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Vegetable Production Series

SWEETPOTATO PRODUCTION IN CALIFORNIA

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PRODUCTION AREAS AND SEASONS

In 2011, California sweetpotato (*Ipomea batatas*) production for processing and fresh market consumption was estimated to be a \$130-million industry, with production of about 582 million pounds on 18,200 acres. In an average year, California produces 20% of the sweetpotatoes grown in the United States and is the second-largest-producing state, behind North Carolina. While sweetpotatoes are usually regarded as a Southern crop, California production exceeds that of Louisiana and Mississippi combined. Merced County accounts for approximately 90% of the commercial acreage planted to sweetpotatoes in California, but they can be grown in many of the warm agriculture production areas of the state.

The primary production area for sweetpotatoes is in sandy soils between Atwater and Turlock in Stanislaus and Merced Counties, centered on the Highway 99 corridor in the center of California. Additional commercial production occurs in Kern County. Typical highly productive soils are sandy to loamy sand in texture. Yield and quality are poorer in heavy soils.

Hotbeds for producing transplants are typically installed from the first week of February through early March. Transplanting from the hotbeds begins in late April and continues into June, though transplanting for seed fields may occur as late as July. Commercial harvest from early plantings begins in mid-July, but crop yields are low at that point so the amount of the harvest is limited. Regardless of location, the bulk of the harvest occurs in September and October, when the roots are dug out and placed into storage. Harvest usually is complete by early November.

SWEETPOTATO ACREAGE AND VALUE

Year	Acreage	Average yield (tons/acre)	Gross value/acre
2007	13,300	14.00	\$7,000
2008	14,500	14.75	\$8,968
2009	17,400	17.00	\$9,112
2010	18,500	17.25	\$8,627
2011	18,200	16.00	\$7,072

Source: USDA—National Agriculture Statistics Service

CLIMATE

Sweetpotatoes are a warm-season, frost-sensitive crop. Daily maximum air temperatures between 85° and 95°F (29.7° and 35.3°C) are ideal for root production, but temperatures above 100°F (>38°C) are not harmful so long as the crop is adequately irrigated and temperatures drop at night. Recent growth chamber research has shown that high day/night temperatures (95°/80°F [35°/27°C]) result in decreased storage root production, but in production areas of California elevated temperatures like this rarely occur at night. Because they are sensitive to even a light frost, sweetpotatoes are planted in spring after any chance of frost has passed. For the same reason, the crop must be harvested before the autumn onset of heavy frost and cold rains, since the roots may sustain chilling injury if they are subjected to temperatures below 50°F (10°C) for even a few hours.

VARIETIES, PLANTING TECHNIQUES, AND SOILS

The edible sweetpotato is an enlarged storage root that grows in various shapes, sizes, and colors. Varieties, particularly those grown for market use, fall into four categories based on their skin color and flesh characteristics: red skin with orange flesh (so-called "red yams"), copper-rose skin with orange flesh ("yams"), cream-tan skin with yellow flesh ("sweets"), and burgundy-purple skin with white flesh ("Oriental"). Most packers have a supply of all four types, though some will specialize in certain types more than others. Orange-flesh sweetpotatoes have a moist texture after baking, whereas sweets may not.

Diane is the main cultivar for the red-yam category. It is characterized by dark red, smooth skin with deep orange flesh. These qualities make it the premium yam-type sweetpotato. At the retail level, it is often labeled incorrectly as Garnet, which was the red-skinned variety that established this market class in the 1970s. Diane is marketed mainly in California, where red-skinned sweetpotatoes are

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popular and often command a higher price. The yam types Beauregard and Covington have copper-colored skin with deep orange flesh. For 20 years, Beauregard was the most commonly grown variety in California and the United States, but in 2009 it was displaced by Covington. Beauregard, while susceptible to nematode damage, has yield and storage characteristics that are superior to those of Covington, but Covington is adaptable to a wider range of growing environments and has better resistance to diseases and nematodes.

Golden Sweet and O'Henry are major varieties in the sweets category. They are characterized by their cream-colored outer skin and yellow interior flesh. Dry matter content for Golden Sweet is typically 30 to 35%. O'Henry has recently displaced Golden Sweet in both acreage and production. O'Henry is actually an off-type Beauregard that naturally mutated to have white skin and yellow flesh. It contains about 20 to 22% dry matter and does not have the dry-flesh flavor and texture profile of Golden Sweet.

Oriental types, and most commonly Japanese yams, make up an important and growing part of the California sweetpotato industry. These include a variety of flesh and skin colors, including white, purple, and red, but their flesh is typically drier than that of a Beauregard, with a more subtle flavor. The most common varieties are Kotobuki and Murasaki-29, both of which have burgundy skin and white, dry flesh.

Recently released sweetpotato cultivars have been granted patent protection, and growers are legally restricted in the sale and distribution of these roots for propagation. Both Covington (released from the North Carolina State University Agriculture Experiment Station) and Murasaki-29 (from Louisiana State University Agriculture Experimental Station) are patented. Future releases of new varieties, like the sweet variety Bonita released in 2012, will carry similar restrictions. Proceeds from the sale of plants and roots from these varieties support the breeding programs that developed them.

Sweetpotatoes are vegetatively propagated from plant cuttings, called "slips," from hotbeds. "Hotbed" is the name used for the nursery area where sweetpotato roots saved from the previous year are used to produce new plants for the production fields. These "seed roots" for the hotbeds typically are placed on the ground in February and covered with a shallow layer of soil. Medium-sized potatoes are typically used for this purpose, but any size root can be used to produce sprouts. Commercial hotbeds in California are typically 8 feet (245 cm) wide and may be several hundred feet long. For warmth, clear plastic is stretched over iron rods bent into half hoops over the bed to form an elevated plastic tunnel running the entire length of the bed. Hotbeds are so

named because they are warmed by the decomposition of cotton gin trash that is buried under the roots. Cold beds, which do not use gin trash, are also used for propagation. It takes approximately 500 to 800 pounds (225 to 365 kg) of roots, depending on the variety, to furnish cuttings for a 1-acre (0.4-ha) planting of the crop.

Sprinklers are used to irrigate hotbeds until the plants are ready to be transplanted—when they are about 12 inches (30 cm) tall. The plants are then cut at or slightly below the surface of the soil. Cuttings from the hotbeds are mechanically transplanted in two rows on 80-inch (200-cm) prepared beds from mid-April through the end of June. Most fields are drip irrigated, but some are furrow irrigated. Cuttings are watered heavily at transplanting and then surface-applied drip tape is set on top of the beds between the two rows. Cuttings are planted 9 to 15 inches (23 to 38 cm) apart within the row. Typical plant populations are 13,000 to 17,000 plants per acre.

Soils selected for sweetpotato production generally range from sand to loamy sand in texture, are well drained, and are low in salts. While the plants can grow in heavy soils, root yield and quality will be reduced. Acidic soil conditions (pH 5.5 to 6.5) are preferred, as this helps suppress pox, a root disease. Sweetpotatoes are moderately sensitive to soil salts: a 10% reduction in yield can be expected if soil electrical conductivity (EC) exceeds 2 dS/m. Furthermore, roots grown in salty soils do not store well and are more likely to develop the abiotic disorder "tip rot" after a few months in storage.

IRRIGATION

More than 95% of sweetpotato fields use drip irrigation; the remaining acreage uses furrow irrigation. Unlike many transplanted crops, no sprinklers are used to establish the crop, nor are the fields typically pre-irrigated. Producers rely on copious amounts of transplant water (> 2,000 gallons per acre [> 19,000 L/ha]) and the expeditious installation of drip system lines to keep water stress at a minimum for the newly planted crop. Maintaining adequate moisture in the soil immediately surrounding the plants for the first 17 days after transplanting is critical to promoting the initiation and development of storage root cells. Surface drip is used because of root intrusion problems in buried lines. A typical installation has one drip line running down the center of an 80-inch bed, irrigating two rows of plants. Occasionally the drip line will be moved from the center of the bed and placed directly in the plant row to facilitate early root growth, but this is generally avoided because it stimulates weed germination in the plant row.

Irrigation frequency depends on the crop's evapotranspiration (ET) requirements and the water-

holding capacity of the soil, but may be done daily once the plants are fully established. Total water use typically ranges from 2.5 to 3.5 acre-feet per acre. Irrigation cut-off dates vary depending on crop development and harvest schedule. Irrigation should be halted when jumbo-sized roots exceed 33% of total root production, unless the crop is slated for processing and maximum total tonnage is desired. There is no evidence to support the practice of discontinuing drip irrigation 2 to 4 weeks prior to harvest in order to toughen the skin and minimize harvest losses, but such practices do reduce the development of scurf if the roots have already begun to develop this disease (see Pest Management, below).

FERTILIZATION

Sweetpotatoes have an extensive root system and make efficient use of soil nutrients. The vines and leaves respond better to applied fertilizers than do the roots. On average, the crop removes 2.7, 1.0, and 4.5 pounds of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) per 1,000 pounds of harvested roots. Phosphorus (P), potassium (K), zinc (Zn), and boron (B) fertilizers should be applied preplant or immediately after transplanting, as determined by soil tests. Up to one-half of the crop's N requirements can also be applied at this time, with the remainder applied later through the drip tape to match the growth characteristics of the field. Because the cuttings used for transplants are rootless, they are very sensitive to fertilizer burn, so inclusion of fertilizers in the transplant water is not recommended.

High-yielding, drip-irrigated fields require N rates of 125 to 175 pounds per acre (140 to 200 kg/ha), one-half of which is applied through the drip tape during the first half of the season when the plants are rapidly growing. If P is needed, 50 to 100 pounds of P_2O_5 per acre (56 to 112 kg/ha) is applied before planting. Potassium (K) is readily taken up by the leaves and roots of the crop, but has been shown to have only modest impacts on sweetpotato root yield. If required, 200 to 250 pounds of K_2O per acre (225 to 280 kg/ha) should be applied to replace what was removed at the previous harvest. Unlike phosphorus, potassium is sometimes applied through the drip tape. Preplant fertilizer should be placed in a band 9 inches to the side of the plant row at a depth of 8 to 10 inches. Alternatively, a banded application of potash directly beneath the drip tape in the middle of the bed can be used. This latter method relies on irrigation water to move the potassium to the plant.

INTEGRATED PEST MANAGEMENT

Hotbeds are a distinct and separate part of the whole production system for sweetpotatoes, and as such they require different pest management techniques than are used for the production fields. The primary method of pest control for the past two decades has been preplant soil fumigation with methyl bromide plus chloropicrin, followed by hand weeding as needed. This fumigation regimen provides nearly 100% control of weeds, nematodes, and fungal diseases. However, with the implementation of laws that require the phase-out of all but the most critical uses of methyl bromide, alternative management techniques are needed. These include 1,3-D (Telone) plus chloropicrin (Pic) applied under plastic tarp, metam sodium/metam potassium, preplant fungicides and herbicides, and solarization.

Weeds are the main pest problem in sweetpotato hotbeds, and hand weeding remains an important component of hotbed weed management. Nonselective foliar herbicides (glyphosate, pelargonic acid) are occasionally used postemergence on weeds, but before the crop plants' emergence. Annual grasses can be effectively controlled with postemergence grass herbicides such as fluazifop (Fusilade), sethoxydim (Poast), and clethodim (Select). Other occasional pests include aphids, which may need to be controlled in order to limit their impact on the growth of plant cuttings. Fungicides are available to help control fungal diseases, but in general these can be managed more effectively with good seed selection and irrigation management. If fungicides are used, applications are made to the seed roots prior to their being covered with soil. Both thiabendazole (Mertect) and dichloro nitroanaline (Botran) can help reduce the incidence of scurf development on seed roots in the hotbed.

Weed management. The primary method for weed control in sweetpotato production fields is mechanical cultivation, supplemented by hand weeding. Hand weeding, though heavily used, is not the preferred method due to the expense and the amount of time it requires. Because sweetpotatoes are a small-acreage specialty crop, only a limited number of effective chemical control options are available for use in the United States, and preplant herbicides are not commonly used in California. Perennial and annual grasses can be controlled with postemergence grass herbicides such as fluazifop (Fusilade), sethoxydim (Poast), and clethodim (Select). A crop oil concentrate is often required to maximize effectiveness. Annual and perennial grasses should be of the proper size and actively growing for good control. Consult your farm advisor or PCA for details and follow label directions with regard to chemical use restrictions.

Since the main method of irrigation is through drip tape set on top of the bed, the bulk of weed germination occurs in this wetted zone, so mechanical cultivation down the center of the bed (with the drip tape temporarily moved aside) is an effective way to control many weeds, provided that the cultivation is done when the weeds are still small and before the crop begins to vine, typically around 5 to 6 weeks after transplanting. Directed sprays of glyphosate (Roundup) with shielded sprayers can also provide effective control of most weeds down the drip line, and eliminates the need to move the drip tape. Chemical contact with the crop foliage should be minimized in order to avoid damage to desirable root development.

Disease identification and management. Sweetpotatoes are vegetatively propagated: roots are sprouted and those sprouts are transplanted to the field to produce more roots. True seed is not used in commercial production because sweetpotatoes rarely flower. An unfortunate consequence of not using true seed, however, is that viruses and many soilborne diseases can accumulate in the plants, greatly diminishing both yield and quality. Common diseases include russet crack (caused by the russet crack strain of sweetpotato feathery mottle virus [SPFMV]), soil rot (pox, *Streptomyces ipomea*), charcoal rot (*Macrophomina phaseoli*), scurf (*Monilochaetes infuscans*), stem rot (*Fusarium oxysporum* f. sp. *Batatas*, race 1), and various forms of soft rot (multiple causal organisms, including *Erwinia*, *Pythium*, *Rhizoctonia*, and *Fusarium* spp.). The fungal diseases are best controlled by using disease-free seed (roots) and by cutting transplants above the ground. Fungicide dips can offer additional protection from stem rot, but because recently released varieties have been bred to be resistant to this disease, this practice becomes less and less common every year. Soil pox is controlled with field fumigation and through the use of resistant varieties; managing soil pH and avoiding late season plant dates can also lessen the severity of this disease. Crop rotation is an important component of disease management in sweetpotatoes; a given field should not be planted to sweetpotatoes for more than three years in succession.

Once planted in the field, sweetpotatoes immediately start to acquire viruses. Research has shown 100% infection by the end of the first season, albeit at low levels within each plant. As these roots are saved year after year, virus levels build up and yield and root quality decline. The only effective way to control virus diseases is through the use of virus-tested plants or roots. The process, developed by UC Davis in the 1960s, involves aseptically cutting the meristem (usually 0.5 mm long) from the very tip of a sprouted root. The cut meristem is placed in a test tube and grown

on synthetic nutrient agar to produce a new plant, which is then transplanted in the greenhouse and grown out for virus testing. The whole process takes 6 months or longer, depending on the sweetpotato variety. Once verified as virus-free, the new plant is propagated through cuttings, which are sold to growers.

Insect and pest management. The main insect pests impacting sweetpotatoes are wireworms (*Limonius* spp.) and grubs (various species, but most likely the larvae of scarab beetles such as the ten-lined June beetle [*Polyphylla decemlineata* and *P. sobrina*]). Preplant soil fumigation with products that contain 1,3-D or metam sodium is the most effective way to control these pests. Preplant insecticides offer some pest suppression, but their degree of efficacy is more variable. Nonetheless, preplant insecticides are used in areas where no fumigation is allowed, such as in buffer zones. Occasionally, western yellowstripe armyworm (*Spodoptera praefica*) can become a problem that will need to be controlled. Sweetpotatoes have a very high threshold for leaf damage before yields are affected, but control measures are generally warranted when the loss of leaf canopy exceeds 30%. Several good insecticides are registered for this use; consult your farm advisor or PCA for details. Dry-flesh varieties such as Murasaki-29 and Golden Sweet are less susceptible to insect damage than the orange-flesh cultivars. As with fungal diseases, crop rotation can help keep soil insect populations in check.

A common but economically unimportant foliage pest is the morning glory leafminer (*Bedellia somnulentella*), which causes severe leaf necrosis from late summer through fall. This pest typically infests sweetpotato foliage too late in the production season to have any impact on root development and yield. Gophers, voles, and ground squirrels are common vertebrate pests in sweetpotato fields and can be controlled with diligent trapping.

Other pests. Root knot nematodes (*Meloidogyne* spp.) and stubby root nematodes (*Paratrichodorus minor*) commonly occur in sweetpotato production fields and should be controlled if present. Root knot nematodes are the more important of these two species and are likely to cause economic damage in susceptible sweetpotato varieties, especially Beauregard and O'Henry. Thus far no management thresholds have been developed, but the general rule is that counts above 10 root knot nematodes per pint (500 cc) of soil, taken in the fall, indicate that treatment is warranted. Soil fumigation with 1,3-D (Telone) is the most effective way to control nematodes, especially in heavily infested fields. Alternative fumigants, nematicides, and fallowing can also be effective, especially in buffer zones where Telone is not allowed. Two sweetpotato varieties, Covington and Murasaki, have good resistance to root knot nematodes.

Postharvest pest management. Pest management for pests of sweetpotatoes in storage is for the most part accomplished by maintaining proper temperature and relative humidity and through exclusion and sanitation. Fruit flies (*Drosophila* spp.) are very common and are considered nuisance pests; a large population usually indicates decay problems. A very high population may warrant application of an insecticide spray. Another common nuisance insect pest in storage buildings is the citrus mealybug (*Planococcus citri*), which typically only becomes apparent after the crop has been in storage for a relatively long time—6 months or more.

HARVESTING AND HANDLING

Sweetpotatoes are typically harvested 90 to 140 days after transplanting, depending on variety. Most of the time, fields are harvested when 50 to 75% of the crop's total root production is U.S. No. 1 or when there is a risk of chilling injury from a later fall harvest. Vines are first mowed to remove most of the leaves and then cut close to the soil using a mechanical vine cutter. A mechanical harvester is used to dig the roots from the soil. This is a large, tractor-drawn platform that has 1 or 2 digger chains running in the center, with bins resting on both sides, and carries 4 to 8 people. As the sweetpotatoes are lifted out of the ground, workers carefully remove, sort, and place them in the bins by hand to limit skinning and bruising. Each bin measures 4 feet by 4 feet and holds approximately 1,000 lb (454 kg) of sweetpotatoes. The roots are initially field sorted into three sizes (medium, No. 1, or jumbo) and checked to see that they are free of cuts and obvious defects. Sweetpotatoes intended for processing typically are jumbos and may include roots that have been cut by the harvester but are otherwise solid and free of disease. They are typically put into large cardboard bins that can hold 1,600 to 1,800 pounds (725 to 816 kg).

POSTHARVEST HANDLING

Most of the harvested crop is stored before packing. Postharvest handling for sweetpotatoes requires a large investment in specialized equipment, bins, and storage facilities. After digging, the bins of sweetpotatoes are placed into a large storage building until they are ready to be packed. Proper conditions for long-term storage are 55° to 60°F (13° to 16°C) at a relative humidity of 85 to 90% and with adequate ventilation. If maintained undisturbed under these conditions, the roots remain marketable for as long as 13 months. In California, these conditions can be effectively maintained for all but the summer months using evaporative cooler equipment.

Curing is a practice that is rarely used anymore because of the cost and time constraints involved in moving large quantities of product into and out of cure rooms. If practiced, curing does promote the healing of cuts and scrapes and improves the roots' long-term storage quality. Proper curing conditions are 85°F (29.4°C) at 85% relative humidity for 4 to 7 days with ventilation.

When ready for packing, the roots are removed from storage, submerged in a water tank for washing, and then dried while traveling along a conveyor belt through a forced-air tunnel. Wash water should be replaced daily. To reduce decay, some packers use sodium hypochlorite (liquid bleach) in the wash water. Scientific studies have demonstrated that chlorinated water reduces microbial populations on produce in general, but unfortunately with sweetpotatoes the chlorine is quickly deactivated by the large amounts of soil in the dump tank. To be effective, active chlorine levels should be maintained at 100 to 150 ppm in the rinse water. Fungicide and food-grade waxes are not typically used on California sweetpotatoes.

The roots are then graded by hand into three sizes:

- U.S. No. 1, roots that are 2 to 3.5 inches (5 to 9 cm) in diameter, 3 to 9 inches (7.6 to 23 cm) long, well shaped, and free of defects
- Medium, roots that are 1 to 2 inches (2.5 to 5 cm) in diameter and 2 to 7 inches (5 to 18 cm) long, and may be slightly misshapen
- Jumbo, roots that exceed the size requirements of the above grades but are of marketable quality and weigh more than 20 ounces (567 g)

U.S. No. 1 sweetpotatoes command the highest price; the prices for the other size grades may be half that of the U.S. No. 1, depending on variety and time of year. Custom packing is very common, and the shipper may pack many other grades such as minis, longs, and rounds.

The graded product is then hand-placed into 40-pound (18 kg) fiberboard cartons for marketing and shipping. Sweetpotatoes are sensitive to ethylene and should not be shipped or stored with ripening fruit or melons that produce ethylene. Ethylene is a naturally occurring, odorless, colorless gas produced by many fruits and vegetables, but it can also be produced by faulty heating units and combustion engines. As an example, propane heaters should not be used to warm sweetpotato storage buildings, since propane combustion produces ethylene. Symptoms are difficult to diagnose, but ethylene can cause internal darkening and pithy areas. Sweetpotato roots are also sensitive to chilling injury and should not be stored below 54°F (12°C). Chilling injury symptoms include surface pitting, accelerated decay, internal pitting, and reduced culinary characteristics (color, texture, taste, and aroma).

Many other commodities are shipped at near-freezing temperatures that can severely damage sweetpotatoes. This sort of damage often goes unnoticed until the product is returned to a warmer temperature.

MARKETING

Sweetpotatoes are botanically unrelated to the Irish potato (part of the *Solanaceae* family, which includes tomatoes, peppers, eggplant, and the weedy nightshades). Irish, or "white" potatoes are tubers (essentially, just thickened stems) whereas the sweetpotato is a true root. Recognizing this, the National Sweetpotato Collaborators Group and the National Sweetpotato Association in 1989 endorsed spelling sweetpotato as a single word. Nonetheless, spelling sweetpotato as two words is a fairly common practice. Both spellings are considered correct.

Sweetpotatoes also should not be confused with the "true yams" grown in many other parts of the world. The word "yam" comes from the African "nyami." It was first used in Louisiana in mid-20th century as a way to market local sweetpotatoes as being different from the types grown in the northeastern states. In the United States, the term "yam" is now used in marketing to denote a moist-fleshed sweetpotato after it has been cooked or baked. All yams grown in the United States are sweetpotatoes, and the USDA requires that they be labeled as such.

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An electronic copy of this publication can be found at the ANR Communication Services website,
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Publication 7237
ISBN-13: 978-1-60107-849-0

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Most sweetpotatoes grown in California are marketed west of the Rocky Mountains, including areas of Texas and Canada, for fresh consumption. The standard unit size is the 40 pound box, but the roots are also sold in smaller box sizes, bags, and even as individually wrapped "microwave-ready" sweetpotatoes. Shipments to other parts of the United States occur when southeastern states have a short supply, but in general the cost of freight to locations on the east coast puts California at a competitive disadvantage there. The exception to this rule would be for organic sweetpotatoes, which are grown almost exclusively in California. Most sweetpotatoes are consumed on major holidays (Thanksgiving, Christmas, New Year's, and Easter), but they are available in the market year-round. Consumption is higher during the cooler months of the year. Sweetpotatoes are typically promoted on the basis of their favorable nutritional profile. They are a good source of vitamins A and C and the minerals manganese and potassium, and they contain about 4 grams of fiber per serving.

Sweetpotatoes used for processing represent approximately 25% of total production volume. Most of these are jumbo roots that are made into fries. Usually the roots are shipped to facilities in the State of Washington where they are cleaned, cut, processed, and then frozen both for the restaurant trade and for the frozen food section of retail grocery stores. Sweetpotato fries have enjoyed considerable consumer adoption since the start of the 21st century. Small amounts of sweetpotatoes are also used to produce sweetpotato chips, flour, and dehydrated animal foods.

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web-08/13-WJC/CR