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Vegetable Production Series

BROCCOLI PRODUCTION IN CALIFORNIA

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PRODUCTION AREAS AND SEASONS

Broccoli *(Brassica oleracea* L. *var. italica)* has been grown in Europe for centuries, but it has only become an important vegetable crop in the United States since 1925. California has four main broccoli production areas: the southern desert valleys (Imperial and Riverside Counties); the southern coast (Ventura, Santa Barbara, and San Luis Obispo Counties); the central coast (Monterey, San Benito, and Santa Cruz Counties); and the Central Valley (Fresno, Stanislaus, and Tulare Counties). Monterey County is the leading broccoli-producing county in the state, with 40 percent of the acreage and production. The south coast has about 30 percent of the acreage, while the desert valleys and the Central Valley each account for about 15 percent.

In the Imperial Valley broccoli is planted from early September through early December for harvest from early December through mid-March. Broccoli is grown year-round in the coastal valleys, with a slight dip in December in both planting and harvest. In the San Joaquin Valley broccoli planting begins in mid-July and continues through December; however, most planting ends in October. The major harvest is from mid-October through December, with less acreage being harvested through April.

BROCCOLI ACREAGE AND VALUE

Year	Acreage	Average yield (tons/acre)	Gross value/acre
2009	115,000	8.0	$6,073
2008	116,000	8.0	$5,718
2007	126,000	7.5	$5,313
2006	127,000	7.3	$4,885
2005	123,000	7.5	$4,226

Sources: California Agricultural Resource Directory 2006–2008 (Sacramento: California Department of Food and Agriculture, 2008); and *California Vegetable Review 2009* (Vegetable Crops Summary, United States Department of Agriculture, National Agricultural Statistic Service, vol. 31, no.1, 2010).

CLIMATIC REQUIREMENTS

Broccoli is a hardy, cool-season vegetable in the mustard family. It is closely related to cauliflower and cabbage, and the cultural requirements for all are similar. Broccoli seed will germinate and grow from 40° to 95°F (4° to 35°C), but optimum growth is obtained when monthly air temperatures average from 60° to 65°F (16° to 18°C).

In commercial plantings under optimum conditions, large leafy plants produce a compact flower head on a tall, green, branching stalk. The center flower head is from 3 to 8 inches (7.5 to 20 cm) in diameter, and plants average 12 to 24 inches (30 to 60 cm) tall. Desirable broccoli has small uniform beads (flower buds), good blue-green to green color, and tight, dome-shaped heads that stand above the leaves for ease of harvest. Hollow stems, watery head rot or other diseases, brown or yellow beads, bracts within heads, uneven bead size, and excessive branching are undesirable.

CULTIVARS

Growers of commercial broccoli in California use hybrids of the Italian green type, also called green sprouting broccoli or calabrese. Cultivars of this type have been selected that take from 75 to 140 days to grow from planting to marketable maturity. The varieties differ in color and size of plant, size of head and florets, and extent to which side shoots (small lateral heads) develop below the terminal head. Proper cultivar selection for each planting period and area is critical to obtaining high yields and desirable head quality.

Although broccoli grows best at cool temperatures, substantial planting occurs when temperatures are high in the hot interior and desert valleys of California. However, growers select the planting date so that the crop matures during the optimum

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temperature range; cold temperatures may also be experienced, since these areas undergo cooler winters than the coast. Seed company breeders, technical support and distributors, university researchers, and a greenhouse/transplant industry help determine utility of varieties through extensive trialing in grower fields.

Principal broccoli varieties currently grown in California are different for each growing region and date of planting. Listed below in alphabetical order, and not in order of predominance or time of planting, are the popular varieties within each growing region.

In the central coast production area Concord, Greenbelt, Heritage, Imperial, Legacy, Marathon, Patriot, and Patron are commonly planted.

In the southern coast area Avenger, Green Magic, and Heritage are common varieties. Belstar, Marathon, and Patron are the most popular for Ventura County.

In the southern desert Castle Dome, Coronado Crown, Destiny, Emerald Crown, Expo, General, Green Magic, Liberty, Sarasota, Tahoe, and XBC 5526 are commonly planted.

In the San Joaquin Valley cultivars include Avenger, Expo, Green Magic, Legacy, Marathon, Monte Carlo, and Tradition.

PLANTING

Broccoli can be direct seeded or transplanted. In the southern desert valleys and the central coast almost 100 percent of the fields are direct seeded. In the southern coast 75 percent of the fields are transplanted. In the Central Valley approximately 70 percent are direct seeded and 30 percent are transplanted. Almost all broccoli, whether direct seeded or transplanted, is grown in double rows on raised beds 38 to 42 inches (95 to 105 cm) wide. Within-row spacing is approximately 5 to 6 inches (12.5 to 15 cm) and spacing between seed lines is 12 to 14 inches (30 to 35 cm). Broccoli is occasionally planted in single rows on 30-inch (75-cm) beds with plant spacing at 5 to 6 inches (12.5 to 15 cm). A typical broccoli planting is approximately 40,000 plants per acre (102,000 per ha). When direct seeded, broccoli is planted with seeding rates of 1 to 1.5 pounds of seed per acre (1.1 to 1.7 kg/ha). Seeding depth ranges from ⅛ to ¾ inch (3 to 19 mm), but most growers aim for ½ inch (12 mm).

SOILS

Broccoli grows best on well-drained soils and is grown on a wide range of soil textures. Fields with light soils are often designated for winter/spring crops to minimize potential harvest delays caused by rain. Broccoli is considered moderately salt sensitive, having greater salt tolerance than some other crops including melons, corn, lettuce, peppers, onions, and carrots. Yield reductions have been measured at soil salinity levels above 2.8 dS/m (ECe in mmhos/cm at 25°C). Yield losses are approximately 9 percent for each increase in soil salinity of 1 dS/m above this threshold.

IRRIGATION

Broccoli requires adequate soil moisture to maximize yield and quality, especially during flower head formation. Overwatering can cause loose heads or hollow stems to develop and can promote root diseases. Broccoli is mostly irrigated with furrows and overhead sprinklers. Many growers use sprinkler irrigation through seed emergence or to set transplants, then switch to furrow or drip irrigation for the remainder of the crop. Most of the broccoli grown in the Central Valley and Imperial County is irrigated by furrow, and most of the acreage on the central coast is irrigated with overhead sprinklers. After transplants are established, irrigations with sprinklers are commonly at weekly intervals on the central coast during the spring and summer. A small number of broccoli acres on the central coast are produced using surface drip irrigation. Drip is not commonly used during the summer on the central coast because of difficulties in achieving quality standards under high evapotranspiration rates. Some growers supplement drip with furrow or sprinklers during the head development phase. In Ventura County the acreage of broccoli grown on drip alone (including establishment) is increasing. Approximately 2 to 3 acre-feet (2,480 to 3,700 cu. m) of water per acre is needed to grow a sprinkler-irrigated broccoli crop in the Central Valley, and 1.5 to 2.5 acre-feet (1,860 to 3,100 cu. m) is used for broccoli production with sprinklers on the central coast during the summer. Furrow irrigated crops in Imperial County receive approximately 3 acre-feet (3,700 cu. m.) of water per acre during the fall. Use of drip irrigation can reduce water use by as much as 25 percent on soil types prone to runoff or on sandy-textured soils that have limited water-holding capacity.

The amount and frequency of sprinkler or furrow irrigation depends on soil type, weather conditions, crop production area, and maturity. The combination of soil moisture monitoring and weather-based irrigation scheduling can be used to determine water needs of broccoli. Water use is highest during the last month of the crop, when vegetative growth is high. Soil moisture tensions are typically targeted for less than 30 to 45 cbars (30 to 45 kPa) during this period. Soil moisture is often allowed to reach moisture tensions greater than 30 cbars between the first sidedressing and flower head formation. Water extraction by the broccoli crop can be estimated using reference evapotranspiration data adjusted with a crop coefficient that is closely related to the percentage of ground covered

by the canopy. At a maximum canopy cover of 95 percent, the crop coefficient is nearly 1.0. Crops established with sprinklers should use a crop coefficient between 0.3 and 0.7, depending on the frequency of irrigation, until the canopy is greater than 30 percent ground cover. The California Irrigation Management Information System (CIMIS), coordinated by the California Department of Water Resources, provides daily estimates of reference evapotranspiration for most production regions of California (see http://www.cimis.water.ca.gov).

FERTILIZATION

Broccoli is a very nutrient-demanding, cool season vegetable, and care must be given to provide adequate nutrition to the crop. Soils on the central and south coast regions can have elevated levels of nitrate-nitrogen (NO_3-N) and phosphate (P_2O_5), which can cause elevated levels of these nutrients in runoff. This makes it difficult for growers to comply with water quality standards established by the Regional Water Quality Control Board. As a result, application of these nutrients needs to be carefully managed.

Phosphorus (P) fertilization should be applied based on soil test results for bicarbonate-extractable phosphorus. Levels above 50 ppm are adequate for broccoli growth; for soils below this level, especially in the winter, preplant applications of 40 to 80 pounds per acre (45 to 90 kg/ha) of phosphate are recommended. The need for potassium (K) can also be determined from soil tests; soils with greater than 150 ppm of ammonium acetate exchangeable potassium have sufficient quantities of potassium for the crop. Potassium fertilization presents no environmental risk, and many growers routinely apply potassium even in fields with high exchangeable soil potassium. Although fertilizing to replace potassium removal with the harvested crop (approximately 100 to 140 lb/ac [112 to 157 kg/ha]) is appropriate to maintain soil fertility, fertilization rates above that level are economically wasteful. Zinc fertilization is recommended if DTPA-extractable soil level is less than 1.5 ppm. Zinc fertilization is commonly practiced in the central coast due to high soil phosphorus levels, which reduce zinc uptake by plants.

Fall application of nitrogen (N) is not recommended due to the risk of NO_3-N leaching beyond the root zone by the winter rains. Small quantities of nitrogen, 20 to 30 pounds per acre (22 to 34 kg/ha), are applied preplant or at planting. At the first sidedress, 50 to 80 pounds per acre (56 to 90 kg/ha) of nitrogen is sidedressed into the beds. One or more additional sidedressings are common, typically several weeks apart. Seasonal nitrogen application to late-fall, winter, or spring broccoli crops in the central coast region ranges from 180 to 240 pounds per acre (202 to 270 kg/ha). Due to residual nitrogen from prior crops and mineralization of nitrogen from soil organic matter, the nitrogen fertilization rates for broccoli grown during the warm part of the year typically range from 160 to 200 pounds per acre (179 to 224 kg/ha). The sidedress nitrogen requirement can be estimated by pre-sidedress soil nitrate testing (PSNT). Soil nitrate levels greater than 20 ppm in the top 12 inches (30 cm) are adequate for crop growth. The test can be repeated later in the season to ensure continuing nitrogen sufficiency. In drip-irrigated fields, nitrogen can be applied through the drip system as well. Typically, drip systems are more efficient at managing water and delivering nitrogen fertilizer, and therefore fertilizer application rates are often 20 to 30 percent lower than in furrow- or sprinkler-irrigated fields.

In the southern deserts and the Central Valley, where soil test phosphorus is usually lower than on the central coast, most growers apply preplant phosphate at 150 to 300 pounds per acre (168 to 336 kg/ha). Ammonium phosphate fertilizers are broadcast before listing or applied in bands during listing. The remainder of the nitrogen is applied in one or two sidedress applications of 50 to 80 pounds per acre (56 to 90 kg/ha).

INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) information is continually being developed for weed, insect, and disease problems in California broccoli. Cultural control methods such as mechanical cultivation, field sanitation, good drainage, and irrigation management to avoid excessively wet soils are important components of IPM that help minimize chemical controls. Pesticides should always be used in compliance with label instructions. For more detailed information about broccoli pest identification, biology, and management, consult ANR Publication 3442, *Cole Crops: UC IPM Pest Management Guidelines* (available online at the UC IPM Web site, http://www.ipm.ucdavis.edu/PDF/PMG/pmgcolecrops.pdf).

Weed Management

Regional differences in weed problems are significant. In the coastal areas winter and spring weeds are favored by cool, moist conditions, and they predominate for most of the year. In the Imperial and San Joaquin Valleys early crops compete with weeds that germinate in warm to hot conditions from midsummer to late fall. Later fall and winter plantings compete with annual winter weeds. During the cool season, common problem weeds in all areas include sowthistle *(Sonchus oleraceus)*, burning nettle *(Urtica urens)*, chickweed *(Stellaria media)*, common groundsel *(Senecio vulgaris)*, little mallow *(Malva parviflora)*,

London rocket *(Sisymbrium irio)*, prickly lettuce *(Lactuca serriola)*, and shepherd's purse *(Capsella bursa-pastoris)*, and, during the warm season, they include common lambsquarters *(Chenopodium murale)*, nightshades (*Solanum* spp.), purslane *(Portulaca oleracea)*, and nutsedge (*Cyperus* spp.).

Some growers manage weeds by stimulating weed emergence with preplant irrigation. After weeds emerge they are removed with shallow tillage, propane flaming, or herbicides.

Most conventionally produced fields are treated with preplant and/or preemergence herbicides. A month after planting, fields are mechanically cultivated and may be cultivated again about two weeks later before the canopy closes. After cultivation a postemergence herbicide is often applied to control broadleaf weeds. Foliar applications of liquid ammonium nitrate fertilizers also burn back broadleaf weeds. Postemergence herbicides that control grasses are registered for use in broccoli. Hand hoeing is done as needed when the planting is 5 to 6 weeks old. Consult your Farm Advisor for advice, as the registration status of herbicides changes.

Insect Identification and Management

A wide variety of invertebrate pests can cause extensive damage to broccoli. Cabbage and seedcorn maggots (*Delia* sp.) burrow into broccoli roots and can be difficult to manage. Flea beetles *(Phyllotreta* sp., *Epitrix cucumeris,* and *Systena blanda)*, wireworms (*Elateridae* sp.) and cutworms *(Agrostis* sp. and *Peridroma saucia)* are common seedling pests that may require control. Cutworms tend to migrate into a crop from field margins. They feed at night, cutting seedlings at the soil level.

The cabbage aphid *(Brevicoryne brassicae)* and the turnip aphid *(Hyadaphis erysimi)* can contaminate heads and must be controlled during head development. The green peach aphid *(Myzus persicae)* can build to damaging levels on leaves of young plants; however, economic damage is rare on older plants unless contamination of the harvested broccoli is at issue. Aphids are attacked by generalist predators and parasitic wasps, which can help suppress aphid populations if insecticide use does not interfere with their activity. It is important to scout for parasitized aphids, or aphid "mummies," which resemble dry, rounded, tan to brown seeds. In cool, wet periods, fungal diseases can also develop in aphid colonies.

Several species of worms such as loopers *(Trichoplusia ni* and *Autographa californica)*, beet armyworm *(Spodoptera exigua)*, and diamondback moth *(Plutella xylostella)* are potential problems depending on the time of year and weather conditions. These caterpillars feed on foliage, and they can infest and damage the broccoli head. All three types of caterpillars are attacked by parasitic wasps in the egg and larval stages. Pupal parasitism of diamondback moth larvae and imported cabbageworm larvae can also be significant. Predators and tachinid flies are significant mortality agents of caterpillars attacking broccoli. Diseases, such as a nuclear polyhedrosis virus that attacks cabbage looper, can also help suppress caterpillars. Field scouts should look for evidence of natural enemy activity when monitoring aphids and caterpillars in broccoli. Worms should be managed by using selective insecticides to avoid making other insect problems more severe. Rotation of insecticide classes is essential for insecticide-resistance management. Concerns of resistance to new-generation pesticides are present whenever one chemical is heavily relied upon as a control measure.

The silverleaf whitefly *(Bemisia argentifolii)* can cause significant damage to fields in the southern desert valleys if not controlled, but only isolated incidences have been observed elsewhere in the state.

Early-season plantings in the southern desert and San Joaquin Valley are more likely to be attacked by seedling pests and worms than are late-season plantings. Broccoli planted in the coastal valleys must be monitored on a year-round basis to determine if population pressures warrant an insecticide application. General UC recommendations discourage heavy use of broad-spectrum insecticides because they destroy the complex of beneficial insects that often keep pest populations in check. Consult your Farm Advisor or licensed pest control adviser with a specific problem. Chemicals that may legally be used to control these pests change frequently.

Nematodes and Disease Identification and Management

Soilborne pests that are potentially significant yet have relatively minor effects on broccoli include the cyst (*Heterodera* sp.) and root knot (*Meloidogyne* sp.) nematodes and the fungal pathogen *Plasmodiophora brassicae*, which causes clubroot disease. Wirestem disease of transplants *(Rhizoctonia solani)* and white mold on older plants *(Sclerotinia sclerotiorum)* can occasionally be seen on broccoli. These soilborne problems can be controlled by field selection, crop rotation, soil fumigation, and applications of lime for clubroot. Seedling damping-off disease caused by *Rhizoctonia solani* occurs sporadically and is managed by cultural practices such as avoiding excessively wet soils during early stages of seedling growth and not transplanting too deeply.

Downy mildew *(Peronospora parasitica)* is a common fungal disease in broccoli. Though symptoms (leaf spots and foliar damage) are obvious in the field, economic loss is rare unless young seedlings are severely attacked or the disease is systemic in mature heads.

Some growers never apply a fungicide for this disease, while others frequently do. Chemical treatment is usually only necessary to protect young seedlings during wet weather, which favors disease. Other leaf spot diseases such as Alternaria leaf spot (*A. brassicae* and *A. brassicicola*), bacterial blight (*Pseudomonas syringae* pv. *alisalensis*), and bacterial leaf spot (*Pseudomonas syringae* pv. *maculicola*) occur on broccoli but are not usually economic concerns. The bacterial blight and bacterial leaf spot pathogens are not known to cause broccoli head rot (described below).

The broccoli head is susceptible to several diseases and disorders that affect the immature flower buds, causing discoloration and/or rot. Head rot diseases are favored by cool, wet weather conditions and are usually spread by splashing water. Bacterial head rot is caused by a complex of pathogenic bacteria species (*Pectobacterium carotovora* subsp. *carotovora*, *Pseudomonas fluorescens*, *P. marginalis*, *P. viridiflava*, and others). Alternaria head rot is a fungal disease caused by the same two species of *Alternaria* that infect leaves; both species can be seedborne. Brown bud or brown bead is a physiological disorder of broccoli flowers that is probably due to nutritional imbalances or deficiencies, and it resembles head rots caused by pathogens. All of these problems can cause economic loss in broccoli, and controlling them with pesticides has not been successful.

HARVESTING AND HANDLING

Broccoli is grown for both fresh and processed markets. Market price sometimes determines how broccoli is harvested—a crop may be hand-harvested two to three times depending upon market price and quality. Value-added fresh broccoli products range from special crown cuts, spears, and fresh florets to broccoli slaws for use in prepack and other convenience-food items destined for export, food service, and domestic consumers. Broccoli is increasingly being exported to Japan and other Pacific Rim markets that require special harvesting and packing but offer premium prices.

Fresh market broccoli is field packed. Good-quality broccoli should have dark or bright green, closed beads (flower buds), and the head (florets on a fleshy stalk) should be compact (firm to hand pressure), with a cleanly cut stalk of the required length. The standard pack consists of heads that average 3 to 8 inches (7.5 to 20 cm) in diameter. Crews cut or snap the stems at 8 inches (20 cm) and place the heads on a harvest-aid belt. Two to four heads are bunched, secured with a rubber band, and cut to a uniform 7 inches (17.5 cm). Fourteen or eighteen bunches of broccoli are packed in a waxed-fiberboard carton that weighs a minimum of 23 pounds (10.4 kg). Crown-cut broccoli consists of a top dome 5 to 5.5 inches (12.5 to 13.7 cm) in diameter, cut from the stem at 5 inches (12.5 cm). A packed carton consists of 34 to 38 bulk-packed crowns and weighs a minimum of 20 pounds (9 kg). Field-cut florets are loosely packed in tote bags and packed into cardboard cartons that weigh 9 to 18 pounds (4 to 8 kg) and contain three to four bags each. Broccoli destined for the freezer is also hand-harvested. The stem is cut at 6 inches (15 cm), slightly shorter than for fresh market. The heads are placed on belts, then collected into large bins or trailers, and hauled to the processor.

POSTHARVEST HANDLING

Broccoli requires rapid cooling to preserve quality and maximize shelf life. Harvested cartons should be taken immediately to the cooler and never allowed to sit too long on the dock before cooling. Liquid icing of the field-packed waxed cartons is the standard cooling method. Immediately after icing, broccoli should be put in refrigerated storage. Hydro-cooling and forced-air cooling also can be used, but temperature management during distribution is more critical than with iced broccoli.

Low temperature is extremely important to achieve adequate shelf life in broccoli. A temperature of 32°F (0°C) with relative humidity of 95 percent or higher is required to optimize broccoli storage life (21 to 28 days). Heads stored at 41°F (5°C) have their shelf life cut in half to 10 to 14 days. Broccoli is extremely sensitive to exposure to ethylene. Floret (or bead) yellowing is the most common symptom. The beads are the most perishable part of the broccoli head; yellowing may be due to over-maturity at harvest, high storage temperatures, and/or exposure to ethylene. Any development of yellow beads ends commercial marketability.

For more detailed information about maintaining postharvest quality, go to the UC Davis Postharvest Technology Research and Information Center Web site (http://postharvest.ucdavis.edu/Pubs/index.shtml) and click on "Broccoli."

MARKETING

Approximately 130,000 acres (52,630 ha) of broccoli are grown annually in the United States for fresh and processed (frozen) markets, with a value of $742 million in 2009. Fresh-market production accounts for 95 percent of the U.S. crop, and domestic freezers get the majority of their raw product under contract with growers who plant specifically for requirements set by the processors. Broccoli is still considered a dual-use vegetable, meaning that varieties suitable for the fresh market can sometimes be utilized for processed products and vice versa.

California produces nearly 90 percent of the broccoli grown in the United States, and Arizona produces

the rest. California exports 15 to 20 percent of its fresh-market broccoli production to other countries. The major markets include Canada (~50%), followed by Japan (~ 35%) and Taiwan (~10%).

Demand for broccoli is steadily increasing, both domestically and internationally. Broccoli demand is attributed to health-related issues and matters of convenience. The salad bar trend in the early 1980s started the rise in per capita consumption. Nutrition information from the U.S. Department of Agriculture (USDA) indicated that the fiber content of broccoli is one of the highest among vegetables and that broccoli is a good source of vitamin C and beta carotene. The highly publicized medical research linking sulphoraphane compounds in broccoli with strong anticancer activity in the body has added a powerful incentive to consumption. The introduction of pre-cut and packaged, value-added products (in the mid-1990s), such as bagged pre-cut florets, diced broccoli pieces, and stir-fry mixes, provided more convenience for domestic consumer markets, food service, and export. Innovative products like broccoli coleslaw and mixes with other vegetables are also helping to expand total broccoli use.

COST OF PRODUCTION

Costs of production of broccoli vary depending on growing location. It is labor-intensive, especially in harvesting and postharvest handling. Sample cost of production studies from Ventura, Imperial, Monterey, and Santa Cruz Counties provide cost development guidelines and differences in production sample costs among regions. These are available at the UC Davis Agricultural and Resource Economics Web site, http://coststudies.ucdavis.edu.

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