes of South America.

Corn can produce about 1000 pounds of grain in 100 days from 1 pound of planted seed, a productivity surpassing all other cereal grains. Corn is found from the equator to Alaska, in many shapes and sizes. This chapter explores the growth, origin, and botanical characters of this remarkable plant.

Wild relatives

The closest wild relatives of corn are the grass-like teosintes of Mexico and Central America. Maize probably originated from teosinte species such as *Zea diploperennis* and *Z. parviglumis*. Teosintes grow vigorously in Hawaii and carry resistance to some of the major corn diseases found here. Corn is not able to reproduce and survive in nature without the help of man, but the teosintes can. As a result they are known to become weeds, as they have in central Queensland, Australia, where they were introduced for animal feed. Modern corns cross readily with teosintes. Their hybrids are vigorous and grassy, growing to 12 ft tall and bearing up to 200 tiny ears per plant. In Hawaii, we bred the HIC9 composite, with 75 percent corn and 25 percent perennial teosinte genes. It is similar to corn in that it is an annual and cannot survive as a weed.

Corn and early American civilizations

Corn was the basis for the earliest agriculture in the Americas. It served as the major food source of carbohydrate energy, and civilizations rose and fell as a result of this dependence. Indians were cultivating a hundred different corn varieties by the time of Columbus. These primitive tropical types of corn are known as races, more than 220 of which have been described in Latin America, from Mexico to Argentina. Most corn races grow well in Hawaii, and the University of Hawaii corn breeding program has evaluated and increased seed of many of these races. Some of their very diverse seeds are shown on this publication's cover.

Great centers of corn diversity occurred in Mexico, Guatemala, the West Indies, Colombia, Peru, Ecuador, and Brazil. These tropical corns have been significant in the ancestry of the best modern hybrids developed in Hawaii. They provide Hawaii and other tropical and subtropical regions with a far richer germplasm pool for future corn improvement than is available for the U.S. Corn Belt, where the daylength sensitivity of most races discourages their use.

One of the most primitive cultivated varieties of corn was Nal-Tel. It was the basis of the development of the Maya civilization in the lowlands of Guatemala and the Yucatan peninsula. Nal-Tel produces several short ears of flinty corn with yellow or brownish kernels. Although over 1000 years old, the variety still yields well in Hawaii, and many modern corn varieties stem from it.

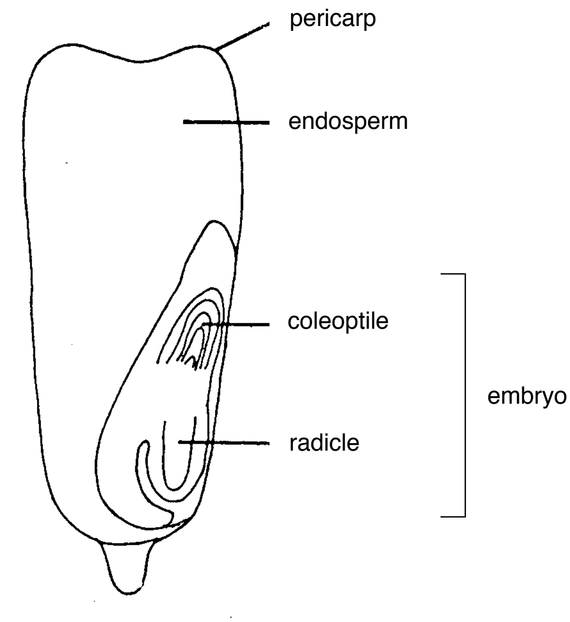
Corn is a plant with great genetic variation. At one extreme, varieties like Canada's Gaspé Flint grow to 3 ft in height, flower in 36 days, and can be harvested in 70 days in Hawaii. At the other extreme, the race Tehua from Mexico grows up to 20 ft in height, flowers in 150 days, and requires more than 200 days of growth before harvest in Hawaii (Fig. 2.1).

The corn seed

The three major parts of the corn kernel are the embryo, the endosperm, and the seed coat or pericarp (Figure 2.2). The embryo (germ) develops into the new plant from the

Figure 2.1. Vigorous tropical races of corn being pollinated in Waimanalo by Jack Kanazawa and Rye Huang.

Figure 2.2. The corn kernel.



fusion of sperm and egg cells. It includes leafy parts (coleoptile and plumule) and the young root (radicle). A rich nurse tissue (scutellum) occurs at the tip of the embryo. It is greatly enlarged in high-oil corn varieties.

Endosperm surrounds the embryo and makes up about 80 percent of the kernel weight. Endosperms vary greatly in type, often as the result of single-gene changes or mutations. Those of commercial importance are discussed in Chapter 3.The outer layer of endosperm cells is called the aleurone, and it can be pigmented many ways. Yellow corn has carotenoids (Vitamin A precursors) in its endosperm, while blue and red corns have anthocyanins in their aleurone layers. Most of these gene mutations are recessive and masked by the field-corn genes. Endosperm tissue is triploid, having two sets of maternal genes, plus the male paternal set.

In field corns the endosperm is 90 percent starch-filled, usually with a soft, whitish portion and a hard (corneous) portion. In flint corns, little or no soft starch is found, and the kernels are translucent and shiny. Dent corns have varying amounts of soft starch, which causes indentations at the tip of the kernel when they dry. In popcorn, the endosperm has only hard starch, whereas in floury and high-lysine corns, it has little or no hard starch.

Waxy corns, which have qualities similar to *mochi* rice, have endosperm consisting entirely of a glutinous type of starch called amylopectin. In the USA, waxy corns are used, among other things, for tapioca, in place of cassava. The starch of most field corn seeds includes about one quarter amylose and three quarters amylopectin.

Corns that are harvested as vegetables include "sweets" and "supersweets." Sweet ("sugary") corn has much of the starch replaced by a water-soluble starch (known as WSP) and sugars. Supersweet corn has little starch and very high amounts of sugar. Mature supersweet kernels are small and shrivelled, and must be stored carefully under dry, cool conditions to preserve their viability.

Endosperm tissue results from cross-fertilization. If pollen grains from a starchy field corn plant fertilize the developing ear of a sweet corn plant, the resulting kernels will have the starchy character. Thus, a sweet corn grower cannot grow field corn, waxy corn, or

Figure 2.3. Pericarp variation among the races of corn.

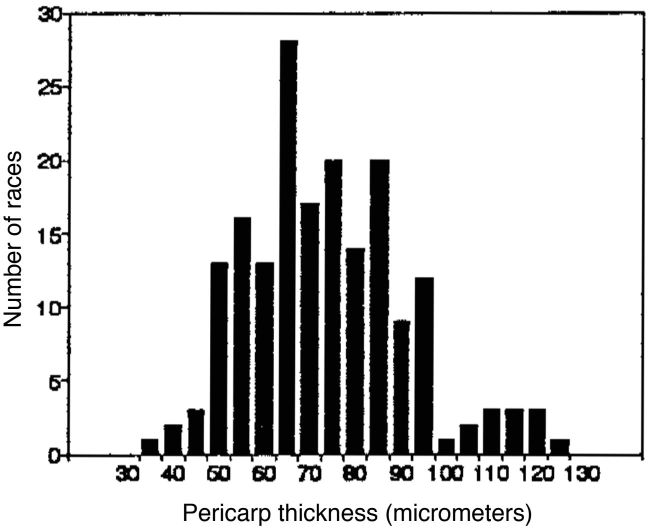
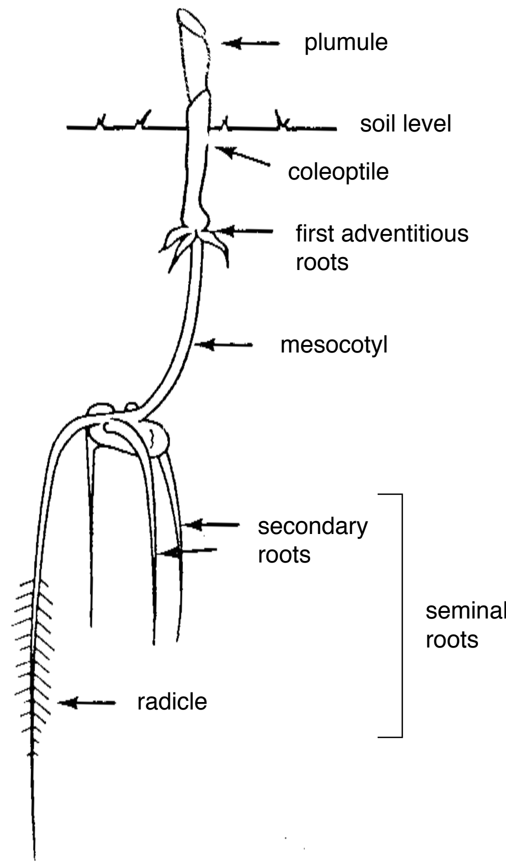


Figure 2.4. One-week-old corn seedling.



even supersweet corn in the same field at the same time without risk of having an unmarketable crop. Similarly, white corns will produce yellow kernels if pollinated by nearby yellow corns.

The seed coat of corn, the pericarp, is the part that often sticks between the teeth after eating an old ear of sweet corn. Pericarp protects the developing seeds from disease and insect damage and is of little food or feed value, except as fiber. The thickness of the seed coat is related to the tenderness of the kernel. Our studies of 180 primitive corn races showed them to be much more tender than modern field corns. In fact, some were as tender as our best American sweet corns, with a pericarp thickness of around 50 micrometers (Fig. 2.3), about half the thickness of a piece of typing paper.

Growth of the corn seedling

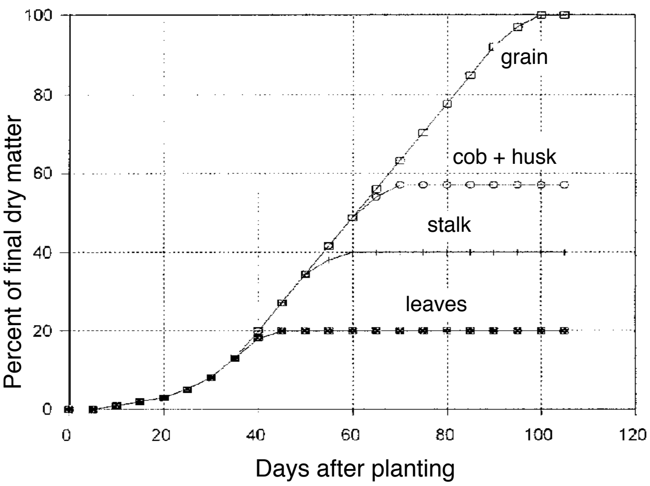
Corn kernels germinate within hours after exposure to a wet environment, such as a moist soil. The radicle (young root) breaks through the embryo side of the seed coat within 36–48 hours of being soaked. Several other seedling or "seminal" roots soon develop from the seed. The leaves emerge following emergence of the radicle and push up through the soil.

Three tissues play a major role in the germination process (Fig. 2.4). The plumule is the first leaf, and it rapidly becomes green when exposed to light. Surrounding the plumule and other developing leaves is a stiff, whitish, leaf-like tube, the coleoptile . It covers and protects the leaves until emergence, which occurs between five and six days after planting in Hawaii.

The mesocotyl is an unusual little stem that bears both the coleoptile and plumule. This stem attaches to the seed, and its length varies from $\frac{1}{2}$ to 6 inches or more. A growth hormone governs this elongation, which serves to push the leaves and coleoptile up toward the soil surface.

At the average planting depth of 2 inches, the mesocotyl will be between $\frac{1}{2}$ and 1 inch long. Seeds that are deeply buried will have very long mesocotyls. Cliff Dwellers living in North America's southwestern deserts a thousand years ago planted their favored variety, Chapalote, up to 6 inches deep in droughty, sandy soils, and the resulting huge mesocotyls are part of the archaeological record. After breaking through the soil surface, the emerging coleoptile is immediately split by the developing plumule and soon withers. The next three leaves emerge from the plumule in rapid succession. At 10 days after planting in Hawaii's lowlands, the

Figure 2.5. Dry matter accumulation of a corn plant.



seedling will have three leaves, each about 2 inches long. A fourth leaf will soon emerge from the growing point. The plumule stops its development at a length of about 2 inches, and soon dies. When growing conditions are cooler, these processes are slowed.

Root development below ground begins to shift from the seed (seminal) roots to a new location at the crown, which is located at the node where the mesocotyl and plumule are joined. This node has normally been pushed by the elongating mesocotyl to about an inch below soil surface. At 10 days after planting, there will be five or six short adventitious roots at this node (Figure 2.4). Later, roots emerge in great numbers and form a fibrous mat at the crown.

The first 10 days of development is a critical period for corn. Drought or flooding, disease or insect damage, soil toxicity or acidity, and herbicides can irreversibly reduce yields. The young seedlings have a high capacity for recovery, however. Hawaii's pigeons and Brazilian cardinals love to bite off the tips of emerging seedlings, but because the growing tip is below ground, new leaves usually emerge, and full recovery may occur. In loose, sandy soils, planting deeply (3 inches) may be wise if bird damage is a problem. Pheasants and chickens are stronger, however, and manage to pull up even the most stubborn seedling.

Field corns produce bigger seedlings than sweet and supersweet corns, although leaf numbers may be the same. Hybrids are much more vigorous than inbreds. The farmer wisely favors hybrids with vigorous early growth, other things being equal.

In Hawaii, we are fortunate to have no significant rootworm or wireworm problems and generally to have well drained soils. Only in Hawaii's highlands would growers be concerned about low temperatures. Seedling emergence and growth is usually strong under these benign conditions.

The maturing corn plant

Vegetative growth of the corn plant is completed in a short 50–70 days in Hawaii, with dry matter accumulation completed in about 100 days (Fig. 2.5). The reproductive phase of ear and tassel growth begins between three and four weeks after planting, with meiotic divisions beginning at around 28 days. A "grand growth" period follows in which plant dry matter increases nearly linearly with time.

The final weight of a plant of field corn is made up of about 45 percent grain, 20 percent leaves, about 20 percent stalk, and about 15 percent of cob, husks, and ear shank. Higher ratios of grain to stover are preferred by growers, but hard to achieve in tropical daylengths.

New leaves originate from the growing point at the tip of the stem. The seedling produces a new leaf about every four days. Mature plants will normally have between 15 and 18 leaves in Hawaii. Hybrids of medium maturity will have about eight of these leaves below the ear. The stem itself does not begin elongating until about three weeks after planting, when the plant is knee-high. Within a short period the stem shoots up, averaging about 3½ inches per day until tasseling. Growth can be slowed greatly by low temperatures, drought stress, severe winds, or suboptimal levels of soil phosphorus.

The roots of corn are estimated to make up 20 percent of the total plant weight at tasseling. Root extension generally keeps pace with that of the above-ground stalk—corn roots are known to reach depths of 6 feet. Roots of a single plant have been found to exceed 5 miles in total length! In the tropics, however, poor rooting is common. Most tropical corn varieties have weak root systems and lodge easily. Rooting is especially poor in wet or compacted soils.

Brace roots form at the lowest nodes of the stalk. They are stem-like in structure and can produce true roots profusely when they contact wet soil. Thus they both support the plant and help nourish it in later development. Corn Belt hybrids have been selected especially for stiff-stalk and superior rooting, to accommodate mechanical harvesting. Strong brace-rooting is common in such hybrids. One of the curiosities in corn is to see a tropical, daylength-sensitive variety growing in the long,

Figure 2.6. Erect-leaved corn plants at tasseling stage (with Guo Hwa Zan).

Figure 2.7. Baby corn ear 3 inches long, with silks.

16-hour days with brace root formation induced at every node up to as high as 6 feet on the stalk!

The tassel is a male inflorescence that begins to form about four weeks after planting, when the stem is only a few inches long. It matures within four to five weeks, emerging from the upper leaves about two months after planting. Breeders favor plants with smaller tassels and erect upper leaves that optimize light interception (Figure 2.6). In Hawaii, the date of pollen shed is often made obvious by pollen-collecting bees (except where insecticides are being applied regularly).

The ears start developing somewhat later than the tassel. Ear "initials" form at every node in prolific corns such as the supersweets, but the plant can adequately feed only the uppermost of these ears to produce seeds. Ear production is constrained by a "source-sink" relationship, wherein the capacity of the source of metabolites (the plant) determines the scale of the "sink" into which they flow (the ears). The number of ears per plant is largely related to available sunlight. Most tropical hybrids can produce two good ears when plant spacing, nutrition, and water are not limiting factors. The flowering stage is a critical one for the plant, during which time stresses due to moisture, heat, nitrogen deficiency, disease injury, and overcrowding can greatly reduce yield.

Corn seeds (kernels) develop almost entirely as a result of cross-pollination by airborne pollen grains. The tassel sheds up to four million pollen grains in a three-day period, and few of these grains live more than two hours. As pollen grains go, corn pollens are relatively large and heavy, and they fall within a few feet of the tassel. They germinate soon after landing on the silk and grow down to fertilize the single egg in each kernel within 24 hours of germination.

Isolation sufficient to avoid cross-pollination between two corn fields requires a separation of about 500 feet, and more if the receiving field is downwind. Isolation can also be achieved by separating the dates of planting by 10 days or more.

The developing ear and kernel

The ear is borne on a wide branch atop a shank bearing 10–15 husks. The husks should elongate to cover the ear fully, leaving 2 inches or more overlap at the tip. Poor tip cover in Hawaii results in excessive damage by insects, birds, and molds. The silks emerge through the tip of the husks, each silk attached to a single kernel. The "baby ears" harvested at silking time (Figure 2.7) are a tasty addition to salads and vegetable dishes, most favored in Asian stir-fry.

The developing ear normally has 12–16 rows of ovules that will grow into kernels. Tropical hybrids usually have about 600 ovules per ear, but they rarely set more than 400 seeds. Greater numbers of kernels will mature at higher elevations or in temperate regions; lower numbers occur under short winter days with low incident light.

Poor seed set can have several causes in Hawaii. Strong, drying trade winds can literally blow pollen away, creating exposed ears with a few, widely-scattered kernels. Silk emergence, which begins at the base of the ear and progresses to the tip, can be delayed greatly on plants that are under drought or nutrient stress. This can lead to poor pollination, with only the kernels at the tip being filled. If initial pollination is adequate but later development is under stress, the ear tip will be poorly filled. This also occurs if light is very low during early kernel development, as in overcrowded fields or during rainy winter periods. Also, temperate hybrids often lose most of their seeds to earworms in Hawaii.

The cob elongates to full length within a week of pollination, and the kernels become obviously swollen at two weeks. The "roasting-ear" stage for field and vegetable corns is about 18 days after pollination, when the kernel splits if punctured with a thumbnail. Supersweet corns continue to be palatable to about 22 days. At this time, field corn is at the "late soft dough" stage, and kernels bubble grudgingly in a puncture test. Field corn kernels at this stage have high levels of starch, a full-sized embryo, and the ability to germinate after drying.

Seed dry weight increases almost linearly with time, an increase largely due to starch synthesis. Dry matter accumulation stops around 40 days after pollination. This stage of physiological maturity is later at lower temperatures, since dry matter accumulation is directly proportional to temperatures between 65 and 85°F. Moisture loss continues for another three weeks or so. Inbred field corn lines typically enlarge at a rate of 7–8 milligrams per kernel per day at 75°F in Hawaii, slowing to 4–5 mg in winter.

The physiologically mature corn seed contains about 35 percent moisture and has a glossy appearance and full color. Most hybrids show a black layer at the base of the split kernel by this stage. From this time on, maturation is solely a function of moisture loss. Moisture content of the kernel drops constantly with time from about sweet-corn stage. It continues after physiological maturity, with a daily loss of about 1 percent of grain moisture. Because we do not have the advantage of frost-kill in Hawaii, corn plants may remain fully green when the ears are at 20 percent moisture. However, corn plants

Figure 2.8 Some of the many mutant forms of corn seeds (top to bottom: shrunken, variegated, dotted, red).

here normally are brown and dry by this stage due to leaf and stalk diseases, notably fusarium and rust. The stages for silage and grain harvest are discussed in Chapter 9.

The mutants of corn

Corn is a favored plant for genetic studies, and a great many of its genes have been described. The Maize Genetics Cooperative maintains an extraordinary collection of genetic markers in the maize genome (see *References*). These include mutant genes that affect the appearance of the plant and kernel, mutants affecting enzymes, and a rapidly increasing number of molecular markers that represent DNA sequences rather than entire genes. Most of these mutants are described and often pictured in the website of the Maize Genetics Center ("Maize DB") at the University of Missouri, *www.agron.missouri.edu*, with photos of many mutants under "images." Seeds of most mutants can be obtained from the Maize Genetics Co-op at the University of Illinois, under the website *www.ag.uiuc.edu/maize*.

Variants familiar to the student of corn seeds include blue corn, dotted and variegated kernels, and shrunken or shriveled kernels (Figure 2.8). Dwarf corn, blue corn, purple plant, tasselseed corn, corngrass, and "lazy corn" mutants that lie flat on the ground are among the interesting single-gene mutants (Figure 2.9). They can be very useful for class demonstrations of genetic ratios and variation. In Hawaii, about 120 of these visible mutant genes of corn have been transferred by backcrossing six generations into a vigorous, disease-tolerant tropical inbred, Hawaii 27. Hi27 originated from a Cuban flint corn and was developed initially in India as line CM104. These mutants are available from the Hawaii Foundation Seed Facility for research and educational uses.

Figure 2.9. Single-gene mutants that drastically change the look of corn plants (continued on next page).

Nana (na2), a gross dwarf.

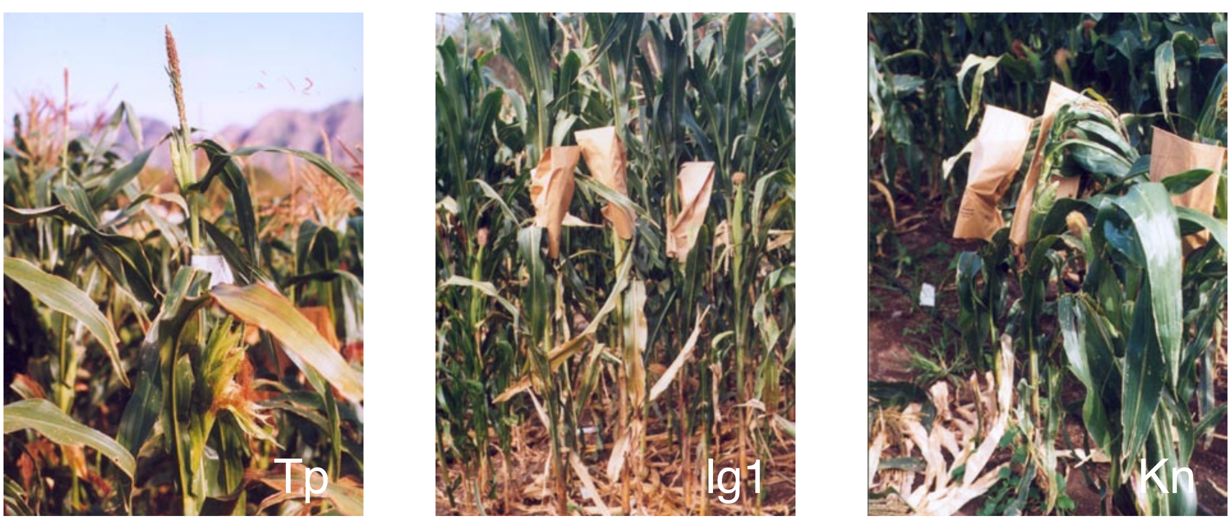
Dwarf (d), a semi-dwarf.

Lazy (la), a corn that grows prostrate.

Figure 2.9 (continued). Single-gene mutants that drastically change the look of corn plants.

Old Gold (Og), striped leaves; tunicate (Tu) ear, covered kernels; corngrass (Cg), grassy leaves and ears.

Multiple-cob ear, gene unknown (photo by R. Boom); tasselseed (ts2), seeds in the tassel; ragged (Rg), cut leaves.



Teopod (Tp) tassel, a single unbranched spike; liguleless (lg), erect, thin leaves; knotted (Kn), cancerous

Chapter 3

Hybrids and Varieties

Good seed doesn't cost, it pays

No amount of good management makes up for poor seed. As one seed dealer put it, "good seed doesn't cost, it pays." In corn, "good seed" equates to good *hybrid* seed, the result of crossing inbreds that have been selected carefully through eight or more generations of breeding.

Choosing the best hybrids to grow in Hawaii is particularly challenging, since none are produced outside of the UH College of Tropical Agriculture and Human Resources corn breeding program, which operates on a tight budget. Even the most superior hybrids from the U.S. Corn Belt perform poorly in the tropics. For example, B73 x Mo17 is a highly successful American hybrid that at one time occupied a third of the world's corn acreage. However, its tropical yields are very low without excessive use of fungicides and insecticides.

Outstanding commercial temperate hybrids of sweet and supersweet corns often fail to produce ears during Hawaii's winters because of the short daylength and problems with diseases like fusarium, virus, rust, and blight. The typical effect of winter's diseases on temperate sweet corns compared to Hawaii-bred sweet corns is illustrated in Figure 3.1.

Maize mosaic virus, common rust, fusarium rots, and earworms lead the list of problems in Hawaii (see Chapter 8). Genetic resistance is available but is almost exclusively in tropically-bred hybrids, notably those from the University of Hawaii. Companies like duPont (Pioneer Hi-Bred), Advanta (Garst, Pacific Seeds), Monsanto (DeKalb, Holden's), Syngenta (Novartis, Northrup-King, and Ciba Seeds), Mycogen (Dow, Cargill), and Agroceres of Brazil also breed corn adapted in the tropics. Major advances have also been made in developing hybrids in Africa by the International Insti-

Figure 3.1. Winter corn production in Hawaii; U.S. Mainland sweet corn in foreground; tropical corn in background.

> Temperate hybrids generally are not grown commercially anywhere in the tropics. Their biggest problems include
> - Diseases—blights, rusts, seedling-rots, ear-rots, viruses
> - Insect pests—earworms, armyworms, borers, aphids
> - Tropical stresses—short days, low light, hot nights, winds, and rains

tute for Tropical Agriculture (IITA); in Southeast Asia by breeders in the Philippines, Australia, and Thailand; and in Latin America by breeders at the International Center for Maize and Wheat Research (CIMMYT). U.S. quarantine laws essentially prevent entry of most of this seed into Hawaii except following increase of seeds in greenhouses by agencies such as the Hawaii Foundation Seed Facility.

Varieties and hybrids

Varieties

Corn seeds come to growers in two forms: varieties and hybrids. Varieties are naturally open-pollinated by winds in a corn field. It is possible to self-pollinate corn by applying pollen from a tassel onto silks of the same plant. But in the field, most pollen grains land on silks of other plants, leading to cross-pollination of more than 95 percent of the seed.

Open-pollinated varieties are less uniform than hybrids. They often show diversity in maturity, plant and ear height, and ear and kernel size. Their variation in maturity can be a problem to a commercial sweet corn grower but an advantage to the backyard grower. Uniformity is generally less important for silage production than for grain and less important for grain corns than for sweet or supersweet corns.

Open-pollinated varieties have a major advantage in that a grower can save and use the seed. Growers who wish to do so, however, should take care to maintain large populations for seed increase. If too few ears are selected (e.g., less than 50), inbreeding depression and loss of yield will occur.

Hybrids

When two selected inbred lines of high uniformity are crossed, their hybrids can combine vigor with uniformity. Seeds that are saved from hybrid plants will produce corn that is highly variable and lower in yield. Hybrids are available in several versions, of which the major ones are listed below with hypothetical examples:

Abbre-viation	Type	Example
SX	Singlecross	A female x B male
SX-M	Modified singlecross	(A1 x A2) female x B male
3X	3-way cross	(A x B) female x C male

Inbreds are the parent lines for hybrids. They are pure lines (relatively homozygous) derived by a combination of self-pollination and sister-brother mating. They are usually very uniform, but small in stature and ear size.

Figure 3.2. A vigorous single cross between its two parent inbreds, with former Waimanalo Research Station manager Herbert Waki.

Singlecross hybrids (SX) result from crosses of two inbred parents (Figure 3.2). The vigor lost upon inbreeding is restored and uniformity is preserved by the hybrid. Singlecrosses that are grown under uniformly good management create an impressive stand that is a delight to behold, and they dominate production in temperate regions such as the continental USA. Singlecrosses are expensive to produce because the farmers' seed must be harvested from an inbred which often has small ears and seeds. In supersweet hybrids, the singlecrosses have tiny seeds and poor germination vigor.

Modified singlecross hybrids (SX-M) can be created by breeders, although with difficulty, to reduce seed production costs. An example would be (A1 x A2) x B, where A1 and A2 are closely related inbreds from the same parents. The farmers' seed is then produced on ears of the (A1 x A2) hybrid. These ears yield better and have larger seeds than the inbred. Modified singlecrosses are preferred where the inbred seeds are small and germinate poorly, such as in supersweets.

Three-way (3X) hybrids involve three inbred parents and are more variable than singlecrosses. They are much cheaper to produce, however, since the farmers' seed is derived from ears of a hybrid (e.g., A x B above). Such seeds are larger but normally produce no better plants than a good singlecross. Singlecross seed production

Table 3.1. Some commercially available Hawaii-bred hybrids and open-pollinated varieties.

Name	Type	Gene	Color Seed	Color Plant
Hawaiian Supersweet				
# 9	OP	bt	Y	Green
#10	3X	bt	Y	Green
#10 Silver	3X	bt	W	Green
Kalakoa Supersweet	OP	bt	Y	Purple
Waimanalo Supersweet	SX	bt	Y	Green
Sarah No. 1	SX	bt	Y	Green
H1035 (field corn)	SX	+	Y	Green
H1039 (silage corn)	3X	+	Y	Reddish
H1055 (silage corn)	3X	+	Y	Reddish

Y = yellow kernels, W = white kernels, bt = brittle 1.

requires only one season or cycle, while 3X hybrids take two. An historical class of hybrids is the doublecross or 4X hybrids, e.g., (A x B) x (C x D), which generally are no longer available to farmers.

Three major classifications of corn seed are breeders' seed, foundation seed, and certified seed.

Breeders' seeds are maintained under the plant breeder's supervision. They represent the product of the breeder's art, and are inbreds or OP varieties. They are used to produce the foundation seeds which are often handled by foundation seed agencies. In Hawaii, such seeds are produced and distributed by the Hawaii Foundation Seed Facility (HFSF) at the UH-CTAHR Waimanalo Research Station.

Foundation seeds are the parent seeds for hybrids. Marketed hybrid seeds are certified as to purity and germination by certifying agencies. In Hawaii, the Hawaii Department of Agriculture certifies seeds. U.S. grading standards for field corn include five classes. Number 1 corn has a test weight of 56 lb/bushel and < 3 percent damaged kernels, while No. 2 corn weighs 54 lb/bushel and has < 5 percent damage.

Recommended hybrids for Hawaii

No list of recommended corn hybrids remains current for more than a few years, due to the advances made by breeders. Some growers still like to plant great old hybrids like Golden Cross Bantam (1936) or varieties like Country Gentleman (ca. 1880), but this often reflects sentimentality and not the reality of the competition. The 50-year old hybrids Silver Queen and Jubilee are still favored by many growers. The serious grower should be prepared to test competitive materials on a regular basis.

Breeding of corn varieties in Hawaii was started in the 1940s by Dr. Albert Mangelsdorf of the Hawaiian Sugar Planter's Association. In the late 1950s, Drs. Takumi Izuno and Donald McGuire started breeding at the University of Hawaii, a program assumed by this author in 1962. Almost 2000 hybrids and varieties have emerged from the author's breeding and yield tests as superior in performance in Hawaii. These are maintained by the Hawaii Foundation Seed Facility (HFSF), founded in 1980 by the author.

Some commercially available hybrids and varieties bred in Hawaii are listed in Table 3.1. Some of these releases have shown durability, including 'Hawaiian Supersweet #9', an open-pollinated variety first released in 1977 and now grown internationally. A large group of "also-rans" back up the releases that have been adopted for commercial production. They are often of equal competence, but their numbers exceed the demands of Hawaii's fledgling corn industry.

Yield-testing of commercially available hybrids and varieties is a responsibility of all serious growers. States like Hawaii no longer finance statewide yield trials of corn hybrids at a level consistent with growers' interests. Corn yields vary significantly from month to month in Hawaii, with the summer highs generally double the winter lows, as seen in Figure 1.4. Some hybrids are not adapted to the winter months but yield well in the summer. It is thus necessary to test hybrids throughout the year. The grower should look for fast emergence, seedling vigor, good root development ("hard to pull out"), standability, low tillering, and high resistance to diseases and insects.

In the USA, new corn hybrids require at least 15 years in development but usually last less than 15 years after release. Growers should be constantly expecting and testing new hybrids in comparison to those being grown. Test plots must include both the new hybrids and the standard commercial ones as "checks," planted at the same time and handled identically.

A recent book titled *Tropical Maize; Improvement and Cultivation,* by R. Paliwal, uniquely addresses the development of varieties and hybrids for low-input corn production in the tropics, reflecting its author's extensive experience with corn in developing countries.

Major types of field and sweet corn

Corn offers growers many options, which are classified most simply into three categories: field corn, sweet corn, and popcorn. The appearance of a corn kernel largely reflects the genotype of the endosperm, the tissue that stores starch. Endosperm-mutant types of corn with commercial use are summarized in Table 3.2. Many of these reduce starchiness and improve suitability as a green vegetable, while others produce unusual starches that are used in plastics and other products.

Field corn

This "wild type" of corn is familiar to all growers, with heavy, starch-filled kernels. The kernel textures can range from very soft to very hard. In this group we find

- Flint corn—hard endosperm, translucent, deep color
- Dent corn—dented cap due to soft internal starch, opaque, intermediate in color
- Floury corn—soft starch, high opacity, low color.

Most tropical corns are flints or denty-flints, which have a tolerance of seed insects and rotting diseases that is much greater than the softer dents. Soft, floury kernels are especially susceptible to seed weevils, which thrive on the improved protein found in the floury mutants, *opaque-2* and *floury-2*. These floury mutant types could be considered for production in Hawaii, as they are superbly nutritious feed for nonruminant animals (pigs, horses) and birds (poultry, pigeons). Hard-endosperm floury corns known as QPM (quality protein maize) have been bred for the tropics at the International Center for Maize and Wheat Research. Normally these mutants involve some loss of yield.

Much interest has been shown in recent years in high-oil corns, and hybrids made under a patented procedure are available for temperate conditions. Corn normally has 4–5 percent oils and fats. These levels can be increased greatly by breeding for a small endosperm, since oils are largely in the embryo. However, seed weight is thus decreased, as is yield per acre. Under the patented process, yields remain high, with oil percentages up 50 percent or more. Feeding these "high-oil" hybrids in animal diets reduces the need for soybean supplementation.

Hawaii's field corn breeding has focussed on tropically adapted flinty and semi-flint kernels. This has led to the release and distribution of more than a hundred inbred lines. These in turn have been combined to make over a thousand hybrids, of which H1035 (a cross of Hi26 with Philippine inbred Pi23) is a typical high-yielder (Table 3.1). Many field corn composites and synthetics have also been produced in Hawaii.

Table 3.2 Endosperm types of commercially available corns.

Gene	Endosperm type	Type of corn, products
su	sugary	sweet, vegetable
sh2	shrunken-2	supersweet, vegetable
bt	brittle-1	supersweet, vegetable
se	sugary enhancer	very sweet, vegetable
wx	waxy	glutinous, tapioca
ae	amylose-extender	high-amylose, plastics
o2	opaque-2	high-lysine, feeds
y	white	white kernel, chips and tortillas

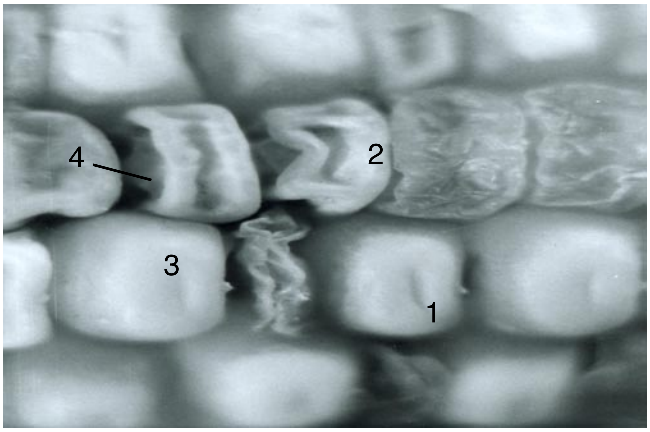
Sweets and supersweets

Vegetable corns are available to growers in many versions, of which four types predominate:

- Supersweet—two widely used genotypes, *shrunken-2* and *brittle-1*, each have opaque, shrivelled kernels low in starch
- Sweet—the historic type (e.g., Golden Bantam), based on the gene *sugary-1*, with a translucent, shrivelled kernel
- Enhanced sweet—*sugary-1* corns with added gene *sugary-enhancer.*
- Glutinous—*waxy-1* corns that are similar to mochi rice.

The sweet corns (with gene *sugary-1)* and super-sweet corns (with genes such as *brittle-1* and *shrunken-2*) can segregate on the same ear of field (or pop) corns, as seen in Figure 3.3. Common sweet corn loses quality too rapidly in the tropics to make it desirable, while enhanced sweets have proven too susceptible to kernel rots to be grown here. Breeding at UH has included all of these genotypes and resulted in the release of 17 composites or synthetics. Among these breeders' varieties, Hi bt Comps 3 and 6 are most suitable for Hawaii's growers. Supersweet hybrids based on *brittle-1* have come to dominate breeding and production in Hawaii. Many Asians prefer corn with the *waxy-1* gene that confers a glutinous, chewy texture like mochi rice. Glutinous corn must be cooked longer for use as a vegetable, and Hawaii's market appears to be too small to encourage production. Some commonly grown hybrids are listed in Table 3.1.

Figure 3.3. Kernels of sugary-1 (sweet corn, wrinkled; 1), shrunken-2 (supersweet, collapsed; 2), normal or wild-type (3) and the double mutant (4) segregate on one ear



Seed production, storage, and viability

The U.S. seed industry produces and markets hybrid seeds with exceptional efficiency and economy (Chapter 10). Good seeds represent one of the best investments the grower makes—seeds for sweet corn should amount to less than 15 percent of a grower's input costs, and for field corns less than 5 percent. In some instances a grower in Hawaii or the tropics may wish to produce his or her own seeds. Seeds of a variety like 'Hawaiian Supersweet #9' (Table 3.1) can be produced economically as part of normal operations. A small field should be designated for seeds, and volunteer corn should be carefully rogued out. Seed yields are about 1 ton/A (~6 million seeds) for vegetable corns and 2 tons/A (also ~6 million seeds) for field corns.

Parent seeds to be planted should be of the best available foundation seedstock, pure as to origin. The field should be carefully isolated in space ($^1/_2$ mile) or time (3 weeks) from other types of corn, so that it flowers at a time when no other corn is flowering nearby. Fields should be inspected at least twice to cull off-type or diseased plants.

Hybrid seed production of three-way crosses can also be economical on Hawaii's farms. Six rows of the female hybrid should be planted for each two rows of male inbred, or rows in the ratio of 3:1:3:1, etc. In an eight-row planter, use the outermost planter boxes for the male parent and the six inner boxes for the female. Careful rogueing of off-type and volunteer plants is important.

As the emerging tassels first appear, all of the rows to be used as female must be detassled. This is best done very soon after emergence from the "boot." It is essential that it be done before any anthers open on the tassels. The best seeds will be obtained if matured in the driest seasons or locations. Only the female can be harvested for hybrid seed. Some hybrids can be created from a female parent that is made to be male-sterile, and detassling is then not necessary.

Seed storage must be done under dry, insect-free, rodent-free conditions. The harvested seeds should be dried down to at most 13 percent moisture for field corns and 11 percent for vegetable corns. Seed weevils (Chapter 8) will ruin seeds within weeks. Freezing is a convenient non-chemical method of eliminating them from small seedlots. Diatomaceous earth can be added to minimize weevil damage, 3–5 ounces per 35-pound bag. Fungicide treatment normally is unnecessary if stored seeds are well dried, but treatment may be recommended to minimize seedling loss to fungus in the field.

Field corn seeds stored in an air-conditioned room at 70°F and 50 percent relative humidity will retain viability for two to five years. Seeds in cold, dry storage (50°F, 50% RH) keep viable more than a decade. Seeds stored dry in a freezer will retain viability for decades. Under all of these conditions, supersweet seeds can be expected to lose viability much faster than those of field corns. Small seedlots are best kept in a tightly covered jar, possibly with added desiccant. Plastic bags can only be used if seeds are very dry. Otherwise, paper or plastic containers are suitable.

Seed viability is tested most easily in Hawaii by planting seeds in moist garden soil. Alternatively, a rolled, dampened towel works well. A paper towel can also be folded in half and moistened, and rolled up after placing the seeds about 1 inch from the long edge. It may be useful to treat seeds with a weak solution (5 percent) of household bleach to reduce fungal infection. The towel cylinder is placed upright in a container holding an inch or two of water. Seeds that have weevil damage or that have been in prolonged storage are preferably tested for germination under field conditions so that planting rates can be adjusted accordingly.

Maturity

In temperate regions, corn hybrids must be chosen very carefully for maturity, with the limitation imposed by the length of the frost-free growing season. Days to maturity is much less important in the tropics, where maturity is a linear function of average daily temperature (Fig. 3.4).

Figure 3.4. Days to flowering in relation to average temperature in Hawaii.

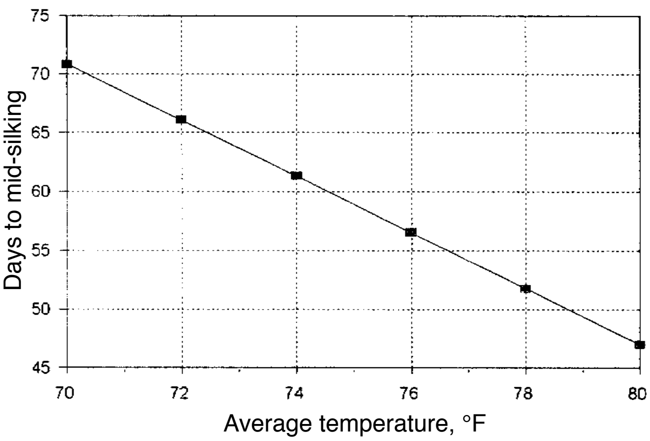


Figure 3.5. Teosinte is a strange-looking tropical grass, but it crosses easily with corn (with author).

Time of flowering in Hawaii can range from 45 to 75 days after planting, depending on the hybrid and the time of year, although the extremes are rare and associated with high elevations or unusually hot areas.

Full-season hybrids that are late in maturity usually maximize yields in the tropics. However, they require more water than early hybrids and may not yield as well on a yield-per-day basis. Such hybrids commonly excel in silage yields but have lower grain-to-stover ratios. Earlier-maturing hybrids use less irrigation water and generally have better grain-to-stover ratios. For Hawaii's lowlands, the following maturities are approximated for adapted hybrids:

Three measures of time to maturity in corn

Days to Maturity	GDD heat units	FAO maturity units
95	2450	500
105	2650	600–700
115	2850	800–900
125	3050	1000

Days to maturity is based on days from planting to physiological maturity, when there is no further increase in grain dry matter. This would be at about 32 percent moisture, and can often be identified by the appearance of a black layer at the base of the kernel. The black layer is best viewed by slicing kernels in half with a knife. Seed growers producing U.S. mainland corns tend to harvest at this early stage and then use forced-air drying to accelerate turn-around time and reduce seed damage by field insects and rots.

The USA heat-unit system is referred to as growing degree days (GDD) from planting to the appearance of the black layer. GDD values are obtained by multiplying the number of days to black layer by the difference between the average monthly temperature and 50°F (below which corn does not grow). For example, a 100-day hybrid growing in the summer at Waimanalo (average 77°F) will have 2700 GDD ($100 \times [77 - 50]$). In the winter (average 72°F), this hybrid should mature in 123 days ($700 \times 1/[72 - 50]$). The FAO (Food and Agriculture Organization of the United Nations) classification is used outside the USA.

Adaptability and yield tests

"Adaptability" has broad connotations. Most temperate hybrids are not adapted in the tropics, and vice versa. Hawaii's growers should first ask whether hybrids have been bred with adequate resistance to diseases and pests for which control measures are unavailable, ineffective, or uneconomic. Most Hawaii-bred hybrids (Table 3.1) can be grown pesticide-free. In contrast, seed producers growing Mainland inbreds in Hawaii must treat the seeds, treat the soil, and spray the plants regularly with both fungicide and insecticide—often costly operations.

A strip test of yield provides practical comparisons for growers. Such comparisons must be made in different seasons of the year. They would consist of strips of two or more rows of each hybrid or variety through the field (e.g., a strip of 200 ft or more). Notes taken during the growing season on incidence of diseases, pests, and lodging are as important as yield itself. A convenient way to estimate field corn yield is to harvest a $^{1}/_{100}$-acre sample areas (e.g., 174 ft of row in a field with 30-inch rows). Shelled grain can be estimated using 80 percent shelling percentage. If grain has not been fully field-dried, or if differences in maturity are great, moisture percentages (MP) of the grain should be calculated. Grain yields are normally presented as adjusted to 15.5 percent MP by the following formula:

$$\text{yield in tons/acre (T/A)} = \text{sample yield (in pounds)} \times 0.8 \times (100 - \text{MP}) \times 1/20 \times 1/84.5$$

Upon simplifying, this reduces to:

$$\text{yield in T/A} = \text{sample yield} \times (100 - \text{MP}) \times 1/2138$$

These yields can be converted from T/A to bushels per acre by multiplying by 36.4.

Chapter 4

Land Preparation and Planting

Seedbed preparation

Corn plants produce 100,000 miles of roots and root hairs per acre. They depend on good seedbed preparation, important also for soil quality and weed management. However, overworking soils with heavy equipment can be harmful as well as unnecessary. No-till or low-tillage practices are increasingly popular in temperate agriculture. Temperate soils have the added benefit of the annual pulverization by winter freeze-and-thaw cycles. Soils in the tropics lack such "climate tillage" and are often subjected to year-round cropping. Compared to temperate-zone soils, much less is known about low-till management of tropical soils, but they are equally vulnerable to damage by compaction. In Hawaii there are examples of former roadways plowed over 30 years ago that are still revealed as strips of poor crop growth across agricultural fields.

Tilth

Good tilth is the key to a good seedbed. It can be seen immediately in the uniformly vigorous emergence of 10-day-old seedlings in experimental fields at the International Maize and Wheat Center (CIMMYT), shown in Figure 4.1. Good tilth implies good aeration, good water retention without undue runoff or percolation, and a loose, granular structure with plant residues thoroughly mixed in. Tillage methods (plowing, chiseling, disking, harrowing, tiller-cultivating) aim to improve tilth by loosening, turning, and mixing the soil, and by burying most or all plant residues prior to or during planting.

It is important to distinguish between the seedbed and rootbed in a corn field. The seedbed comprises 2 inches of soil around the seed. It must be thoroughly cultivated and firmed down enough to convey mois-

Figure 4.1. Good tilth and precision planting ensure uniform emergence and high yields at CIMMYT in Texcoco,

ture evenly to the kernel. The rootbed is the interrow space, normally more than 2 feet wide, that will not be root-filled for 5–7 weeks after planting. It need not be prepared beyond plowing, but it should be kept loose and well aerated.

Fertilizer application in relation to tillage is discussed in Chapter 5. Herbicides, crop rotation practices, and plowing in legume green manure crops are subjects returned to later in Chapter 7.

Plowing

The two immediate objectives of plowing are to incorporate plant residues or weeds and loosen compacted soil. Compaction varies greatly in Hawaii's diverse soils, which are all young by temperate-zone standards. Clayey soils compact badly under heavy equipment when wet, and some of them may crack open when dry. Granulation of such soils must rely on root growth and organic matter plowed under when soil moisture is just right.

North American corn growers have revolutionized seedbed preparation, planting, and harvest techniques. While this has led to savings in labor and time, it comes at the expense of major investments in large equipment. One cannot fairly compare corn production in Hawaii with Iowa, which grows corn on an area six times the size of our entire state. Nor can one easily transfer to Hawaii or elsewhere in the tropics production practices based on U.S. mainland soils, climate, practices, or equipment. For just one example, farm equipment maintenance and repair is much more costly in Hawaii—if indeed it can be done at all.

For land preparation, a wide array of equipment is available, often fitted to specific soils and seasonal conditions. Farm equipment dealers are the best source of information on this subject. Plowing equipment includes the classic moldboard plow and the disk, chisel, lister, and rotary tillers. Heavy soils and lava lands or coral mixtures require plowing or chiseling. Hawaii's more granular lateritic soils can be adequately prepared as a seedbed with disking alone. Disking works best if the soil is just moist enough that it fractures well when turned over. Where there is a heavy sod cover, disking alone is less effective than disking after plowing, and a result of disking alone will be less effective action of pre-emergence herbicides and subsequent return of the sod problem.

The moldboard plow cuts, lifts, and turns a furrow better than any other tool, especially on tough soil or with heavy plant residue cover. Plowing to at least 8 inches is generally sufficient. As a general rule, the depth of moldboard plowing should not exceed half the moldboard width.

The lister or middlebreaker turns soil away in opposite directions to create a trench in which seeds are to be planted. While this may be useful in arid areas, it is generally undesirable on irrigated, clayey soils, because it concentrates water in the seedling development zone.

Large rotary tillers (rotovators) can prepare a seedbed in one operation and are convenient for small-farm operations. They are relatively slow, and the rootbed soil area can easily be over-worked and lose tilth.

The coulter is a fluted disk that precedes the planter, pulverizing only the soil directly around the seed. Some pre-emergence herbicides, such as Eradicane®, function best following rotovation.

Subsoiling is the process of chiseling or deep plowing below the level of the normal plowing operation. It has long been claimed to be of greater value than has been proven; in fact, there is relatively little evidence of its worth in Hawaii. Deep chiseling can break up low-porosity subsurface pans that occur naturally in some soils, or that form as a result of plowing. Hardpans are rare in Hawaii's soils. It is best to concentrate tillage efforts on creating the conditions favoring moisture and nutrient availability in the precious upper foot of soil that will host nearly all of the corn plant's root system. If chiseling is necessary for this layer, conditions are pretty tough.

Secondary tillage

Secondary tillage includes all soil preparation after plowing and before planting. It aids in incorporating corn stalk and weed residues and can improve soil aeration and tilth. Leveling, weed removal, incorporation of herbicide and fertilizer, clod-busting, and preparation of the seedbed strips all may warrant some secondary tillage. The narrow seedbed is best tilled by attachments to the planter itself.

Disks are the standard tools for secondary tillage. Cross-tandem disks have two rows of disks arranged in tandem but at an angle of about 30° to each other. They penetrate well to 4–6 inches and can intermix pre-emergence herbicides thoroughly. Disks can be used immediately following a plow because they ride through crop residues and sod with relative ease. Spring-toothed harrows and field cultivators are dear to the temperate-zone farmer, but they are rarely suitable in Hawaii's soils for year-round corn operations, where freshly plowed soil is immediately given secondary tillage.

No tillage?

No-till and low-till farming have made great advances in recent years and gained some strong supporters. The aim is to reduce labor, energy use, and trips over the field (saving time and minimizing compaction) during soil preparation. Herbicides are used to provide weed control, while tillage is confined to the narrow seedbeds. In the southern USA, much of the land that is double-cropped to corn is planted with no or minimum tillage.

Two compelling problems make the no-till approach uneconomical for corn in Hawaii. Where corn grows continuously through the year, the presence of propagules of diseases like blight, smut, and fusarium rot on plant residues is a major disadvantage. This is partially overcome by incorporating the residues with tillage. A second problem is posed by grassy perennial weeds—including sedges, perennial grasses, and herbs—for which elimination is virtually impossible without soil incorporation of herbicides (see Chapter 7).

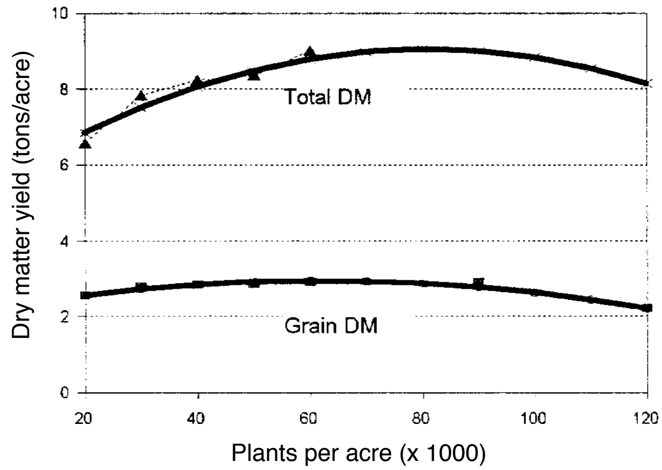
Plant density

Planting corn with a dibble-stick was an activity done with great reverence by Indians like the ancient Maya. The planting season was marked by a two-week period of abstinence and quiet anticipation. It would have astonished them to watch a modern 16-row corn planter cultivate and place the corn seed and fertilizer, herbicide, and insecticide at a rate of 60 acres in a 10-hour day—over a million seeds! Planting time still requires the best effort of the farmer, the best performance of the farm's equipment, and perhaps a bit of reverence at the act of germination and growth.

Optimal plant density for field or silage corn should maximize the weight of harvested corn kernels per acre, not the length of the ears. The huge dried corn ears often displayed in an office or county fair are attractive but misleading. Such showcase specimen ears result from planting rates that are too low, producing poor yields of grain per acre. Corn plant population densities doubled in the USA between 1960 and 2000 to an average of over 23,000 plants per acre. Rows are closer—no longer does a mule's hips determine the width of corn rows. A row spacing of 30 inches is still common, but 24 inch spacing or paired rows are increasingly common. Increasing fertilizer use makes it possible to nurture more plants per acre.

Silage and sweet corns can be planted effectively at higher populations than grain corn. Modern stiff-stalk hybrids can be planted thickly without the hazards of lodging or barren stalks. Weed management is enhanced by high populations that achieve early canopy closure. Hybrids that are potentially prolific (multiple-eared) ensure few earless or barren plants. Such prolificacy characterizes all UH corn hybrids.

Figure 4.2. Corn yield response to increasing plant



Research in Hawaii showed that both grain and silage yields can be increased by choosing higher planting densities (Fig. 4.2, after Chung, Brewbaker, and Ritter 1982; the solid lines represent fitted curves derived from the actual data [dotted lines]). However, lodging can increase greatly at very high densities, making them unacceptable for grain corn.

Planting densities recommended for vigorous summer growth in Hawaii

Corn type	Seeds/acre	Plants/acre
Field corn for grain	28,000	25,000
Field corn for silage	40,000	35,000
Supersweet corn	35,000	30,000

These planting densities are recommended assuming that fields are irrigated, weed control is excellent, N is applied at 150 lb/acre or more, and no more than 15 percent loss of seedlings occurs. In areas without irrigation, lower plant populations are advisable. In Hawaii's low-light winters on Windward sides of the islands, plants will be small in stature, and it is tempting to increase population density. No data are available, however, to support the advantage of this practice.

Corn grain yields changed little in our studies as populations were increased over a surprisingly large range, so long as moisture did not become limiting

(Fig. 4.2). The actual weight of grain per acre in trials ranging from 20,000 to 90,000 plants per acre have on occasion been negligibly different. At high populations the plants have weaker stalks with more lodging. This can be serious if the crop is carried through to dry grain. More seedling mortality, more barren plants (without ear), delayed flowering, and smaller ears—all ensue from high planting rates.

Silage ("green-chop") production improved at higher plant populations, increasing with population to 30,000 plants per acre and above (Fig. 4.2). The higher yields were offset by the added seed cost, the reduction of grain-to-stover ratio, lower feed quality, and, possibly, loss of total digestible nutrients at high plant densities. An optimal density for silage is probably about 35,000 plants per acre.

Because most tropical corn hybrids are highly prolific, lower populations often yield as well as high ones. A low population requires less seed and forms stronger stalks and larger plants and ears. Hybrids differ in the populations at which they fare best. Most commercial corn hybrids are marketed with a suggested optimal planting density. Each grower must plant a population that fits the farm's soil and climate conditions, management practices, and fertilizer regime—and growers should be prepared to experiment.

Planters and planting depth

A common source of poor stands is overly deep placement of seeds. Corn does not germinate well when planted too deeply, especially if the soil is dense or cold. Seeds planted at $1\frac{1}{2}$–2 inches depth will be well enough covered with soil to be positioned in the moisture zone. In very light, friable (easily crumbling) soils, the depth can be increased, with 3 inches as a practical maximum. Bird damage to seedlings can occur and is offset slightly by deeper planting.

Planter selection has become more challenging as grain planter designs have been revolutionized and multi-row planting has become routine. Early corn planters used revolving planter plates with cells matched to the size of kernels. Seed producers graded seeds to size, and planter plates were chosen carefully to be of the appropriate size for each hybrid.

Table 4.1. Guide to rate of planting of corn seeds per acre.

Harvested population*	Planting rate	Inches between seeds at row spacing: 24-inch	30-inch	36-inch
16,000	18,830	13.9	11.1	9.3
20,000	23,530	11.1	8.9	7.4
24,000	28,240	9.3	7.4	6.2
28,000	32,940	7.9	6.3	5.3
32,000	37,650	6.9	5.6	4.6
36,000	42,350	6.2	4.9	4.1
40,000	47,060	5.6	4.4	3.7

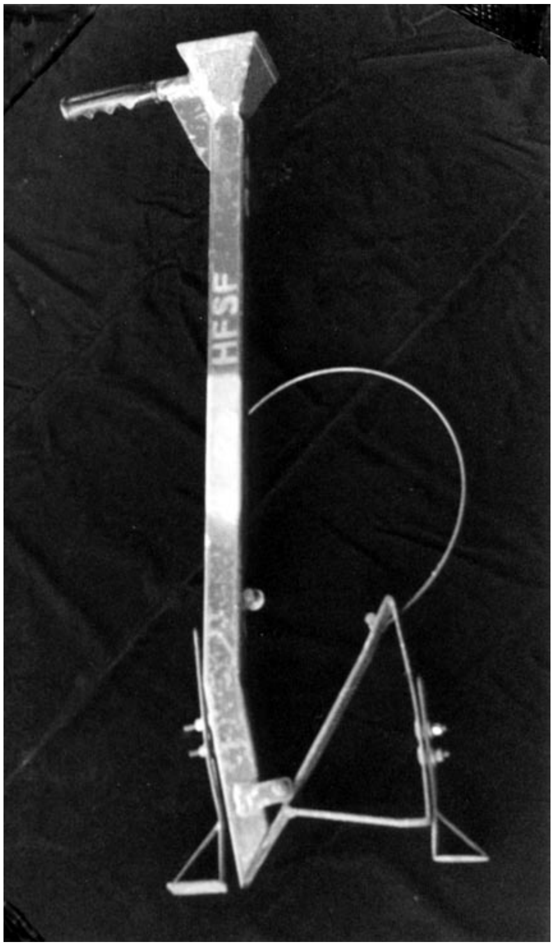
*A 15 percent loss of stand is assumed; more can be expected with

Plateless planters now dominate sales, often designed for 8, 16, or more rows. They have finger-type or vacuum-type seed pick-ups and plant seeds individually without reference to size. This revolution was encouraged by the shift from varieties and double-cross hybrids with large seeds to the small-seeded single-cross hybrids. All new planters feature electronic monitors that use photoelectric sensors to count the seeding rate for each planter and also identify clogged planters.

Regular calibration of a corn planter is advisable unless accurate electronic planter monitors are used. Following the owner's manual, the planter should be set for the correct population. Calibration can be done on a roadway, moving at exactly the speed planned, since changes in speed affect the rate of drop. For 30-inch rows, a distance of 87 feet equals $\frac{1}{200}$ acre. Seeds dropped in this distance can be counted and multiplied by 200 to give seed counts per acre. The relationship between seed spacing and plant population is shown in Table 4.1. Some planters are designed to plant paired rows for silage corn, with 30-inch spacing between the pairs.

The operator of a small farm (or large garden) has a more limited choice of planters, as the technology has followed the trend to large acreage. For the small farm, two- and four-row plate-type planters are still available for three-point tractor hitches. In the large garden, hand-held jabber planters can save planting labor (Fig. 4.3).

Figure 4.3. Corn seed jabber, a major labor-saver for small-scale corn growers.



Chapter 5

Fertilizers

N, P, and K

Hawaii's soils are valuable to corn primarily for their function in keeping the plants upright. They do not hold water or nutrients well, they have little organic matter, they are very poor in base status, and they often are very low in pH and available nutrients. Under these conditions, no fertilizer equals no corn.

The "big three" nutrient elements for corn growth are nitrogen (N), phosphorus (P), and potassium (K). They constitute the major input costs for a corn farmer. These elements derive from soil or fertilizer compounds that contain ammonia ($NH4^+$) or nitrate ($NO3^-$) ions, the phosphate ($PO4^-$) ion, and potash salts containing potassium (K). Fertilizer bags are labeled according to the contents of N, P_2O_5 (phosphoric acid), and K_2O (potash), as in the examples below:

15-15-15 =
15% N, 15% P_2O_5 (or 6.6% P), 15% K_2O (or 12.4% K)

10-30-10 =
10% N, 30% P_2O_5 (or 13.2% P), 10% K_2O (or 8.3% K)

The following discussion will only scratch the surface of the very broad subject of meeting the corn plant's nutritional needs. For a particularly thorough treatment, consult *Modern Corn Production* by Aldrich et al. (see *References*).

Nitrogen (N)

N is the key element for high corn quality and yield. It is taken up and used for plant growth throughout the life of the corn plant. It stimulates vegetative growth, increases the protein content of grain and stover, increases the number and size of ears on a plant, and intensifies green color.

Corn yields increase in responses to increasing N to very high levels of applied N fertilizer, when other factors then become limiting. For example, a linear increase occurs in sweet corn yields in Hawaii with increasing application of N to 200 lb/acre (Fig. 5.1). Residue N from a prior crop such as soybean can substitute for applied N.

A practical level of N for sweet corn is 180 lb per acre per crop in the main growing season, although continued yield increases may be expected at higher application levels. In winter, the level may be reduced. Grain yields also increase linearly with N to about 175 lb/acre but then tend to taper off (Fig. 5.2).

Total plant yields continue to increase at higher levels of N, as the plant enlarges without further increase in grain. Growers who seek to set yield records in the USA must exceed 350 bushels/acre. This feat is only possible with applications of > 250 lb N, > 120 lb P_2O_5, and > 150 lb K_2O, and actual amounts vary with the soil.

Nitrogen occurs in fertilizers as free ammonia, urea, or salts of ammonium or nitrate. Anhydrous ammonia is a liquid when stored in pressurized tanks but turns to a gas when it is delivered to the soil and encounters

Figure 5.1 Sweet corn yield response to applied nitrogen (based on studies by R.L. Fox; yields of husked ears).

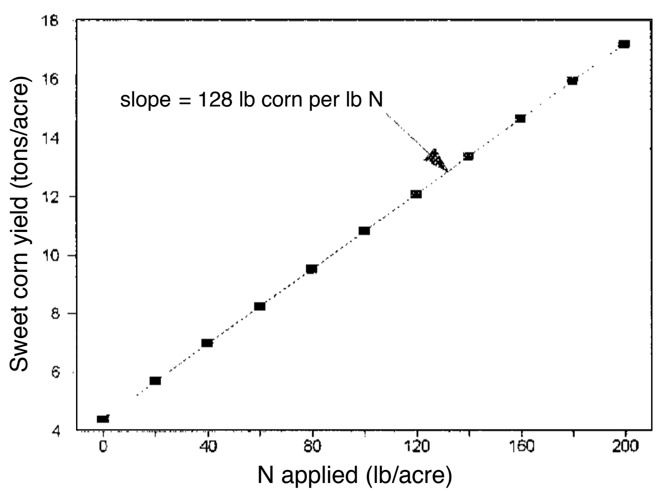


Figure 5.2 Grain yield response to applied nitrogen; based on several published studies.

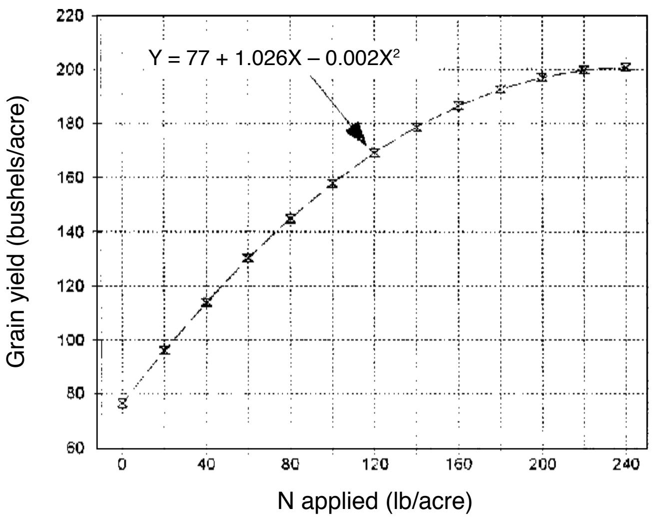
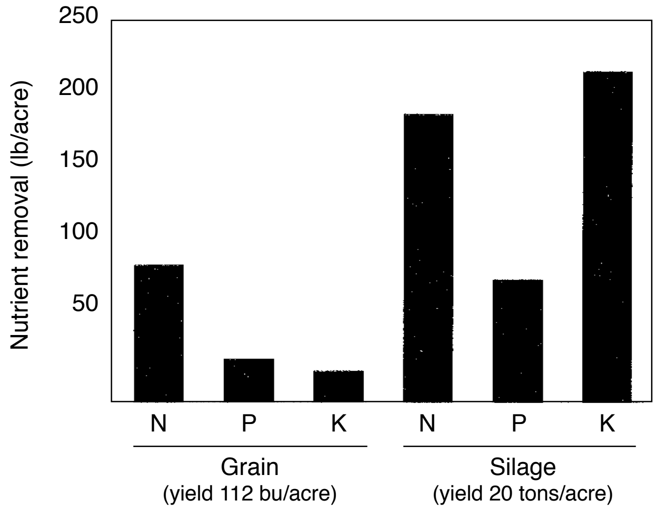


Figure 5.3. Removal of nitrogen, phosphorus, and potassium by corn harvested as grain or silage.



normal atmospheric pressure. On the U.S. mainland it is the most-used form of N.

Most of the fertilizer N applied to soils is converted to nitrates by soil bacteria during the growing season. These nitrates do not persist in the soil for long periods because of leaching and denitrification. The potential for leached nitrate to pollute groundwater is a significant environmental concern and a good reason to apply N fertilizers judiciously and precisely to meet crop needs. For example, N losses from leaching can be reduced by applying the fertilizer in split applications. Denitrification converts soil nitrates to a gaseous form that escapes to the air. It occurs rapidly in warm, moist soils, especially those containing high amounts of organic material. N applications as urea or ammonia salts are preferred for such soils. Improved drainage also reduces N losses from denitrification.

N removal by harvested grain or silage is summarized in Figure 5.3 Harvest of the entire plant removes at least twice the amount of nitrogen as harvest of grain alone, here shown to be about 200 lb per acre.

If N is needed at the rate of 180 lb per acre, 857 lb of ammonium sulfate are required to supply that amount. This is calculated by dividing the amount of N needed (180 lb/acre) by the percentage contained in the material (21%); i.e., 180 divided by 0.21 = 857 lb.

Nitrogen deficiency symptoms include

- light green or yellowish leaves
- a V-shaped pattern of light green or yellowish color on lower leaves
- premature drying along leaf midribs and at the leaf tip
- stunted plants, slow to flower
- short ears, often poorly filled.

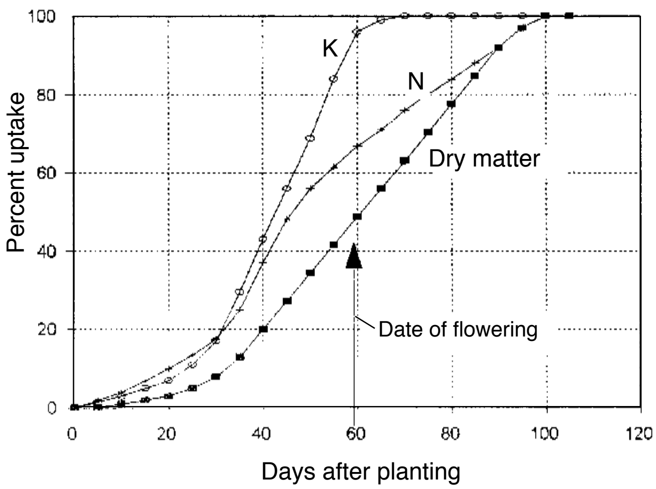
Phosphorus (P)

Phosphorus has two important functions in plant growth: it acts as a building block for cellular compounds, and it aids in energy transfer (as adenosine triphosphate, ATP) to fuel cellular processes. The requirement for P is greatest in young tissues and in those with high metabolic activity. The critical need for P applied as fertilizer is early in plant development, when the root system is too small to forage for soil P. Root uptake of P is aided by symbiosis with mycorrhizal soil fungi, which colonize roots and extend the range of the root system.

Corn accumulates P throughout the growing season, generally in direct relationship to dry matter accumulation. About half of the total P in above-ground tissues of mature corn plants is in the grain (Figure 5.3). When both grain and stover (stalks) are harvested, about 60 percent of the applied P is removed from the field.

Phosphorus mobility is very limited in soils. P movement is greater in sandy than in clay soils. Even in sandy soils, however, P may move less than an inch from the point of placement. P can bind to clay minerals containing iron (Fe) and aluminum (Al), which impedes its uptake by roots. Hawaii's volcanic soils often have high levels of Fe and Al, and P can be held very tightly. Soils thus may have very high P contents but very little P that is readily released into the soil solution to become

Figure 5.4 Uptake of nitrogen and potassium in relation to dry matter during growth of corn.



available to plants.

Heavy applications of P are required when beginning corn production on soils that have the ability to bind P strongly. Only when sufficient P has been added to satisfy the P adsorption capacity will additional P become available for root uptake. Much of the P provided to a corn crop thus is not available until a second crop is grown. On coralline soils or soils limed above pH 6.5, the amount of available P is low. The CTAHR publication *Predicting phosphorus requirements of some Hawaii soils* (Hue et al.; see *References*) provides more information on this subject.

Phosphorus deficiency symptoms include
- purplish leaves
- stunted growth
- delayed flowering
- poorly developed roots
- reduced kernel size and number.

Potassium (K)
Like all grasses, corn takes up potassium in large amounts. When both grain and stover are removed entirely from the field, a 20-ton silage crop removes over 200 lb per acre of potassium (as K_2O). Potassium is essential for vigorous growth, yet it never becomes a part of organic compounds or proteins in the plant. Although K is found in very high amounts in most soils, little is available for plant uptake. Its mobility in soil is much less than that of nitrate, and leaching losses are generally not important except on sandy soils.

K deficiency is unusually rare on corn in Hawaii. However, it is considered wise to add K in an amount at least equal to that removed by the harvested crop. Heavy N fertilization creates a lush vegetation that also requires much K. The grain contains less than one third of the K in the above-ground portion of a mature corn plant (Fig. 5.3). As a result, when corn is harvested only for grain, most of the plant's K is returned to the soil.

Potassium deficiency symptoms include
- yellow to brown discoloration of lower leaves
- scorching of the leaf edges when plants are small
- greater tendency of plants to lodge
- small ears that fail to fill out fully at the tip.

Rates of N, P, and K uptake
The rates of N and K uptake in corn are roughly proportional to the accumulation of dry matter (Fig. 5.4). P uptake, not shown in the figure, closely follows dry matter accumulation.

Nitrogen is taken up disproportionately before flowering, during the "grand growth" phase when the corn plant increases dramatically in height. Due to N's mobility and ease of loss, applied N is best fed through irrigation water in direct relationship to the grand growth curve. A common alternative in Hawaii is to sidedress N at knee-high stage, after four weeks of growth, as the plants begin the grand growth phase. About 60 percent of the N needed by the plant has been taken up by the time of pollination, and the filling grain continues to demand N until maturity.

Phosphorus uptake parallels dry matter increase, with about 40 percent of the plant's requirement taken up by the time of pollination (not shown in Fig. 5.3). A critical stage for P uptake is when plants are very young and the roots are inadequately developed to reach a large soil volume and find enough of this immobile element. Deficiency symptoms are rarely observed once grand growth is under way.

Potassium uptake is rapid during early growth, with as much as 80 percent of the plant's K uptake completed by the time of pollination (Fig. 5.3). The deficiency symptoms for K, like those of P, are usually seen only in very young plants.

Secondary nutrients, micronutrients, and lime

Secondary nutrients
The secondary nutrients differ from N, P, and K in that they are generally not required in fertilizers for corn.

They may be needed, however, on certain soils. Symptoms of secondary nutrient deficiencies are often more easily detected on other crops that are more sensitive than corn. It is best to verify suspected deficiencies of secondary nutrients by analyzing crop tissues before attempting corrective measures.

Calcium (Ca)

Calcium is important in the formation of plant cell walls and in neutralizing cellular acids. The growing tissues of corn contain 0.4% Ca, while the seeds contain less than 0.01%. Calcium deficiency is rarely seen in corn, and its identification is complicated by side-effects. Although Ca is the most abundant nutritive element found in soils, it becomes limiting for corn in very acid soils, where high levels of manganese, iron, or aluminum can form complexes with Ca and make it unavailable. Correction of soil acidity by raising pH with lime usually corrects Ca deficiency. Also, most P fertilizers contain some calcium.

Magnesium (Mg)

Magnesium has a principal function in the formation of chlorophyll, and it accounts for 0.3 percent of the weight of a corn plant. Mg is abundant in most agricultural soils. In Hawaii, soils in low-rainfall zones may have excessive amounts of Mg in relation to Ca, which can reduce Ca uptake by plants. In highly leached soils of high-rainfall zones, Mg levels can be unusually low. Deficiency symptoms include yellow leaf streaking and purpling of the leaf tips and edges. Correction is most economical with dolomitic limestone or epsom salts.

Sulfur (S)

Sulfur has many functions in the plant, among them the formation of the essential amino acids in proteins—cysteine, cystine, and methionine. Deficiency of S is unlikely in Hawaii's soils, thanks to its volcanoes and ocean surroundings. However, it can occur in our highlands, away from coastal showers, and it can be prevented by the use of sulfate-containing fertilizers like calcium sulfate (gypsum) and ammonium sulfate.

Micronutrients

Micronutrients important in corn production include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Zinc is the only one to be of concern in Hawaii. Each of these elements is used by the corn plant in only very small quantities, but deficiency of any of them can cause plant injury. Manure applications can have a very favorable effect on soil micronutrient levels. It rarely pays to apply special micronutrient supplements to corn fields, although boron deficiency has been reported on heavily fertilized coastal soils.

Zinc deficiency has been noted a few times on coralline soils in Hawaii. It affects young corn plants and is evidenced by broad, whitish bands on the leaves, parallel to the midrib, and stunted growth. The plant later outgrows the symptoms. Although routine soil analysis does not measure Zn, a special analysis for it may be appropriate when planting on newly exposed subsoils. If plant tissue analysis confirms lack of Zn as a problem, side-dressing with Zn chelate will ameliorate the symptoms.

Beyond Hawaii, micronutrient deficiencies in corn are known to occur on soils that are highly alkaline or calcareous, derived from peat bog, very sandy, extemely depleted, or highly leached. Deficiency symptoms of copper, boron, iron, and manganese are relatively easy to identify in corn, but they have not been documented in Hawaii. Chlorine is an important building block of corn tissues, accounting for about 0.5 percent of a plant's dry weight. Deficiency symptoms are unknown on corn, except as reduced yield.

Excessive or toxic levels of some elements also reduce corn growth. Corn does not thrive on saline soils or when irrigated with very salty water, due probably to a complex of problems involving sodium, calcium, and other elements. Soils high in aluminum or manganese often exaggerate deficiencies.

Lime and soil pH

The optimum soil pH range for corn is 5.6–7.5. If soils are too acid, deficiencies of phosphorus, calcium, magnesium, potassium, or molybdenum may occur. Somewhere below pH 5.6 on mineral soils, corn begins to suffer. At pH 4.0, it will barely survive.

Liming improves the soil for microorganisms. They speed the decay of plant residues and release of N, P, secondary nutrients, and micronutrients to the soil. Liming strongly acid soils to raise pH above 5.6 reduces the solubility of aluminum and manganese, which are often present at toxic levels in soils of low pH. (For more on soil Mn toxicity, see CTAHR's *Managing manganese toxicity in former sugarcane soils on Oahu;* see *References*). The approximate amounts of agricultural lime needed to raise the pH level one unit in soils of different textures in Hawaii are listed in Table 5.1. More detailed information can be found in CTAHR's *Liming acid soils*

Table 5.1. Approximate lime requirements as predicted by soil texture for soils of Hawaii.

Soil texture	Lime requirement (lb/acre) to raise pH from: 4.5 to 5.5	5.5 to 6.5
Sand	540	800
Sandy loam	1000	1400
Loam	1500	2000
Silt loam	2400	2800
Clay loam	3000	3800

of Hawaii (see *References*).

The most common liming material is agricultural limestone, which is largely calcium carbonate ($CaCO_3$). Agricultural lime contains magnesium in amounts that range from a trace to as much as 45% magnesium carbonate ($MgCO_3$). Limestone that contains a significant amount of magnesium (minimally 5–10%) is called dolomitic limestone ($CaCO_3 \cdot MgCO_3$), or dolomite. Dolomitic limestone is often recommended because application of pure calcium lime may cause magnesium deficiency.

Another source of lime is hydrated lime, a fine powder that reacts completely with soil acids within a few weeks but is generally too costly for use on corn. Gypsum (calcium sulfate) will not raise pH, but does supply calcium and sulfur more quickly than crushed coral, an inexpensive source of calcium. Calcium nitrate supplies calcium, but it may lower rather than increase soil pH.

Quicklime (burned lime, CaO) is a very caustic white powder that is more effective per pound and acts more rapidly than other liming materials. However, it tends to form granules or flakes unless mixed thoroughly with the soil.

The approximate neutralizing value of these sources compared to limestone (as 100%), are dolomitic limestone 110%, hydrated lime 140%, and quicklime 180%. This means that 2000 lb of quicklime would have about the same effect as 3600 lb of limestone of equal purity. The amount of lime to obtain a specific increase in soil pH depends on soil texture plus the fineness, purity, and neutralizing value of the lime material used.

Fertilizer application

Fertilizers consist of various compounds called carriers containing major plant nutrients in the percentages indicated by the formulation, such as 10-30-10 or 21-53-0, which indicates the content (percentages) of nitrogen (N), phosphoric acid (P_2O_5), and water-soluble potash (K_2O).

Secondary elements (Ca, Mg, and S) are often present in fertilizer carriers. Minor elements (Fe, Zn, Cu, Mn, B, and Mo) are sold in mixtures as “trace elements,” “micronutrients,” or “minor elements” and individually as “chelates.”

Fertilizer can be applied in many ways, including being broadcast and disked into the soil before planting, “banded” (applied along the row) after the plant emerges, and by “fertigation” through the irrigation system.

The initial growth and nutrient uptake of the corn seedling is relatively slow, but it is critical because the leaves being produced will support the plant during the subsequent grand growth phase. As previously noted, fertilizer N is used most efficiently when about one-third is incorporated at the time of planting and the remainder is applied in weekly doses. Alternatively, two-thirds can be applied as side-dressing during early growth. Three examples of fertilizer application practices developed in Hawaii are as follows.

- CTAHR’s Waimanalo Research Station—apply 800 lb of 15-15-15 per acre before planting, adding 100 lb of urea as side-dressing (at knee-high corn stage) to make a total of 150 lb N, 120 lb P, and 120 lb K per acre.
- Commercial farmer—apply 400 lb of 8-23-24 per acre as starter with seed, side-dress 400 lb of urea (46-0-0) at 30 days, or 400 lb of N fertilizer split into five applications with irrigation until tasselling. When chicken manure is available, apply 2–7 tons per acre and then apply inorganic fertilizer as needed.
- Commercial seed producer—following a preplant complete fertilization of 400 lb of 16-16-16, all fertilizer is applied through drip irrigation, with weekly applications in proportion to N uptake (Fig. 5.4).

Organic fertilizers

Organic soil amendments such as animal manure and crop residues add valuable humus to the soil. Humus has a large surface area per unit of weight and volume, and it usually contains all the elements essential for plant growth. Nutrient elements held on the organic surfaces of manure are generally readily available to roots. Nutrients in crop residues are more slowly released, coming into solution as the tissues are decomposed by soil microorganisms. A drawback accompanying the benefits of plowing under weeds and animal manure is that they often contribute weed seeds to the field.

Incorporating crop residues is a desirable practice to improve soil tilth and return N, P, and K to the soil. However, the nutrient-supplying benefit of mature corn stover is not immediate. After grain harvest, corn stalks contain only a small amount of N (0.8–1.0% of dry weight). Decaying organisms in the soil use N to fuel the decomposition of carbonaceous materials, but the amount of N in the stalks is too little compared to the amount of carbon. Therefore, the microorganisms will use soil N and thus tie up as much as 20 lb/acre of N during the decomposition process. Later, this N will be gradually released as the organisms die. Whenever mature, dry plant materials such as corn stover or sugarcane bagasse are incorporated into the soil before planting a subsequent crop, increased amounts of N fertilizer must be applied to compensate for the N requirements of the microbial process of decomposition.

Incorporating green manure crops grown before a corn crop can provide more readily available nutrients than stover residues because the crops are usually plowed under when young and green. They have more N in relation to carbon and can make a net N contribution to the soil system, particularly when they are nitrogen-fixing legumes. However, because the succulent tissues of green manures are rapidly decomposed, they may make less of a long-term contribution to soil tilth than the more persistent, carbonaceous material of mature crop residues. In Hawaii, plowing in a rotational green manure crop of sunnhemp (*Crotolaria juncea*) has been found to be excellent for maintaining soil tilth and providing a high nitrogen input.

Planting legumes in rotation with corn can reduce the N fertilizer requirement. In temperate-zone corn production, N fertilizer for the corn crop is reduced by 30 percent following soybeans or field beans and up to 70 percent after alfalfa or green manure legumes. These reductions may not be applicable in tropical conditions and should be determined by observation and by monitoring the crop need for N with plant tissue analysis.

The average composition of fresh cattle and horse manures (at 25% dry matter) ranges from 0.3 to 0.6% nitrogen, 0.20 to 0.35% phosphoric acid, and 0.15 to 0.70% potash, besides significant amounts of secondary nutrients and minor elements. Green manure from legumes like koa haole (*Leucaena* species) and sunn-hemp have over 3% N and have made superb contributions toward high corn yields in Hawaii. In many tropical countries where inorganic fertilizers are not readily available, green manure from nitrogen fixing trees such as leucaena provides most or all of the nutrients for corn growth. In these situations, corn and legumes are often intensively managed in rotations, as intercrops, and in systems of "alley farming."

Organic matter also influences productivity indirectly by improving soil structure. During its decomposition there is a profound influence on soil aggregation. Well decomposed organic matter increases the cohesion of sandy soils. Coarse organic matter decreases stickiness of clay soils. Good soil structure and the organic matter itself improve aeration, water-holding capacity, permeability, and resistance to erosion.

"Organic farming" is the attempt to raise crops without agricultural chemicals, including fertilizers, insecticides, herbicides, and fungicides, and also eschewing the use of genetically-modified or transgenic hybrids or varieties. Those who wish to try growing corn this way in Hawaii will need a strong back, a deep pocketbook, lots of cow manure, and good luck with weeds. Superior Hawaii-bred corn hybrids can be grown without chemicals applied to the plant itself, a goal of all serious plant breeders.

Soil and tissue testing

Soil and tissue analysis is often recommended to determine the need for soil amendments (lime and P) and applications of K, Ca, and Mg. The most important tests for the majority of farmers are those for soil pH (lime requirement) and the soil's levels of available P and K. For some soils, a test for Mg and Zn is useful. In general, testing for N is impractical because N is mainly in the soil organic matter and must be released by biological processes before it can be used by crops. These processes are influenced by temperature, moisture, aeration, pH, compaction, and the previous crop. Also, there is no better indicator of N deficiency than corn itself.

The reliability of a soil test depends on the adequacy of the sample taken to represent the entire field to be fertilized, so random samples should be taken over each distinct field area. As a first step, the farm is divided into sampling areas differing in productivity, topography, texture, drainage, color of topsoil, or past management.

Soil samples should be taken to the depth of the root zone, about 12 inches for corn in Hawaii, when the soil is neither too wet nor too dry. A minimum of ten samples should be taken from each sampling area and mixed thoroughly to form a composite sample. A one-pint quantity of this mixture should be placed in a clean plastic bag and labelled. Tissue samples are commonly taken from the leaf subtending the uppermost ear. Analysis can be done at commercial laboratories or by

CTAHR's Agricultural Diagnostic Service Center via local Cooperative Extension Service offices. Details on soil sampling and analysis can be found in the CTAHR publication *Testing your soil; why and how to take a soil-test sample*, Hue et al., 1997 (see *References*).

The CTAHR publications mentioned in this chapter are available from the CTAHR Web site, *www.ctahr.hawaii.edu*. They are also included in the comprehensive publication, *Plant nutrient management in Hawaii's soils—approaches for tropical and subtropical agriculture*, which can be obtained via an order form available on the Web site.

Tissue analyses can reveal unsuspected minor element deficiencies. An example from studies in Indiana (Table 5.2) involved unusually poor seed set in two fields (B6, B11) vs. excellent yield in another (A12). All plants were very vigorous, and although potash inadequacy was suspected to be the cause, the loss instead was revealed to be due to boron deficiency. Similar yield losses with irregular kernel fill have been observed on alkaline soils in Hawaii.

Table 5.2. Tissue sample analyses of ear leaves that revealed minor element deficiencies in Fields B6 and B11 as cause of poor seed set.

Element	Sufficiency level*	A12	B6	B11
N	2.80	2.90	2.96	3.01
P	0.25	0.29	0.28	0.28
K	1.80	0.54	0.82	1.05
Ca	0.30	0.45	0.37	0.37
Mg	0.25	0.23	0.18	0.25
Fe	60	161	78	161
Mn	25	36	21	44
Zn	20	6	4	10
Cu	6	4	2	2
B	6	9	3	5

*Nutrient sufficiency levels for sweet corn, based on ear leaf
Source: www.agcom/purdue.edu/AgCom/Pubs/NCH/NCH-43.html

Chapter 6

Water

Pan evaporation and evapotranspiration

Pan evaporation

Loss of water in a day is customarily measured as "pan evaporation," for which a special pan ("Class A" pan) of water is used. Daily evaporation data from four stations in Oahu's Pearl Harbor area ranged from 0.15 inch in winter to 0.30 inch in summer over a 10-year period (Fig. 6.1). Evaporation loss from the average swimming pool correlates well with this data, exceeding it slightly if the pool is fully sunlit. Data on pan evaporation were summarized for the entire state of Hawaii by Ekern and Chang in 1985 (see *References*). On the island of Oahu, pan evaporation varied from a low of 20 inches per year in the cool, cloudy uplands of the Koolau mountain range to a high above 90 inches in the leeward Ewa coastal plain.

Honolulu's summer climate has a day classified as "high demand for Class A pan evaporation" (0.75 cm, or 0.3 inch, per day). Evaporation losses are influenced by temperature, humidity, sunlight, and wind. Our Waimanalo corn fields average 75°F temperature, 60% relative humidity, 16 x 10^6 joules of light per square meter, and 10-mph winds. Under these conditions, the average home swimming pool would empty completely in about a year if no water were added (the average of the data shown in Figure 6.1 is exactly 7 ft of water per year). However, averages can be misleading! For example, rainfall at our Hamakua research station has averaged 105 inches over a 20-year period during which annual receipts of rainfall ranged from 40 to 180 inches.

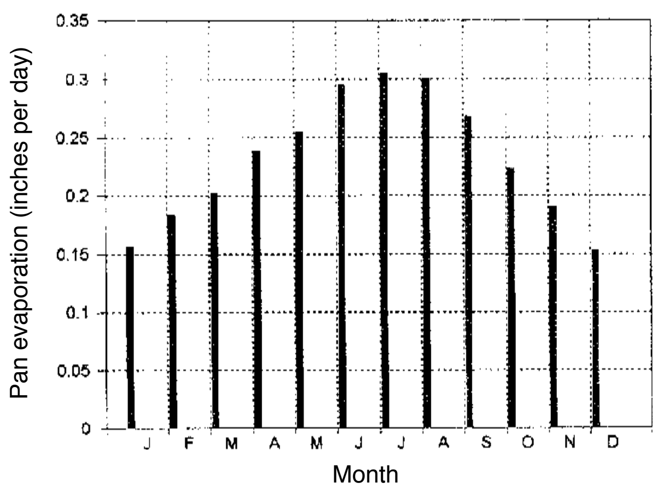
Evapotranspiration

The loss of water by a plant is "evapotranspiration" (ET). This constitutes use of water by the plant itself, and it is much more difficult to measure than pan evaporation. The water use by corn is small during early vegetative growth but increases linearly with time, peaking at the time of pollination. Most of this early loss of water from the corn field is by evaporation from the soil surface, which represents 30–50 percent of the total water loss by American corn crops. This loss amounts to about $\frac{1}{4}$ inch per day or 7000 gallons per acre (an acre-inch = 27,000 gallons). Later, water use increases in proportion to plant volume, with 50–80 percent of this use due to transpiration by the plant itself (Fig. 6.2).

Water use decreases gradually after the sweet corn stage, which occurs 20 days after pollination or about 70 days after planting. The highest correlation between yield and water use occurs during the period from five weeks before flowering to three weeks after flowering. The values for Figure 6.2 are modified from Iowa data but can be considered representative of what must also happen in Hawaii.

Water use by the corn field also varies with plant vigor and plant density per unit area. Corn grown in the winter in Hawaii may produce less than half the total biomass of summer corn. Cooler temperatures of winter

Figure 6.1. Pan evaporation in Honolulu, Hawaii.



also ensure reduced ET and pan evaporation.

Very-low-density corn plantings generally require less water. Weeds quickly use up water during early corn growth and can be a much greater factor contributing to soil moisture depletion than either the density or the vigor of the corn crop.

Water use efficiency

Grain yield is highly correlated with seasonal water use. The best grain yields (210–230 bu/acre) on the sunny but windy plains of Texas occurred with water use of 2–3 feet of water (700–900 mm). We can expect use of this magnitude in dry, windy seasons on the Ewa plain of Oahu. The Texas data give the following relationship, with ET in inches:

$$\text{grain yield in bushels per acre} = 0.025 \times (\text{ET} - 12 \text{ inches})$$

The formula indicates that no grain at all develops if water use is less than 1 foot. In contrast, sorghum continued to produce grain to levels down to as little as 6 inches per growing season. Looked at another way, the corn yields in Texas increased about 10 bushels per inch of water after this minimum of 12 inches of water was provided. The Texas formula is probably quite applicable to our dry, windy regions in Hawaii but may be lowered by our shorter, cooler days with lower winds.

The efficiency of water use (WUE) increases as yield increases, tapering off at high yield levels. In Texas, this proved optimal around 160 bu/acre (10 t/ha) and had the following relationship to yield:

$$\text{WUE} = 0.23\,Y - 0.07Y^2$$

This optimal yield occurred at an ET level of 36 inches of water (911 mm). In these studies the relationship of grain yield to total dry matter yield was consistent and highly correlated ($r^2 = 95\%$). With the great range of growing conditions encountered by Hawaii's corn farmers, experiments similar to those that produced the Texas data need to be repeated for almost any new production site. Where water costs are high, this deserves even greater attention.

Symptoms of moisture stress

Moisture stress (drought stress) is perhaps the most obvious kind of stress a corn plant can have, because it is a large, leafy factory whose wilting is obvious to anyone. A bluish-green color develops under protracted moisture stress. Different types of leaf firing (brown, necrotic areas) characterize different corns. Some will show tip firing with only minimal stress, while others can recover from wilt with little leaf necrosis. Poor flowering and pollen production ensue.

The distribution of corn roots depends on the availability of soil moisture, and drought tolerance in turn depends on the depth of the roots. Rooting depth is normally quite shallow (< 2 ft) in the tropics, because early seedling growth is accelerated by high temperatures. Depth of root penetration may be reduced by nutrient deficiency—notably phosphate deficiency—or by excessive early-season moisture. Corn is able to use water to a depth of 5 feet or more in permeable, well drained soils. The depth of water extraction up to the time of tasseling varies considerably with the season, but generally more than 70 percent of the moisture used is from the top 2 feet of soil.

Drought stress is known to be associated with reduced feed quality. Under severe lack of moisture, corn silage will have higher levels of toxic nitrates.

Breeding drought tolerance

The development of drought tolerance has been a longtime target for plant breeders of many crops. Great progress has been made in corn by reducing maturity and plant stature, thereby reducing water requirements. Recent progress has been made by focusing on the anthesis-silking interval. A critical period for any type of stress is at flowering. Sustained early drought will increase the anthesis-silk index (ASI), the period between the date of pollen shed and the appearance of silks (normally about one day in Hawaii). When high temperatures are combined with moisture stress at the time of pollination, ASI can increase to a week or more and grain yield can be reduced significantly. Breeders have selected parents and hybrids with low ASI response to stresses such as drought, largely to benefit farmers relying on rainfed agriculture in the Corn Belt or in the tropics.

Irrigation water needs

Water ranks up with fertilizer as a major cost and production headache for successful corn production in much of Hawaii. Water costs are often unreasonably high for agriculture of any kind; labor costs are similarly high. The soils of Hawaii are often highly permeable and irregular, and can be unsuitable for furrow irrigation of crops like corn.

Hawaii's soils are generally young and shallow, with poor moisture-holding capacity. Rainfall is irregular and unreliable. Areas with adequate, continuous rain-

Figure 6.2. Ratio of evapotranspiration (ET), or water use, to pan evaporation during the life of a corn plant.

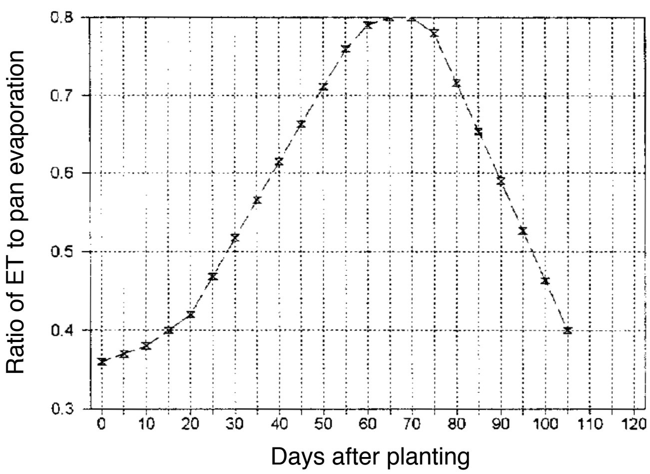


Figure 6.3. Pivot-center irrigation on corn fields.

fall are highly overcast and have low levels of incident light, leading to uneconomic corn yields (much as with sugarcane). Thus, irrigation is commonly required for reliable, maximum corn yields, and it may be necessary throughout the growing period.

Corn requires between 3000 and 4000 gallons of water per bushel of grain produced, or a half million gallons for a 150-bushel crop. Since an acre-inch of water equals 27,000 gallons (a hectare-cm equals 100 kiloliters), these values will equal about $\frac{1}{8}$ acre-inch per bushel or 19 acre-inches per 150-bushel crop. About 2 inches (5 cm) of irrigation per week are required during the vegetative growth of corn. This increases to about 3 inches after six weeks of growth until the sweet corn stage (Fig. 6.2). Special attention must be given to maintaining a high soil moisture content during the time of tasseling and silking.

Forms of irrigation

Irrigation can be provided in many ways to corn plants: by overhead sprinkler, moving water gun, drip tubing (on the surface or buried), or surface-furrow irrigation. A system of overhead "impact" sprinklers is probably the most effective and reliable for irrigation in Hawaii. The water need only be cleaned by simple filters. The uniform distribution of water from sprinkler systems is essential, and it requires uniform water pressure and little interference from trade winds. These conditions optimize during the early morning hours in much of Hawaii. Disadvantages of the overhead sprinkler system include

- high initial set-up cost
- poor water distribution due to movement of trade winds
- high labor costs for system maintenance.

Center-pivot sprinkler systems are relatively new to Hawaii (Figure 6.3), but they are the primary solution to irrigation in much of the western USA. Irrigation through water guns has been applied for large-scale sugarcane and corn production in Hawaii, but it has disadvantages similar to those of the overhead sprinkler.

Surface drip irrigation is used widely for seed corn production in Hawaii, with buried header pipes and highly filtered water. It maximizes water use efficiency, reduces weed competition, and leads to high uniformity of growth and maturity. It can be modified for fertigation. Occasional cleansing of the tubes with sodium hypochlorite may be necessary, as well as measures to control ants. Conventional drip tubes can survive two or more production periods, reducing investment cost per crop. Equipment for placement and recovery of drip tubes is available, and corn rows can be spaced so as to allow two rows per tube.

Buried-drip irrigation has been used for sugarcane and other crops and can reduce water use by up to 50 percent. Installation costs are high, but are reduced with modern equipment that buries drip tube during planting. Problems for corn include difficulty in providing adequate moisture at germination and increased soil compaction during land preparation and planting. These practices are generally too costly for use on field or silage corn. Engineering advances continue to promise savings in water use for all crops.

Salinity and irrigation

Corn's tolerance of salinity is similar to most vegetable crops and less than that of many field crops. Salinity is usually measured as electrical conductivity in decisiemens per meter (dS/m). This value multiplied by 640 approximates the parts per million (ppm) of dissolved solids.

In its later growth stages, during grain fill, corn tolerates fairly high salinity, above 8 dS/m. When young, however, it reacts about as follows:

< 1 dS/m	no effect
1–4 dS/m	increasing damage
> 4 dS/m	severe growth inhibition

Sprinkler irrigation water with salts in solution above 4 dS/m can lead to tip-burning of corn leaves, and stunting would also be observed at this level. Well water can exceed 1 dS/m in Hawaii, so it is important to evaluate salinity whenever it is suspected. Most river water in Hawaii is very low in salinity. Intrusions of salt water from the ocean can cause severe stunting of corn in low-lying, leeward shore areas. Even under saline conditions that do not otherwise affect plant appearance, yield loss may be great.

Salt accumulates in soil with successive irrigations if there is little leaching below the root zone during irrigation or by rain. The necessary amount of leaching increases linearly with salinity: at 2 dS/m, 20 percent of irrigation should leach below the root zone, and at 4 dS/m, about 40 percent.

The use of sewage effluent has been considered as an irrigation supply for corn in Hawaii, because the effluents contain little of the heavy metals, and corn accumulates less of these than most vegetable crops. If such water is being considered, counsel should be sought from CTAHR.

Chapter 7

Weed Control

Major weeds in Hawaii's corn fields

Weeds cause much more anguish to farmers in the tropics than to growers in temperate regions, who have frost as a major "herbicide." Weed seeds often persist for years in tropical soils and can blow in from neighboring fields year-round.

Some of the most common weeds of Hawaii's corn fields are listed in Table 7.1. Many other species may occur in corn, but those listed in the table often become serious. The weeds are largely tropical and are classified as grassy and sedge-like (monocotyledons) or broad-leaved (dicotyledons). Several different groups of herbicides are used specifically against these types of weeds. In some instances, a specific herbicide can eliminate one family of weeds, thus encouraging another.

Common monocot weeds include the (despicable) sandbur (*Cenchrus echinatus*), crabgrass (*Digitaria* spp.), wiregrass (*Eleusine indica*), and foxtail (*Setaria verticillata*) in the grass family (Gramineae). Nutgrass (*Cyperus rotundus*) belongs to the related family of sedges, the Cyperaceae, and can become a serious pest due to its tolerance of most common herbicides. The "nuts" (tubers) of this sedge are long-lived and can number in the thousands under a square foot of soil, taxing the patience of the most dedicated farmer (for a better understanding of this weed enemy, read *Nutgrass control in the lawn, landscape, and garden*, Nishimoto et al. 1998; see *References*). An herbicide that provides effective if costly removal of the nutsedges is methylhalosulfuron (Manage®).

Common broad-leaved weeds in Hawaii are the amaranths (*Amaranthus* spp.), purslane (*Portulaca oleracea*), honohono grass (*Commelina diffusa*), the spurges (*Euphorbia hirta*), and a recently arrived viny cucumber, *Claviceps grandis*, that was introduced to Hawaii as a food! Most of the broad-leaved weeds are annuals (Table 7.1).

Weed competition and yield loss

Weeds compete with corn primarily for water and nutrients, and attendant yield losses can be great without proper weed control. A rule of thumb is that one weed per foot of row reduces yield 10 percent. The yield losses vary depending on the types of weeds, their population, and the stage of corn growth. *Emilia sonchifolia* is a pretty little weed (Fig. 7.1) that can significantly reduce early growth of corn in Hawaii.

It is not unusual in low-input agriculture in the tropics to lose over half of corn's potential yield to weed competition. In addition to directly reducing yield, weeds serve as alternate hosts of some diseases. Weed cover

Table 7.1. Important weed species in Hawaii's corn fields.

Weed	Scientific name	Type*	Control by atrazine**
Grasses (monocots)			
sandbur	Cenchrus echinatus	A	F
crabgrass	Digitaria spp.	A	F
wiregrass	Eleusine indica	A	F
foxtail	Setaria verticillata	A	P
johnsongrass	Sorghum halapense	P	P
Sedges (monocots)			
nutgrass	Cyperus rotundus	P	P
Broad-leaved weeds (dicots)			
amaranth	Amaranthus spp.	A	G
spiny amaranth	Amaranthus spinosus	A	G
ivy gourd	Claviceps grandis	A	F
honohono	Commelina diffusa	A	G
flora's paintbrush	Emilia sonchifolia	A	G
spurge	Euphorbia hirta	A	G
apple of Peru	Nicondra physalodes	A	G
purslane	Portulaca oleracea	A	G
cocklebur	Xanthium saccharatum	A	G

*A = annual weed, P = perennial

Figure 7.1. Severe weed competition on Oahu from one weed, Emilia sonchifolia.

Figure 7.2. Weed management by animal-drawn tillage on a small Southeast Asian farm.

can enhance fungal disease injury from rusts, blights, and molds by extending dew periods. Many insects find refuge in weeds, including earworms, aphids, thrips, and red spiders.

Plant nutrition is a key factor in the competition between corn and weeds. Weed species often accumulate nutrients more rapidly than corn. Spiny amaranth uses two to three times as much nitrogen, phosphorus, and potassium as corn does during the first month of growth. Nutgrass can be a major competitor for nitrogen, gleaning it from the soil immediately after corn planting, when the corn root system is still too small to compete.

Water also becomes a limiting factor when weeds are uncontrolled and lead to wilting in a dry corn field. An estimated acre-inch of water taken up by a healthy weed cover during the growing period is sufficient to supply the water needs of corn for approximately five days at peak flowering time. Severe water shortage for two days during the critical flowering period can reduce corn yields significantly.

Weed competition for light, so important with smaller crops, is uncommon in Hawaii's corn fields. Of greater concern may be the shade from windbreaks. Elsewhere in the tropics several tall grass species, such as johnsongrass, can reduce corn yields by shade competition.

Tillage practices and crop rotation

Long-term field management can minimize weeds by periodically tilling or killing perennial weeds and by preventing annual weeds from forming seeds. Tractor-pulled mowers serve usefully after harvest to prevent weeds from producing seed. A common problem in Hawaii is created by the wet, low-light winter season, when weeds thrive and tillage may be difficult or impossible. At such times the use of contact herbicides may be a practical solution.

So-called "organic" farming methods that eschew herbicides call for repeated field visits with a sharp hoe to avoid yield loss to weeds. Low-growing legume ground covers have been evaluated for corn in Nigeria, with herbicide application to create planting strips for the maize.

Cultivation after corn emergence is a common practice, usually at the time of "lay-by" when a high-N fertilizer is side-dressed in the rows. It is important that weeds be removed before they drain nutrients provided to the corn. The critical stage in Hawaii is about 3–5 weeks after planting. During the 10 weeks required for a sweet corn crop, there are many weeds that can complete their life cycle, and they must be cut or removed before they produce seeds.

Continuous and careful prevention of seed reproduction ultimately can produce nearly weed-free fields. However, this is much more easily achieved in temperate zones than in Hawaii and other warm climates, where weed management requires year-round diligence. The farmer who depends on water buffaloes in developing countries (Fig. 7.2) suppresses weed seed formation by timely cultivation. Complete freedom from weeds, however, is an impractical—or at least uneconomic—ideal for the moist tropics.

Corn can be grown continuously on the same land in Hawaii without major yield decline, provided there is adequate attention to nutrient removal and replacement. Corn has been grown for almost four decades in three 3-acre fields at the Waimanalo Research Station without yield loss, and the fields are almost weed-free. On many soils, however, maximal yields probably would always follow some type of rotation in which soil tilth and micronutrient fertility are optimally restored, e.g., by a cover crop. Crop rotations and low-till plantings are not common for Hawaii's corn lands, due largely to the problem of carryover effects on corn of the herbicides required in these systems. If a long-term weed management strategy has led to suppression of major weed species, however, a crop rotation with a legume cover crops such as *Crotolaria juncea* (sunnhemp), *Canavalia ensiformis*, or *Mucuna* spp. can be recommended.

Herbicides

Weed control is impractical in Hawaii— if not economically impossible—without the use of herbicides. Large-scale growers must arm themselves with a copy of the *Weed Control Manual* (see *References*; Web site *www.meisterpro.com/wcma*), which provides details on more than 70 chemicals that can be used in weed management for corn. Many are host-specific; some are preemergence, some postemergence; some apply only to field corn; some cannot be used if corn is to be grazed; and few tank mixtures are permitted by the labels.

The four major classes of herbicides in use on corn are listed in Table 7.2. These chemicals are available in different formulations, with rates of application suggested by the product manufacturers. Rates can normally be reduced for sandier (vs. more organic) soils, and where weed seed populations are known to be low. All large chemical companies provide websites addressing their products and issues such as applicability and safety (see *References*).

Herbicides used for local-area control of growing weeds before planting corn are either systemic herbicides such as glyphosate (Roundup®), effective against most types of weeds, or contact herbicides such as paraquat (Gramoxone®), effective against most annual weeds. When applied while the weeds are growing vigorously, glyphosate is particularly effective against johnsongrass, and thus can minimize tillage. An herbicide highly effective against the nutgrasses (sedges) is methylhalosulfuron (Manage®), which is formulated to control weeds without harming grasses.

Table 7.2. Herbicides commonly used for weed control in corn.

Type, subtype	Chemical name	Trade name
Postemergence (applied to growing weeds)		
Systemic	glyphosate	Roundup
	glufosinate	Liberty
Contact	paraquat	Gramoxone
	methyl halosulfuron	Manage
Plant hormone	2,4-D	
Preemergence (applied to the soil to prevent weed emergence)		
Thiocarbamate	EPTC	Eptam, Eradicane
	butylate	Sutan+
Triazine	atrazine	Aatrex
	simazine	Princep
	cyanazine	Bladex
Acetanalide	alachlor	Lasso
	propachlor	Ramrod
	metalochlor	Dual
	dicamba	Banvel D
Dinitroanalines	pendimethalin	Prowl

Herbicide-resistant corn

Resistance to herbicides has been developed and introduced into essentially all major crops. Transgenic lines are genetically modified organisms (GMOs); they are available in corn for the herbicide glyphosate, as Roundup-Ready, by Monsanto, and the herbicide glufosinate-ammonium, as LibertyLink, (LL) by Aventis and Syngenta. They also are available stacked with insect resistance from *Bacillus thuringensis* (Bt) in corn hybrids. Conventionally-bred varieties with tolerance of Lightning®, an imidazo-linone herbicide, are also available as IMI Clearfield®. Another new non-transgenic mutant confers resistance to Poast®, a nonselective grass herbicide, in hybrids known as SR-corn hybrids ("sethoxydim-resistant"). No doubt there will be many additions to this array in years to come.

Systemic herbicides like glyphosate and glufosinate can be sprayed directly over transgenic corn fields. Fields must be of a specific size and must be approved by state and federal regulatory agencies. Clearance by

USDA, EPA, and FDA after many years of tests show these transgenics to be entirely safe.

Four major classes of preemergence herbicides

Thiocarbamates

Preemergence herbicides of this family may be necessary under some conditions in Hawaii. EPTC (trade names include Eptam® and Eradicane®) and butylate (Sutan®) are useful in controlling persistent grasses and the nutgrasses. These herbicides must be incorporated thoroughly into the topsoil. The effectiveness of such preemergence herbicides depends greatly on field moisture and the avoidance of clumping of soil particles in upper soil layers.

Triazines

Triazine herbicides are the most widely used on corn. They are applied during or after tillage and in some cases after planting or even after seedling emergence. Atrazine (Aatrex®) is the most widely used, and it is a superior herbicide for corn. It can not be used in some crop rotation schemes due to its carry-over in soils. Simazine (Princep®) and cyanazine (Bladex®), related to atrazine, are most effective on broad-leaved plants but less effective against grassy weeds.

Acetanalides (acetamides)

Often used as supplements to or in tank mixes with triazines, the acetanalides include the widely used alachlor (Lasso®). The related propachlor (Ramrod®), metalochlor (Dual®), and dicamba (Banvel D®) can be used in rotation with Lasso as supplements to improve grass control.

Dinitroanilines

Pendimethalin (Prowl®) is a dinitroaniline that can be used pre- or postemergence in sweet and field corn.

The effectiveness of preemergence herbicides varies with soil types, weed species, and climatic conditions. Growers should try different formulations, at different doses within the range allowed by the product label, on a small-plot basis. Tandem use or mixtures of two or more herbicides often gives better control and prevents domination of fields by a single weed species. The label specifies the other herbicides that can be used in such combinations.

Postemergence herbicides, applied during corn growth, may be recommended as an emergency step to control weeds when pre-plant or preemergence application is inadequate. The hormone 2,4-D can be used in monocot crops such as corn for control of broad-leaved weeds such as honohono (Table 7.1).

Atrazine can be used postemergence with a nonphytotoxic oil, but 2,4-D should not be added. Cyanazine (Bladex®) can be used also, but without oil or other herbicides. Dicamba (Banvel D®) can be used alone or with 2,4-D. Paraquat can be used if directed carefully to weeds that are growing in the inter-rows and not allowed to contact the corn. For corn seed crops only, Evik® can be used in Hawaii for improved postemergence grass control.

Environmental concerns

Concern about environmental damage from certain pesticides is well founded, but this is not so for all pesticides. The long-residue herbicides like EPTC (Eradi-cane®) and atrazine (Aatrex®) are often mentioned, and their restriction to specific uses and users has been instituted. Care should be exercised in the use of all pesticides, and product labels always carry cautions that are carefully spelled out by the manufacturers. The continuous use of certain herbicides can lead to shifts in the spectrum of tolerant weed species, and concerns about groundwater contamination. A recommended practice is to alternate the acetanalides in successive plantings. Table 7.2 includes only a fraction of the many herbicides that can be used on crops like corn.

Ecologically sound practices that minimize weeds in sustainable agricultural systems include crop rotation, discussed earlier, and the use of live mulches. Fire is increasingly being considered for weed control, as flame-throwing hardware evolves. This apparent return to “slash and burn” farming may appeal to organic growers. Despite its ecological attractiveness, fire and slash afford only short-term control of the tough perennial tropical grasses and sedges. Advice on such practices and on herbicide regulations in Hawaii should be sought from specialists at CTAHR or in the Plant Industry Division of the Hawaii Department of Agriculture.

Chapter 8

Diseases and Pests

Pesticide-free corn production

Pesticide-free crop production must be a goal for all corn growers and plant breeders. No major crop can claim to be much closer to this goal than corn in Hawaii. Freedom from pesticides does not mean freedom from pests and diseases, but the pest management program must ensure that the damage is not of economic importance. Two important facts underlie our ability to grow some corns free from insecticide and fungicide in Hawaii:

- breeding that has successfully surmounted all major pests and diseases in Hawaii
- freedom of the Hawaiian Islands from some pests, notably stalk borers and downy mildew.

Many of the insects and diseases reviewed here can inflict economic damage on susceptible corns in Hawaii. The key is to grow the most resistant germplasm available. In Hawaii, this simply demands that every grower continuously evaluates new hybrids.

Plant diseases and insect pests take a huge bite out of the profits of corn production in the tropics. Diseases based on viruses, bacteria, and rusts, and insects like borers and earworms, thrive the year around in warm climates such as Hawaii, adding to their potential severity. Ideally, their control should be based on the maximum available genetic resistance, together with insect predators and parasites.

The lack of adequate pest resistance in U.S. mainland corn hybrids when grown in Hawaii virtually rules out their use for commercial production. Notable is their lack of resistance to maize mosaic virus (Fig. 8.1), a resistance only available in Caribbean germplasm and now found in all Hawaii hybrids. Hawaii's seed corn industry (Chapter 10) is based almost entirely on unadapted temperate germplasm and is compelled to use pesticides heavily.

This chapter provides an overview of some of the diseases and insect pests of corn and sorghum that are significant in Hawaii. Reviews of the subject are included under *References*.

Diseases

The diseases that occur on corn in Hawaii range widely in severity, depending on the environment (highland, lowland) and season of production (Table 8.1). Severity scores in the table are given on a 1 to 5 scale, with 5 = most severe, assuming susceptible germplasm. Data are estimated for summer and winter seasons, and for Hawaii's few highland producers.

In general, our subtropical environment and year-round production provide ideal conditions for plant diseases and their vectors. Several corn ventures in Hawaii that were based on U.S. mainland germplasm failed to turn a profit due to disease build-up. Quarantine restrictions have prevented introduction into Hawaii of some serious corn diseases found elsewhere in the world. These include corn downy mildew (serious in much of Asia but controllable by seed treatment) and several viruses (MCDV, MRDV, MSV). Most other diseases have been present in Hawaii throughout the century.

Table 8.1. Major diseases of corn in Hawaii, with severity on scale of 1 = low to 5 = high.

Disease	Lowland winter	Lowland summer	Highland summer
Maize mosaic virus	5	4	1
Maize dwarf mosaic virus	2	1	2
Common rust	4	2	3
Southern rust	4	2	2
Northern blight	4	2	5
Southern blight	2	1	3
Yellow leaf blight	1	1	2
Bacterial leaf blight	1	2	1
Brown spot	2	1	1
Fusarium rots*	4	2	2
Smut	1	1	1

*Assuming no seed treatment.

Maize mosaic virus (MMV)

MMV is a dwarfing disease (Fig. 8.1, 8.2A) that can be the most important economic disease of corn in Hawaii. It effectively eliminated corn production here until resistance breeding was initiated in the 1940s by Dr. Albert Mangelsdorf of the Hawaiian Sugar Planters' Association. The virus is transmitted by a planthopper, the corn delphacid, *Peregrinus maidis* Ashmead.

MMV originated in the Carribean islands, and the disease is thought to have contributed to the collapse of the Mayan civilization in Central America (Brewbaker 1979). Symptoms of MMV include elongated white streaks over the veins of leaves, often enlarged in older tissues, including husks (Fig. 8.2A). Plants may be severely or only mildly stunted, bearing small ears with shortened husks. Husk shortening exposes seeds to insects and birds and increases damage from ear-rot fungi.

Commercial field and sweet corn hybrids of the world rarely show any tolerance of MMV. It grows only on corn, lacks alternate plant hosts, and is severe only in regions where corn grows continuously around the year. Because of the importance of MMV in Hawaii, CTAHR's Waimanalo Research Station became a world center for research on MMV.

All important Hawaii supersweet and field corn inbreds and hybrids carry the *Mv* gene for general resistance to this disease. The gene was discovered at Waimanalo in the 1960s and in the 1990s it was genetically mapped to Chromosome 3:80 and flagged with molecular markers. Many selected high-combining inbred lines with both tropical and temperate origins have been converted in Hawaii to MMV resistance. The virus does not seem to become serious when more than half the plants in a field are resistant.

Figure 8.1. Mature plants dwarfed to 1-foot height by maize mosaic virus.

Other viruses

Maize dwarf mosaic virus (MDMV Strain A) and a strain known as sugarcane mosaic virus (SCMV-MB) are transmitted by aphids and can become serious in Hawaii. The disease is never seen at pesticide-free Waimanalo Research Station, where aphid predators and parasites appear to control the vector as an effective agent for spread of the virus. The symptoms include broad chlorotic stripes between the veins, similar to zinc deficiency but distinct from the narrow MMV stripes along the veins. Dwarfing may or may not occur. The virus can be serious in its synergistic combination ("lethal chlorosis") with another virus, MCMV, which was observed on one occasion on Kauai and later eliminated by growing no corn for short seasons each year. Many other serious viruses affect maize worldwide, and exclusion of their insect vectors is an important continuing challenge for plant quarantine agencies and corn producers in Hawaii.

Common rust

Common rust is caused by a fungus, *Puccinia sorghi* Schw., and can be extremely serious on susceptible corn in Hawaii (Fig. 8.2B). Year-round production especially encourages epidemics of common rust. The sexual cycle is completed many times throughout the year on *Oxalis* sp., a common weed. This facilitates evolution of new races of the fungus. Corn labeled "resistant" to this disease for U.S. mainland production is routinely found to be susceptible in Hawaii.

Symptoms of common rust include bands on leaves showing cinnamon-brown eruptions at the early stage of infection, with subsequent development of brownish pustules $\frac{1}{8}$ inch in diameter producing uredospores. Moderate temperature and high humidity levels favor common rust development, and it is especially severe in winter months on windward sides of the islands. Resistance to common rust is of two types. A race-specific resistance is based on Rp genes that act as gene-for-gene resistance. Only one of these is still effective in Hawaii, all others having fallen to the evolving pathogen; this resistant locus is *rp677A*, discovered at Waimanalo. The second type, general resistance, has been bred into many Hawaii corn varieties and hybrids. It acts largely to suppress growth of the fungus in the later, uppermost leaves, above the ear, that are of most importance in providing sugars to the developing ear.

Southern rust

This rust is caused by the fungus *Puccinia polysora* Underw., which produces abundant orange-red lesions on leaf blade, leaf sheath, and husks. The lesions are smaller and more orange than those of common rust. Southern rust is favored by hot and moist weather, a rarity in Hawaii. All temperate sweet corns are highly susceptible, and severe epidemics simply eliminate their production under Hawaii's conditions. In contrast, most tropical varieties and Hawaii hybrids are characterized by a high level of genetic resistance. When lesions are found in abundance under the outermost husks, the rust is assuredly southern rust, and not the common rust, and they can often be found together.

Northern corn leaf blight (NCLB)

NCLB is caused worldwide by the fungus *Exserohilum turcicum* Pass. (Leonard & Suggs), the perfect stage of which is called *Trichometasphaeria turcica*. The disease is especially serious in Hawaii's cool highlands (Fig. 8.2C). The fungus is favored by moderate temperatures (68–78°F) and extended dew periods (>12 hours). The disease has three common hosts in Hawaii: corn, sorghum, and johnsongrass. Symptoms of NCLB include small grayish or chlorotic flecks on the leaves that later enlarge into egg-shaped tan or grayish lesions up to 2 inches in length. After long periods of cool, moist weather, these lesions may engulf the entire leaf.

Resistance to NCLB, like that to rust, is of the two types, specific and general. Specific resistance genes like *Ht* and *Ht2* that are in use in some temperate countries are not effective in controlling the pathogen in Hawaii, due to its rapid evolution here. General resistance is available in many tropical types of corn, however, and has been bred into some of the better corns for Hawaii. Plants with this nonspecific resistance produce smaller lesions, rare on upper leaves, with limited sporulation.

Southern corn leaf blight

This blight caused by *Bipolaris maydis* (Nisik.) Shoem. (formerly *Helminthosporium maydis*) occurs in Hawaii but is rarely serious. Its lesions are small and distinctly surrounded by a reddish-brown halo (Fig. 8.2D). They occur on leaves, stems, and ear husks. The disease is favored by plowdown of stalks and by warm, damp weather. Despite the fact that these conditions often occur at the Waimanalo Research Station, this disease has inexplicably failed to thrive there in the author's 35 years of growing pesticide-free corn in that location.

Yellow leaf blight

This disease is caused by *Phyllosticta maydis* Arny & Nelson and is seen on corn only in Hawaii's cooler highlands. Its lesions are small ($\frac{1}{5}$ inch x 1 inch) and yellowish. They may coalesce, however, and then they mimic northern blight. Resistance is common in corn, but the pathogen has other grass hosts, such as foxtail and sudangrass, and is thus omnipresent.

Bacterial diseases

Bacterial leaf blight (BLB) is one of two bacterial diseases of corn in Hawaii. Neither are serious, evidently as a result of widespread genetic resistance. Bacterial blight is believed to be caused by the bacterium *Acidoborax avenae* (formerly *Pseudomonas avenae*). It occurs on relatively few genotypes of corn, but it can be very serious on those, causing water-soaked leaf streaks that may coalesce and senesce to cause serious loss of leaf surface. Resistance appears to be simply inherited.

Bacterial stalk rots caused by *Erwinia* spp. occur occasionally in Hawaii. They can become serious when overhead irrigation water is dirty. The organism initiates disease in the whorl leading to senescence of the upper leaves and ultimately a smelly rot that can topple the stalk. Stalk rot is favored by plant stress of many types, including high temperatures and high moisture levels, and can also be caused by fungi like *Fusarium* spp. All stalk diseases weaken the plant and result in leaning or lodging of plants as they mature. Add a good freeze and howling prairie winds, and a stalk-rotted corn field can be laid flat. Thank goodness these are uncommon events in Hawaii.

Brown spot

Brown spot is caused by *Physoderma maydis* Miyake

Figure 8.2. Some prominent diseases of corn in Hawaii: A, maize mosaic virus; B, common rust; C, northern leaf blight; D, southern blight.

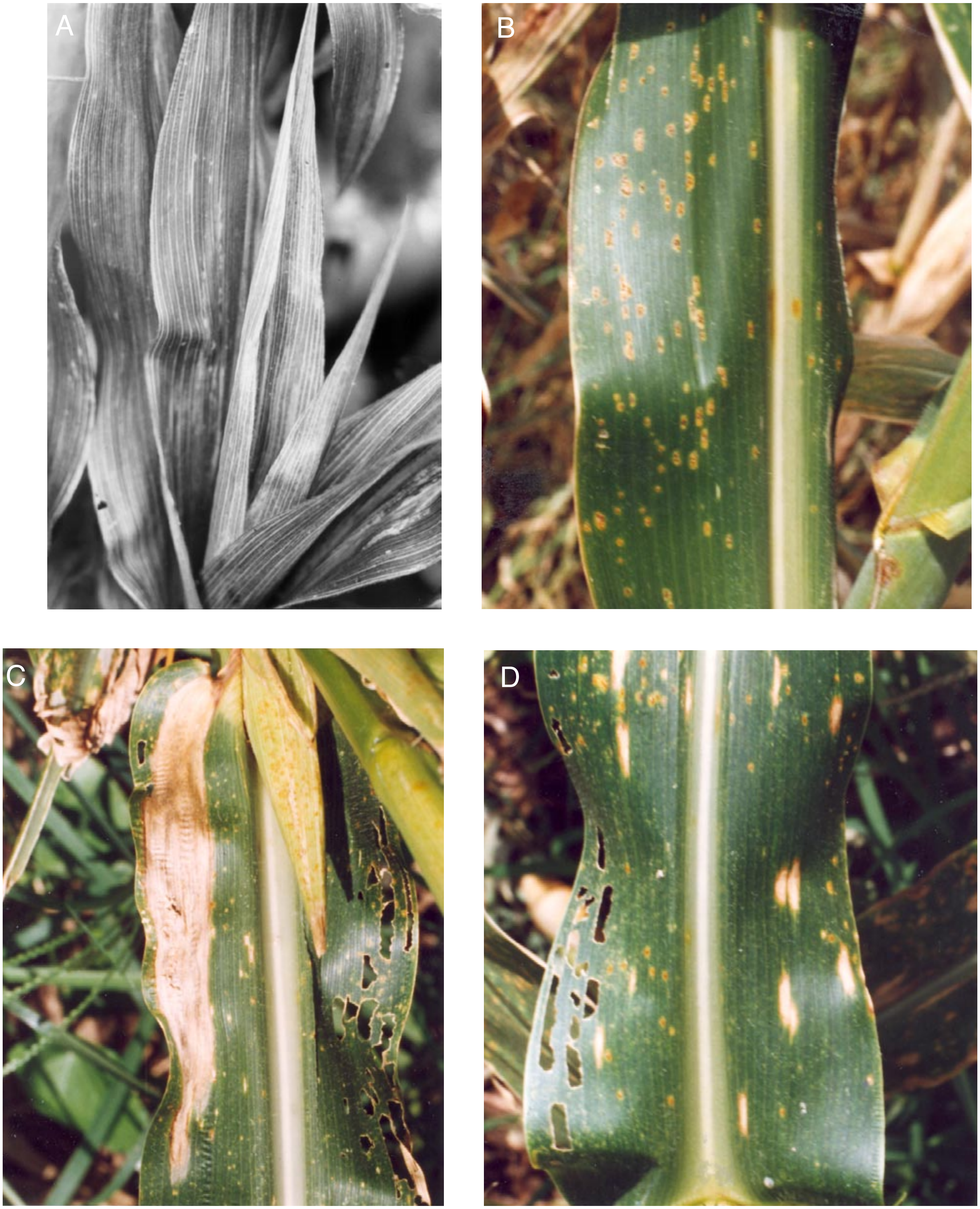


Figure 8.3. Hawaii's earworms really enjoy a U.S. mainland sweet corn.

Figure 8.4. Ear of a tropical corn inbred with 18 husks that provide a long, tight husk cover, minimizing insect

and may often be seen on corn in Hawaii, notably on temperate sweet corns. It is rarely serious enough to reduce yields. The fungus favors leaf sheaths and the base of leaves, where small lesions fuse to create brown, elliptical lesions. Sustained hot wet weather may be necessary to cause the banded leaf spotting that has been seen elsewhere, and much tropical corn germplasm is resistant.

Rots of seedling, ear, and kernel

Fusarium verticillionoides (formerly *F. moniliforme* Sheld.) and related fungal species are common in soils around the world. They can cause seedling death and rots of the stalk, ear, and kernel in Hawaii. Continuous corn production favors the fungus, especially when corn stalks and ears are plowed down, ensuring its survival in the field. Many U.S. mainland sweet and supersweet hybrids will not even germinate in Hawaii's soils previously cropped to corn, especially if planted without seed treatment in winter months. However, lines bred in Hawaii have high general resistance and germinate well. Many of the softer-kernel types, including the dent and floury corns, also cannot be grown in Hawaii without concern for kernel and ear rots that can reduce yield. Leaf spotting due to *Fusarium* spp. is uncommon or not easily recognized in Hawaii, although it may be serious elsewhere (e.g., Caribbean islands). Rotted ears may contain fusariform toxins that preclude their safe use as feed for animals.

Pythium spp. cause seedling damping off in many plants. This can become serious in corn fields following sustained rainy periods. The fungi are encouraged by continuous corn production and plowdown of trash.

Aspergillus spp. are aflatoxin-producing fungi that can develop on improperly dried corn kernels, but levels in Hawaii appear much lower than in the southern USA or the moist tropics. Two species, *A. flavus* and *A. parasiticus*, are common in warm soils throughout the world and infect many types of plants. On corn, they develop most rapidly in incompletely dried kernels with moisture content between 15 and 20 percent. They are characterized by a unique green mycelium on infected ears. Hard tropical flint corns show less infection, possibly because of their rapid rate of dry-down. Toxins with estrogenic activity are produced by other fungi that rot corn, but this has not been documented in Hawaii.

Smut

Corn smut is caused by *Ustilago maydis* (DC) Cda. and is present but uncommon in Hawaii. No description of these large, ugly smut galls is needed for the average corn grower. Smut occurs on ears, tassels, and cut stalks. The galls rapidly turn from gray to black and then ooze. In Central American tropical highlands, these mushroom relatives are harvested young as a delicacy known as "huitlacoche." Although most tropical corn germplasm is quite susceptible to smut, the disease is rare. Head smut (*Sphacelotheca reiliana* [Kühn] Clint) does not occur in Hawaii but can be serious elsewhere around the world.

Insects and mites

Hawaii has a dedicated quarantine service that generally has succeeded in excluding many of corn's worst insect pests. So far excluded are the stalk borers, European (*Ostrinia nubilalis*) and Asian (*O. furnicalis*), as well as a host of African and Central American worms (genera such as *Sesamia*, *Chilo*, *Eldana*, *Busseola*, and *Diatraea*) that can drill corn full of holes. The fall armyworm (*Spodoptera frugiperda*), a serious corn leaf and stalk feeder, has also been excluded. Nonetheless, many of the minor insects pests of corn (including thrips, aphids, leafhoppers, and beetles) have made it into Hawaii.

Rootworms constitute another great group of corn pests still not found in Hawaii. These include corn rootworms (especially *Diabrotica* spp.) and many types of cutworms (noctuid moths) and wireworms (including the click beetles). Hawaii does have some cutworms and armyworms that appear to be associated with corn only in grass pastures newly opened to cropping.

Corn earworm

The earworm (*Heliothis zea* Boddie) needs no introduction to Hawaii's farmers, for it has many hosts and is one of the most destructive insect pests of corn in the world (Fig. 8.3). In the USA alone it accounts for field corn yield reduction of 4 percent per year, and up to 15 percent in sweet corn. Hawaii-bred corns are highly resistant, and Hawaii's growers often simply cut off the tips of sweet corn ears to remove the worms and their damage.

The earworm hatches from eggs laid by a night-flying moth. The eggs are deposited along the stalk and in the tassel, but most are laid in the young silks soon after they have emerged. The larvae hatch within hours, crawl down the silk into the protection of the husk tip cover, and begin to feed. Earworms eat silk, kernels, and soft cob, and they cannibalize other earworms along the way. The typical U.S. Corn Belt sweet corn ear bears 7–9 soft husks that barely cover the tip of the ear, and it can host a half-dozen or more earworms (Fig. 8.3).

CTAHR breeders have achieved a high degree of earworm control by developing hybrids with many (10–13) tight husks. This restricts the silk channel to a very narrow size, and only one worm thus can make it down to the ear. An example is shown in Figure 8.4; each husk derives from one node in the shank that supports the ear. Insecticide controls are not recommended on CTAHR silage or grain hybrids.

Earworms can be controlled on sweet corns by several insecticides that are best applied at three-day intervals as a directed spray over the ears and central stalk. A transgenic form of resistance called BT has become available, as noted later in this chapter. Timing of the insecticide application is critical, and it should be before, not after, the silks emerge. Once an earworm gets down into the ear, no spray will reach it. Home garden control can be effected by using an eyedropper with a dilute solution of pesticide (labeled for use on earworms in corn), in water or mineral oil, and putting a few drops in each ear. Seed producers who harvest no corn as feed or food have a wider array of pesticide options.

Borers

The lesser cornstalk borer (*Elasmopalpus lignosellus*) evaded Hawaii's quarantine barriers and arrived in the 1980s, first attacking sugarcane and later corn. Its mature larvae are greenish and about 1 inch long. They can be found tunneling into young corn stalks at the soil surface. A warm-weather pest, they enjoy weedy fields on well drained soils. Good land preparation and high soil fertility appear to minimize injury. These borers are as yet restricted to a small area on Oahu.

Figure 8.5. Corn leaf with holes caused by rose beetle feeding.

Weevils

Grain weevils are among the worst pests of corn in the tropics. In Hawaii, the lesser rice weevil, *Sitophilus zeamais*, is the common weevil pest. It can reduce corn grain to powder and hulls in a few weeks. The weevils are black to reddish-brown, $\frac{1}{5}$ inch in length, with an elongated beak or snout familiar to most corn growers. Adult weevils live four to five months, laying 300–400 eggs in holes placed in the kernels and covered with a neat little cap (operculum). The eggs hatch to form white grubs that feed in the kernel, pupating and mating as adults in three to four weeks.

Rice weevils are best controlled by storing small seedlots in cool chambers (under 60°F), and they can be killed by freezing for a few days. Large lots of stored grain can be protected by adding diatomaceous earth, about 1 tablespoon per 10 pounds. Fumigation and various chemical treatments are possible but should be used only with proper advice and care. Early harvest and quick dry-down greatly reduce rice weevil infestation.

Planthoppers

Corn planthoppers (*Peregrinus maidis*) were mentioned earlier as the vector for maize mosaic virus; this insect is a pest primarily because it is a transmitter (vector) of viruses. There is no reason for corn producers in Hawaii, except seed producers, to grow corn that is not resistant to MMV. High populations of corn delphacids can cause "hopper burn" to seedlings but are found only in fields of susceptible hybrids, leading the author to suspect synergism. Systemic preemergence insecticides are used against this pest by seed producers and would be recommended for growers of temperate sweet corn hybrids.

Thrips

Thrips of several genera are found on corn worldwide. The genus *Frankliniella* is found in Hawaii. These tiny insects live on undersurfaces of young seedling leaves, causing them to become mottled and often silvery in appearance. Thrip development is favored by dry weather, and infection is much more serious when fields are under regular insecticide sprays. Pesticide-free Waimanalo plantings have rarely shown damage in the past 35 years, and none of it affected yield. This appears to be due to an abundance of predators and parasitoids of the thrips, insects that are lost from the ecosystem when insecticides are routinely applied. Thrips are often a serious problem for seed producers in Hawaii, who must rely on pesticides. Total losses of newly-germinated seedlings have been recorded by the seed industry in dry winters. Thrips appear to facilitate fusarium fungus damage to seedlings, and the high fusarium resistance of Hawaii-bred corns may also confer thrip tolerance.

Mites

Spider mites are represented by several genera, found worldwide, serious to Hawaii's seed producers but almost never seen at Waimanalo. Like thrips, they favor the undersurface of leaves and dry weather. *Tetranychus* spp. occur in Hawaii, and the females are red. Mites tend to be found piercing and sucking on older leaves, spinning silvery webs, and causing early leaf senescence and misery to any hand-harvester. As with thrips, the mite populations are reduced by many predatory and parasitic insects in fields that are not sprayed.

Aphids

Corn leaf aphids (*Rhopalosiphon maidis*) occur worldwide and are found on a large array of hosts in Hawaii (including sorghum, bermudagrass, asparagus, sugarcane, and panic grasses). Dry hot weather favors population increases. Corn is not a favored aphid host in pesticide-free Waimanalo fields, where many predators and parasitic wasps thrive. Aphids seek refuge in the tassels and under husks, however, and are a great nuisance to sweet corn growers.

Aphid parasites leave bloated mummies behind, while predators such as lacewing and syrphid fly larvae "leave no bones" (quoting Dr. Wallace Mitchell, in Brewbaker 1975). We discovered a recessive gene that confers tolerance to Hawaii's aphids, which may be a single race. The insects are only found as females, since they reproduce without resort to males, and without sex they should have no genetic variability.

Beetles

Rose beetles (*Adoretus sinicus*) eat almost anything in Hawaii, including corn leaves, and are familiar to every grower. The holes they create are unsightly and always draw the attention of people unfamiliar with corn pests, but the damage is rarely serious (Fig. 8.5). The beetles fly into fields in the early evening, avoiding lighted areas. Damage is heaviest on the margins of fields. The author has grown popcorns that the rose beetles ate right down to the leaf midrib, but most corn appears much less tasty.

Nitidulid or "pineapple" beetles also occur on corn. They feed on yeasts in ears opened by earworms or birds, but they are rarely serious.

Miscellaneous pests

Insects and diseases in Hawaii are complemented by several other pests, among them at least four introduced birds: parrots, pigeons, Brazilian cardinals, and pheasants. Charming house pets can terrorize corn fields, as witness the destruction to corn fields in Northern Australia by the beautiful golden cockatoos. Still rare in Hawaii, feral parrots could become serious pests in corn fields, for a parrot can husk and clean a sweet corn ear in minutes.

Brazilian cardinals and pheasants (*Phasianus colchicus*) do their damage at the time of germination. With unerring accuracy, pheasants will pull out every germinating kernel in a row of corn, and their only effective control on Lanai (according to Karl Manke) was a "pesticide" called buckshot. The cardinals and pigeons seek out the seed after plumule emergence, unfortunately killing the growing point while failing in most cases to unearth the rooted kernel. They are especially annoying on delay-planted seeds. Environmental protectionists appear to have effectively eliminated methods of controlling pesty birds in Hawaii, so a convenient device on a small scale is to feed them a couple times during kernel emergence.

Several rat and mice species infest Hawaii's fields. They are normally more serious on sweet corn and in weedy fields. Feral pigs are a serious grower problem in Hawaii. They can mangle a corn field, usually seeking a location safely away from roads and buildings. Feral deer, cattle, sheep, goats, and other large animals have been found in Hawaii's corn fields, not to mention ill-mannered and larcenous humans, easily the worst pest of corn in most of the tropics.

Pests and diseases Hawaii doesn't want

It should be evident that Hawaii has an important spectrum of corn diseases and pests, but there are many more that it doesn't want. Genetic resistance and adapted hybrids are generally available to handle all of the corn pests and pathogens now present in Hawaii. Breeding of added resistance is under way, anticipating that new pests and diseases will surely arrive in the future from the millions of tourists generally unfamiliar with the need to protect Hawaii's environment from unwanted pests. Continued vigilance in enforcing quarantine regulations is to be assumed. Similar vigilance on the part of seed producers and corn growers is of the greatest importance.

Serious insect pests of the world that are not now in Hawaii were described at the beginning of the discussion of insects, above. These included the stalk borers, cutworms, rootworms, armyworms, and wireworms. Many smaller insect pests also occur on corn outside Hawaii, of which a melange of virus-transmitting leafhoppers and planthoppers is of most concern.

Viruses lead any list of diseases of concern, as they tend to travel with their vector insect. Maize streak virus of Africa is awesomly destructive, although genetic resistance has been identified by former CTAHR student S. K. Kim and his colleagues. Virus-like myco-plasms and spiroplasms cause corn stunt in Latin America, transmitted by leafhoppers.

Several potentially serious corn leaf and stalk diseases not found in Hawaii include *Cercospora* leaf spot, Stewart's wilt, the downy mildews, and head smut. One of the new techniques of genetics, marker-assisted selection, affords a way to breed into corn resistance to these diseases before they arrive.

Early diagnosis is essential to keep all pests of corn in check. In most states of the USA the grower has access to many forms of technical assistance in the diagnosis and resolution of pest problems, including dealers in seed and pesticides, commercial pesticide applicators, grower organizations, farm publications, and many types of public agencies.

Compared to their U.S. mainland counterparts, corn growers in Hawaii are much more dependent on themselves, as well as on the resources and services of CTAHR at the University of Hawaii, and they should not hesitate to use (and help support) their university's public service. Assistance can also be sought from commercial seed producers and agrichemical suppliers on most islands. CTAHR's Agricultural Diagnostic Service Center provides, at little cost, soil analysis and plant tissue analysis, fertilizer recommendations calibrated to Hawaii's soils, and diagnosis of plant diseases and insect pests. Web sites of many U.S. agricultural colleges address corn production and its pests and diseases.

Pesticides and BT transgenics

Most fungicides and insecticides have restrictions for use that change faster than this manual can be revised to reflect current conditions. Hawaii's corn industry is of two entirely different types with regard to the value or necessity of pesticide use for insect and disease control. Hybrids that have very high tolerance of local pests are bred in Hawaii for the field, silage, and sweet corn industries. It is hoped that this will minimize or even eliminate necessity for insecticide sprays. The seed industry is based on unadapted temperate germplasm for the most part, and it must rely on regular use of pesticides to optimize seed production.

Transgenic corn cultivars based on the bacterium *Bacillus thuringensis,* referred to as BT, have been created to provide protection from chewing insects to corn, soybean, cotton, and many other crops. Sweet corn with construct BT11 was introduced into Hawaii in the year 2000 for its potential value in eliminating earworms. In Hawaii, the transgene has no advantage for control of boring insects. This earworm control comes at the expense of much higher susceptibility of these temperate hybrids to viruses and fungi. There is added concern that earworms will evolve resistance-breaking strains here in the tropics, where the worms are omnipresent year-round. Intellectual property rights precludes the use of BT11 by the public sector, e.g., in breeding CTAHR hybrids and open-pollinated varieties like 'Hawaiian Supersweet #9', widely valuable to growers throughout the tropics.

Chapter 9

Harvesting and the Harvested Crop

Grain

Chemical constituents

The grain of corn is an exceptional grass seed, noted for the energy it packs. Field corn grain consists of about 72 percent starch, of which amylose makes up about 27 percent and amylopectin the rest. Protein content averages 10 percent, most of which is in the form of an indigestible globulin, zein. Fats are largely in the embryo and make up an additional 4–5 percent of the kernel. The values for starch change dramatically in sweet and supersweet corns and in specialty corn mutants like *waxy* (no amylose) and *amylose-extender* (60 percent amylose). The endosperm and embryo of corn seeds differ markedly. Endosperms have 98 percent of the kernel's starch and 25 percent of its protein. The embryos have 85 percent of the fat, 80 percent of the ash, and 70 percent of the sugars.

Specialty corns

Specialty corn types are of increasing interest for industry and include high-lysine, high-oil, waxy, and low-lignin varieties. Better-known specialty corn types include popcorn and sweet corn. Specialty corns often involve changes in the chemical constituents of endosperm and embryo. Amino acid contents of corn have been the subject of intensive research to raise levels of lysine and tryptophane. These amino acids are normally found only at low levels of 150 and 40 mg/g N, respectively, in corn kernels. Two mutants, *opaque-2* and *floury-2*, raise these levels, but both result in floury kernels that are light in weight and difficult to keep free of insects and disease pathogens, which thrive on such kernels.

Hard-endosperm opaques have been bred for the tropics at CIMMYT, and are referred to as QPM ("quality protein maize"). These have the nutritional advantages of *opaque-2* but with a more crystalline endosperm. Their yields are said to be comparable to normal field corns. These high-lysine corns are of great value in human diets and in those of non-ruminant animals such as pigs and poultry.

High-oil corns are being bred to reduce costs of the soybean and other high-energy supplements to corn grain in feeds. However, high-oil corns have big embryos and smallish endosperms that lead to lower grain yields per acre. A newly patented process promises high-oil hybrids with up to 50 percent increase in oil and little loss of productivity.

Low-lignin corns have brown-midrib genes such as *bm3* that greatly reduce lignin and improve digestibility of stover. However, they were associated with a 20 percent reduction in grain and plant yields in Hawaii studies. These genes also increase susceptibility to lodging, which is not important to Hawaii's silage growers but could be for grain producers.

Time of harvest

Most tropical grain corn is harvested as food and must be carefully dried and protected from corn's many animal and insect pests (Fig. 9.1). Even in Hawaii, damage by rats and weevils can be great when field corn is carried to full maturity (<15% grain moisture) in four months. However, grain harvest must await stoppage of the flow of sugars from leaf to kernel, the stage known as physiological maturity. This can occur as early as 38 days after pollination. It usually involves the formation of a black cell layer, visible at the base of kernels sliced with a knife.

Following physiological maturity, grain loses moisture constantly at a linear rate. At 80°F in Hawaii, the grain will dry to about 15 percent moisture in about four weeks, losing about 1 percent of its moisture per day. Harvesting at full maturity in Hawaii always has to contend with the potential for loss from the rats and weevils or from lodging and ear diseases on susceptible hybrids or at higher plant population levels.

Moisture content is a critical factor in the storage of shelled corn, and it should be less than 13 percent for

Figure 9.1. Corn ears drying high above the goats on a Nepalese house.

long-term storage of large seed lots. When grain has more moisture, it heats up, which leads to molds that spoil the corn and may cause toxicity when the product is fed. Serious problems can arise from corn stored above 15 percent moisture, if well aired. This is due to aflatoxin production by aerobic fungi, discussed in Chapter 8 (on p. 56), which raises serious concerns for the health of both fed animals and humans.

Grain drying

Grain may be dried by forced-air or heated-air dryers on the farm, although custom drying at the granary is conventional on the U.S. mainland. Viability is lost if kernels are dried above 110°F, but corn for processing can be dried at temperatures as high as 140°F. Corn ears with grain at 35 percent moisture (physiological maturity) will dry to 13 percent in about four days with forced hot air (around 105°F), while ears at 25 percent moisture should dry down in three days. In dryer areas of Hawaii, however, ambient air alone can dry grain well. Rate of dry-down is directly proportional to the air volume moving over the ears.

Pricing of grain is based on moisture content, and the value of drying down must be adjusted accordingly. To calculate the change in weight from one moisture content to another, multiply the initial quantity (or price) by the ratio of the dry matter percents of the initial and final moisture contents. For example, 1000 lb of corn at 30 percent moisture will become X = dry weight = 824 lb at 15 percent moisture, obtained by the formula

$$X = 1000 \times (100 - 30) \div (100 - 15)$$

Several processing methods can be used to improve feed efficiency. One of them is to harvest high-moisture grain that is not fully dried down in the field. Ears harvested at 25 percent or higher moisture are as much as 8 percent more efficient as feedstuffs. Storage then requires acid preservatives or special silos to inhibit fungal molds. Greater increases in efficiency occur with processing, as in steam-flaked corn that is steamed for half an hour and then rolled. But then you could also feed cornflakes, a $4 box of which brings about 4 cents to the corn grower!

Green-chop and silage

Green-chop

Freshly harvested corn to be processed as forage or silage is known in Hawaii as "green-chop." It is an excellent energy feed for ruminant animals and is especially effective in optimizing milk yields from dairy cows. Grain is the conventional product of corn, facilitating long-term storage and certain types of processing. However, the feed value of corn is much greater (up to 35 percent more) when the whole plant is harvested. Ensiling the green-chop is not necessary in the tropics if year-round production and marketing permits continuous green-chop harvest.

Corn normally produces higher energy yields than other forage crops, especially in the tropics where grasses are often below 40 percent digestibility. Grass fields must be harvested almost monthly in the tropics to avoid loss of quality. Corn green-chop is mature in three months and is available with low labor and machinery costs. Harvesting corn as silage is often a matter of choice on the U.S. mainland, because low grain price or early frost makes silage a useful alternative to grain harvest. In Hawaii, however, silage harvest should be a target that determines the choice of hybrid and market plans.

Silage hybrids

It has been written that "corn hybrid selection is one of the most important management decisions in silage production" (Roth and Undersander 1995). Most modern corn hybrids have been bred to maximize grain and the ratio of grain to stover, and they are dwarfed in stature. Silage hybrids achieve maximal yields of total plant (grain + stover) by growing tall and lush as full-season hybrids. In Hawaii, most silage hybrids (Fig. 9.2) are 9–12 feet tall, flower in about 9 weeks, and reach physiological maturity 5–6 weeks later (i.e., 100–110 days to harvest as silage). Plant density is often increased greatly for silage compared to grain production.

Hybrids bred from tropical inbreds are generally superior in silage yield. These include the hybrids bred at CTAHR, those bred at CIMMYT, and those of commercial companies. Such hybrids are generally tall (10 ft), high-eared ($3\frac{1}{2}$ ft) and full-leaved (Fig. 9.2). They flower in about 9 weeks, and reach physiological maturity 5–6 weeks later (i.e., 100–110 days to harvest as silage). Silage corn often has a more casual plant stature, as opposed to the stiff-stalked dwarfs that dominate temperate grain production. Standability (lodging resistance) must be high for any hybrid to be planted under high population densities. However, due to the early time of harvest and to Hawaii's benign climate (rarity of strong winds, frost, etc.) the need for a stiff stalk is less critical here than in temperate regions. Resistance to diseases and pests should be optimized in order for the farmer to avoid use of pesticides over the corn plants themselves. CTAHR's hybrids are bred this way and can be grown pesticide-free.

Considerations at planting

Whole plant and grain yields "follow the sun" in the moist tropics. Monthly trials over a four-year test period produced grain yields at Waimanalo ranging from 1.8 to 4.9 t/A. This variation paralleled variation in incident sunlight during the grain-filling period (Fig. 1.4). Whole-plant weights also varied over 100 percent in crops throughout the year.

Plant populations were reviewed in Chapter 4, and Figure 4.1 showed that in CTAHR trials the maximal silage yields occurred at populations of 70,000 to 90,000 per acre. In practice, nearly similar grain yields occurred at 40,000 plants per acre. At this density, experimental small-plot trials maximized silage yield at 40 tons per acre (65% moisture), while higher densities were associated with unacceptable increases in lodging.

Fertilizer requirements of corn depend on density,

Figure 9.2. Typical silage-type hybrids bred from tropical inbreds in Hawaii, with Dr. Jay Chung.

expected dry-matter yield, and expected use of the crop. Figure 5.3 showed the amounts of N, P, and K removed when corn is harvested as grain vs. silage. Silage and green-chop corn remove twice the amounts of N and P as grain alone, while the potash removed is four to six times as great. Soil planted continuously to corn must be managed with care to replace the nutrients removed. Forage low in N has reduced digestibility, and weed competition alone can reduce corn fodder digestibility from a respectable 70 percent to less than 50 percent by stealing soil N. A rule of thumb is that the amount of N applied should be increased by 20 lb/A for silage vs. grain, and by another 20 lb if weed competition is unavoidable or weed control is impractical.

Considerations at harvest

Maximum yields for green-chop and silage occur after the grain reaches the stage of physiological maturity. At this stage the plants should be green, except for a few lowest leaves. Kernels will be at about 35 percent moisture, while the chopped materials from the entire plant should average about 65 percent moisture. Horizontal silos require somewhat higher moisture levels (65–70 percent) than bag or upright silos. The kernels should be hardened and glassy looking (dent corn will show deep denting). This stage can be estimated by snapping ears and viewing kernels on the side opposite from the germ or embryo. Little or no liquid ("milk") should show at the base of the kernel. Many hybrids will show a black layer at the base of cut kernels at this stage of physiological maturity. After this time, no further dry weight is accumulated by the kernels. Most hybrids reach this stage at about five weeks after silking in Hawaii's lowlands, or about 95 days after planting. In the winter or in highlands, these periods are stretched out in linear relation to temperature. The height of cutting at harvest affects forage quality, as the base of stems is of low quality and low moisture. Discarding the bottom 18 inches of plants (vs. a 6-inch cutting height) can increase crude protein 5 percent but reduces yield (as dry matter) by about the same amount.

A microwave test for silage moisture

Moisture content of fresh green-chop or silage can be estimated with fair accuracy using samples cooked in a microwave. Measure out (preferably in grams) a sample of 4–8 oz (about 100–200 g) and spread it on a plate. Cover loosely and cook on high for 4–6 minutes, then weigh; then cook again 1–2 minutes, weigh again, and repeat this until the weight does not change. If a 100-g sample dries down to 40 g, the moisture lost was 60 percent. Grain moisture can be measured similarly and should be around 35 percent at silage harvest.

Silos and silage-making

The reader is referred to the excellent guide to silage published by the American Society of Agronomy (Roth and Undersander 1995; see *References*). Ensiling results from a pickling process that proceeds very rapidly at high tropical temperatures and can pose serious challenges to growers. The faster the silo can be filled and the tighter it can be packed, the better. This pickling process should lead quickly to a beneficial acid bath (pH 4–4.5) in a low-oxygen (anaerobic) state. This will destroy rotting organisms without major loss of feed value. If corn is ensiled when over-mature, it does not pack tightly and can overheat. Aerobic (oxygen-using) organisms then cause it to mold. The same kind of spoilage, with losses to 30 percent of feed value, can occur if silos are not tight or bunkers are not solid-walled and well covered.

Horizontal or bunker-type silos on a concrete base predominate in Australia and Hawaii. If corn is harvested for silage too early, i.e., too green and wet, much feed value can be lost through leakage from the silo. Among additives that can improve the ensiling process, urea is the most widely used to raise protein content. About 10 lb of urea per ton of green-chop is recommended. Good quality silage will have

- high grain content (>40 percent by dry weight), indicating full maturity
- good storage quality with no mold
- high palatability from well timed harvest and care in ensiling
- good, sweet odor.

Nitrate toxicity can result from the accumulation of nitrates in lower stalks and leaves of corn. Little nitrate occurs in grain or the upper leaves. High nitrate levels can cause poisoning problems with ruminant animals, in which nitrates are converted to nitrites in the rumen. Animals can show symptoms such as pink eye, abortion, and reduced weight gain or milk production. The problem is largely restricted to cattle grazing on old corn fields, after grain is harvested. Nitrate levels increase in stover under high N regimes, drought, high plant populations, cloudy weather, and micronutrient shortages. This is unlikely to become a problem in green-chop or silage in Hawaii, and nitrate levels can be measured by simple tissue tests. High-nitrate silage can be safely fed when supplemented with grain, urea, vitamin A, and iodized salts.

Vegetable corns

Baby corn

The immature ears of any corn can be eaten and are best before any seed development takes place. Thus it is the young cob that is eaten as a vegetable, usually prepared in combination with other vegetables, because it nicely soaks up flavors from its surroundings (e.g., in stir-fry). Commercial production of baby corn should be based on seedless hybrids that are made genetically male-sterile.

Supersweet corn

Chapter 3 discussed the various types of corns available for use as a vegetable. Among these, the best for tropical production are supersweets based on a gene called *brittle-1*. The quality of sweet corns lacking this gene is as fragile as a snowflake in Honolulu and is quickly lost after harvest. Hybrids bred at CTAHR are superior in disease and insect tolerance and are robust and dark

Figure 9.3. 'Waimanalo Supersweet' hybrids harvested in 10 weeks, with Xuebo Xhi.

green at harvest, about ten weeks after planting (Fig. 9.3).

Postharvest handling of sweet corn is a major problem for producers and markets in the tropics. U.S. mainland varieties of sweet corn lose quality so drastically by the time they are marketed that they would be considered barely fit for pig feed. The image of rushing sweet corn from the field to the boiling pot to get the best flavor is indicative of the speed with which the old sugary varieties converted sugar to starch after harvest. The supersweet varieties, even when eaten raw in the field, are routinely found by Hawaii's visitors to be of superior quality to the sweet corns they are accustomed to. The amazing advantage of the UH supersweets is that with proper handling they can retain superb table quality for up to three weeks.

Supersweet corn retains its quality best if chilled promptly after picking. In commercial production, the ears can be field-chilled with ice water or crushed ice. Commercially, they are often stacked in boxes of four to five dozen ears. A short chilling period will stop enzymatic activity. When ears of supersweets are then placed under refrigeration, they will retain quality for several weeks. As with other vegetables, vacuum packing in plastic produces an attractive, high-quality, and highly marketable product.

Figure 9.4. Hawaiian supersweet ears at harvest stage, husked and unhusked.

Time of harvest

It is critical for vegetable corns to be harvested at the correct time, a "window" of perhaps three days. They should be harvested when the kernels are fully distended but before the deposition of starch (Figure 9.4). In Hawaii, this is normally between 17 and 20 days after silks emerge. Temperature is the controlling factor, and hot summer days accelerate maturity. The judging of maturity is a task for the experienced picker, and time to maturity varies slightly among hybrids. Normally, the silk will have just turned to a deeper color and withered slightly. Supersweet corns average around 75 percent moisture, and sweet corns average around 72 percent. Many UH hybrids show a mixture (3:1) of dark yellow and pale yellow seed colors at the time of peak maturity.

The tip of the ear will feel well filled at the sweet-corn stage. At this stage, the kernels have full color, and when subjected to the thumb-nail punch test, they burst. Ears rarely fill to the very tip under Hawaii's short tropical days. Do not expect tropically bred corns to expose the ear tip at maturity (Fig, 9.4), as this is an invitation to severe earworm injury and even worse consequences (birds, rats, beetles, yeasts, molds). It would be nice if an occasional frost would remove these factors, but they are omnipresent in the tropics and force breeders to select ears that have long, tight husks with no chance of eartip exposure. Again, the choice of temperate hybrids with few, thin husks risks major crop injury and yield loss in the tropics.

The postharvest quality of corn depends entirely on its genotype (Chapter 3). Field and waxy corns are eaten as a vegetable in many tropical countries, and they can be stored many hours or days without major quality loss. Field corns can also be harvested at late sweet-corn stage, and the embryo and endosperm can be squeezed out of the pericarp with the back of a knife for use in corn fritters. Loss of sugars leads to rapid diminishing of quality in sweet corns based on the *sugary-1* gene or gene combinations with *sugary-enhancer*. The supersweet corns, based on genes such as *brittle-1* and *shrunken-2*, are much less fragile, but care in postharvest handling will create a quality market willing to pay the price for their exceptional quality.

Chapter 10

The Corn Seed Industry

Accelerating genetic progress

The corn seed industry seeks to provide growers worldwide with high quality hybrids and varieties, and is under constant pressure to accelerate genetic progress. This progress with corn seeds is basically a function of the number of generations required to create new germplasm. Three primary processes are involved: *population improvement* by selection among segregating materials, *inbreeding* for the creation of new lines, and improvement of existing inbreds by *backcross conversions*. In most examples, from 8 to 20 generations are required to complete these creative processes. Once created, the "breeder's seed" will be in limited quantities (ounces or pounds), and major increases are required to provide the "foundation seed," also known as "parent seed," for large-scale evaluations in experimental and on-farm trials. Hawaii has come to play a major role in accelerating genetic improvement of corn.

Winter nurseries

Corn is a plant that cannot easily be bred in greenhouses. Breeding nurseries during temperate winters are grown in the tropics to accelerate genetic progress. Among the regions to which breeders have gone for winter nurseries are Hawaii, southern Florida, Puerto Rico, Mexico, Chile, and New Zealand. Multinational corporations arrange for their own facilities and crop lands, while contractual services also have been created to accommodate the needs of smaller seed producers and university scientists.

Year-round nurseries

A transition from winter nurseries to year-round nurseries occurred in the 1990s. Year-round breeding was initiated at UH as early as 1970, with small and highly manageable breeding nurseries planted essentially every month of the year. These trials illustrated that Hawaii's climate is suitable to year-round production, and that rapid genetic conversions involving 10 generations could be made in only three years. During that period, genetic conversion of otherwise-excellent inbred parents became a major task for breeders, notably with transgenics. At the same time, the small-scale increases of parent seeds were shown to be financially sound in places like Hawaii. This prompted most corn seed companies to convert to year-round breeding and seed production of corn in Hawaii. Several thousand acres are now occupied annually by the seed industry, a major transition from the first 5-acre winter nursery that we founded on Molokai in 1966. These seed companies are now located on most of the islands of Hawaii and constitute a significant think-tank industry (acreages and values were summarized in Chapter 1, Fig. 1.1 and 1.2).

Hawaii's seed industry

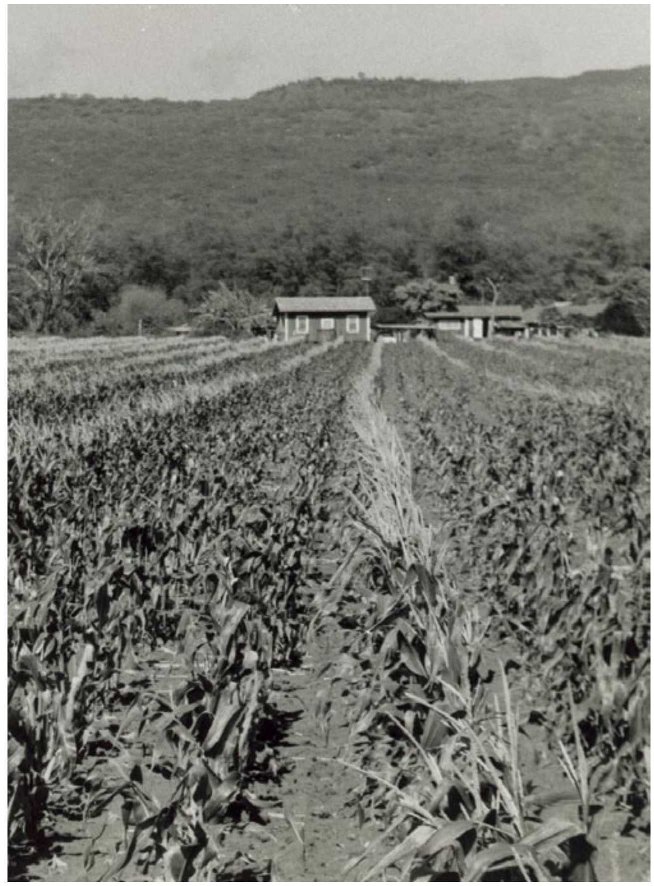
In 1960, the corn seed industry of the USA involved about 200 companies with a $50 million annual investment in research. By the year 2000, mergers had occurred involving most of these companies. Many mergers involve pharmaceutical giants (Aventis, Ciba-Geigy, Dow, duPont, International Chemical, Monsanto, Novartis, Syngenta), reflecting the increasing interest in transgenic varieties and special corn products. Essentially all of the major companies have year-round operations in Hawaii.

Hawaii's seed research is not confined to American seeds—breeders from Europe and Asia have sent seed. In the tropical winter, the most challenging germplasm is from north temperate regions such as Canada and France. It is normally preferred to grow these in winter nurseries at approximately the same latitude south, in Chile, Argentine, and New Zealand.

Three major functions occur in most seed industries: breeding nurseries, parent seed increases, and grow-outs. Breeding nurseries (Fig. 10.1) are laid out for hand-pollination in short rows, blocked for convenience in pollination. The blocks include ear-to-row progenies for self- or sib-pollinations, paired-row inbreds to be

Figure 10.1. Precision planting of corn breeding nursery in 5-m plots of CIMMYT in Texcoco, Mexico (see also Chapter 4).

Figure 10.2. A corn hybrid production field on Kauai, with one male row (with tassels) to two female rows



intercrossed, and large blocks for self or sib increase. Often every plant in such nurseries will have a Lawson 402 tassel bag covering every hand-pollinated ear, on silks protected previously by Lawson 217 ear-shoot bags. Tassels are often removed from pollinated plants to slightly increase grain yield. Many breeding nurseries involve transgenic conversions that can introduce many exotic genes into this ancient crop.

Parent seed production fields (Fig. 10.2) are usually isolated by a distance (600 ft or more) or by time (one month or more). This may involve open-pollinated increase of inbreds or the production of a hybrid with increase of the male parent inbred. Timely production and shipment of seeds to the U.S. mainland are essential.

Grow-outs are observational nurseries for the purpose of identifying off-type plants. These are largely of inbred seedlots intended for commercial production, to identify the vigorous off-type hybrid contaminants. It also includes testing of hybrids to identify rare selfs of the inbred parents.

History of Hawaii's seed industry

Cooperative trials were conducted in the winters of 1964–65 and 1965–66 by the author (Brewbaker 1969) and seed producers Don Shaver (Cornnuts, Inc.) and Clarion Henderson (Illinois Foundation Seeds) to evaluate some Mainland corn inbreds. Their performance attracted serious interest, and a 5-acre test planting was made in late 1966 on Molokai. The following spring we described these experiences in a paper on winter corn seed production on Molokai (Brewbaker and Hamill 1967). Later, the results were presented at the annual meeting of the American Seed Trade Association.

Illinois Foundation Seeds and Cornnuts collaborated in establishing Molokai Seed Service and were joined later by Corn States Ltd., which set up Hawaiian Research Service on Molokai with a large initial planting for Pioneer Hi-Bred International. The industry rapidly expanded from the 5-acre Yoshida farm on Molokai to 500 acres in 1968–69, with Trojan Seed Co. on Maui, Pioneer Hybrid International on Kauai, and Pride Division, Northrup-King, on Kauai. Dole Pineapple (Castle & Cooke) conducted corn tests on Lanai under Karl Manke, and continuing evaluations were made at CTAHR research stations on several islands. In 1969, there were about 41 acres on Kauai, 120 on Maui, and 430 on Molokai (see Fig. 1.2 for more recent acreages).

Sugarcane production in Hawaii declined dramatically between 1980 and 2000, from 250,000 acres to 50,000. A major decline also occurred in pineapple acreage. Both of these trends liberated tillable acreages often suitable to corn seed and diversified crop production. The bold increases in acreage and values of Hawaii's seed industry (Fig. 1.2, 1.3) reflect this opportunity.

A unique production regime

Unique environments are demanded by the seed industry, whose primary months of production are during Hawaii's worst weather. The industry has thus concentrated on the leeward portions of the islands, where sunlight is maximized and rainfall minimized. These regions had formerly been favored for sugarcane production, which is no longer a formidable competitor for land but may still be attractive for tourism-related development. Loss of these fine agricultural lands is irreversible. The acreage demands of the corn seed industry remain relatively small in the context of the hundreds of thousands of acres becoming available for crop production in Hawaii.

Unique germplasm characterizes Hawaii's corn seed industry, for it is almost wholly temperate. Much of it is ill-adapted to short winter days (11–12 hours during seed development). Almost all of this germplasm is susceptible to the leafhopper-transmitted maize mosaic virus. Most of it is very susceptible to common and southern rust and to northern blight, prevalent in Hawaii's winter months. There is no thought of trying to grow such valuable but unadapted germplasm pesticide-free!

Unique pesticide regimes are imposed by the seed industry, reflecting the value and the high quality expected of germplasm produced by the seed industry. Seeds are treated before planting, and preemergence insecticide is usually incorporated at the time of planting for control of leafhoppers and thrips. Subsequent insecticide and fungicide treatments are applied on a 5–7 day regime, and scouting for any new outbreaks is rigorous throughout the growing season. One result of this insecticide regime is that many predators and parasites of corn pests are also eliminated or reduced in population. These insects serve to greatly reduce the severity of damage from thrips, leafhoppers, aphids, and mites in pesticide-free fields to levels of insignificance, as is the case at CTAHR's Waimanalo Research Station.

Unique production patterns are involved, based largely on a Mainland October harvest and a November planting in Hawaii. Pollination is normally focussed on the first weeks of the new year, with seed harvest in time for return to North America packaged for summer plantings in April. These production months are among the worst for sunlight in Hawaii (see Fig. 1.4) and are often the best for rainstorms, which has driven the seed industry to the drier leeward locations.

Hawaii Crop Improvement Association

The Hawaii Crop Improvement Association, founded by the author in 1969, serves the seed producers of Hawaii and includes members from all the major companies. Annual meetings are held to review policies of the state and USDA, to address research issues of common concern, and to exchange information. Several conferences have led to publications (see *References*). This seed industry has grown to be one of Hawaii's most valuable (and underappreciated) think-tank industries. It involves hundreds of local and visiting scientists annually, and it was valued at $40 million in the year 2001. Like other agricultural industries, it has a major "multiplier effect" of 200–250 percent in the communities it serves. It offers intellectual job opportunities to young scientists and academic training for UH student field trips.

Corn is only one of the crops HCIA presently serves; others include sorghum, soybean, and sunflower. The seed industry can be expected to expand to other crops (e.g., ornamentals, papaya, coffee, forest trees) and other challenges in the future, and it fully deserves the interested support of universities and colleges, industries and land owners, and governmental agencies within the state of Hawaii.

Appendix 1

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Web sites

www.agry.purdue.edu/ext/corn/cgg4.htm
A useful list of Web sites dealing in almost any way with corn, covering production, a list of seed growers, breeding, genetics, diseases, etc.

www.hawaiiag.org
Statistics are combined here for all of Hawaii's agriculture: crop production statistics, crop pests, crop diseases, crop management considerations.

www.acga.org
American Corn Growers' Association; since 1987; information on production major U.S. crops, yields, grower income.

www.aphis.usda.gov/biotech
Animal and Plant Health Service of USDA, biotechnology regulations and procedures for transgenic corn.

www.ncga.com
National Corn Growers Assoc.; since 1957; 130,000 members; products from corn, marketing, national production figures by state; includes an extensive list of nonfood, nonfeed uses of corn at *http://lepton.marz.com/ncga/comm_dev_center/index.htm* (accessed 9/2/03).

www.cimmyt.org/english/webp/research/maize
International Center for Maize and Wheat Research; summaries of maize research, release of germplasm.

www.nass.usda.gov/hi/speccrop
Hawaii production data for seed industry and forage crops.

w3.aces.uiuc.edu/maize-coop
Information on Maize Genetics Coop, stock center collection of mutants of maize, with photos and detailed information.

www.agron.missouri.edu/images.html
Information on maize genetics; includes photos of mutants from *Mutants of Maize*.

www.boh.com/econ
Economic reports on business and agriculture in Hawaii.

www.necga.org
Nebraska Corn Growers Association, one of many state-based associations.

Appendix 2

Some Favorite Recipes for Hawaii's Supersweet Corn

Picking
Ears are ripe 18 days after the silks appear, or about 10 weeks after planting. Pick when the tip of the ear feels well filled and the silks have changed from whitish to brownish. Eat fresh if you like; they are excellent.

Tender loving care
Please put ears into the refrigerator or onto ice within an hour! These ears are growing and respiring, and they will overcook without your help. In a hot car, for example, they will lose all that precious flavor and sweetness in two hours.

Cooking
Try 2 minutes per ear in microwave, or until the corny smell is evident. Or leave husks on and grill 5–10 minutes. Or steam-cook. However, don't boil forever immersed in hot water! If you must, throw out the corn and drink the water.

Freezing
Most recipes calling for frozen corn assume you've blanched the ear, chilled it in ice water or the freezer, cut the kernels off with sharp knife, and frozen them in ziploc bags (two to three ears = 1 cup). Baby ears can also be frozen similarly.

Corn fritters
Beat yolks of 3 eggs, mix in 2 c corn, season to taste; then add $^1/_4$–1 c flour (more for "oysters," less for pancakes). Fold this into the 3 stiffly beaten egg whites. Fry in corn oil in wok at 350°F. Serve with coconut syrup or powdered sugar. Variations include the addition of chopped onions and peppers.
(Note: You can use young field corn for this, harvested at sweet-corn stage; scrape off all the rich juices from the ear! Either supersweet or field corn ears can be frozen forever.)

Supersweet corn salad
Vegetables can include 2 c corn, $^1/_2$ c each chopped pepper, tomatoes, and onion (plus celery, parsely, etc.). Mix 2 tbsp oil with 2 tbsp red wine vinegar and a package of taco seasoning; pour over vegetables to marinate an hour or so before eating.

Supersweet corn relish (salsa)
Combine $^1/_2$ c white vinegar, $^1/_2$ c water, $^1/_4$ c sugar, 1 tsp dry mustard, 1 tsp salt, 1 tsp pepper, 1 tsp celery seed, $^1/_2$ tsp turmeric. Bring to boil and simmer a few minutes. Add 2 c corn, $^1/_2$ c chopped onion, and 1 c chopped red/green peppers and bring back to boil. Then refrigerate, stirring occasionally. Like most salsas, this will last a long time in the refrigerator.

Spicy creamed corn soup
Saute $^1/_2$ chopped onion in butter, add and simmer 2 cups corn and $^1/_2$ c chicken stock (or two boullion cubes + $^1/_2$ c water) and some minced parsely. Then toss into blender and back to saucepan with more butter and 1 c milk. Season with salt, pepper, chili pepper, and paprika or curry to taste, bring to boil. Take off the heat and top with $^1/_4$ c whipping cream. Serve hot or chilled. Four servings.

Corn malunggay soup
(Malunggay is *Moringa oleifera*, a tree with small green leaves favored in the cuisine of the Philippines.)
Make your favorite malunggay soup and add 1 c corn. Or: saute garlic and onions with chopped-up chicken for a few minutes. Add 5 c water and 1 c corn and simmer 15 minutes. Season with salt and patis (fish sauce), add 1 c malunggay leaves, simmer some more.

Corn bisque and seafood (crab, shrimp, prawn, lobster)

Make your favorite bisque; add 1 c corn. Or: simmer shells in 2 c milk for 15 min, strain. Melt 2 tbsp butter in saucepan and stir in 2 tbsp flour for 3–5 min to make roux; then gradually add the 2 c of hot milk, stirring to thicken. Then add chopped seafood, 1 c corn, $\frac{1}{4}$ c sherry, a little paprika, salt, pepper. Simmer 5 min. Top with $\frac{1}{2}$ c whipping cream (warmed) if no dieters are around.

Stirfry

(Supersweet corn is great in stirfry, but baby corn is super! Pick, blanch, freeze your own.

Toss in the baby ears early, to soak up all those nice flavors; or, add frozen supersweet kernels for the last couple of minutes.

Scalloped corn

Mix 2 c corn, $\frac{1}{2}$ c milk, 1 c bread crumbs, $\frac{1}{2}$ chopped onion, $\frac{1}{4}$ c chopped pepper, salt, and pepper. Pour into greased 1-qt. casserole, dot with butter, bake at 350°F for 30 min. Serves 6. Many versions of this recipe exist.

Polenta

(Don't leave this only to Italians; delicious!)

Follow recipe on box of polenta or corn meal, adding $\frac{1}{2}$ cup supersweet corn kernels together with the grated parmesan for the last minutes of cooking. I like it made with Hawaii's rich milk and an egg.

Corn soufflé

(Bake this inside Hawaii-grown peppers!)

For a 4-serving soufflé, saute 1 c corn kernels, some oregano, and $\frac{1}{2}$ c chopped peppers in butter; stir in $\frac{1}{4}$ c cornmeal and 1 c milk; simmer 5 min. Remove from heat, stir in $\frac{3}{4}$ c shredded cheese (jack, cheddar, parmesan) and 3 egg yolks and 3 whipped eggwhites. Bake in 375°F oven for 35 min.

Steamed maize bread

(From "Maize on the Menu" by S. Africa's Home Economics Dept. of the Maize Board)

Mix $\frac{1}{2}$ c flour, $\frac{1}{2}$ c cornmeal (or polenta), 2 tsp baking powder, a little salt, 1 tbsp sugar. Beat well 2 eggs, 2 tbsp oil, and a little milk. Put 1 c corn in blender with $\frac{1}{2}$ c milk. Then mix all this stuff together and pour into a well greased 1-qt pan. Put into your steamer in the wok for about 2 hours. Surprising!

Supersweet ice cream

(No kidding—visit Manila!)

When making your next batch of ice cream, don't add strawberries, but try $\frac{1}{2}$ c supersweet kernels (cooked). Or if you prefer less stuff in your teeth, toss corn into blender and add the soup.

Supersweet milk

You can go to Bangkok and buy this. Or, make your own; pick ears a little mature (e.g., 22 days after pollination). Microwave-cook, cut kernels off ears, and put in blender with a small amount of water. Then add more water, blending at highest speed until frothy. Pour through cheesecloth, adjust sweetness by adding sugar, chill rapidly (e.g., in freezer). Drink fresh or within a few days.

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(References are to chapter number, not page)

Six problems encountered in corn production in Hawaii

poor pollination due to strong tradewinds

turcicum leaf blight

corn earworm

tropical corn rust

plants stunted by maize mosaic virus

corn smut (uncommon)

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