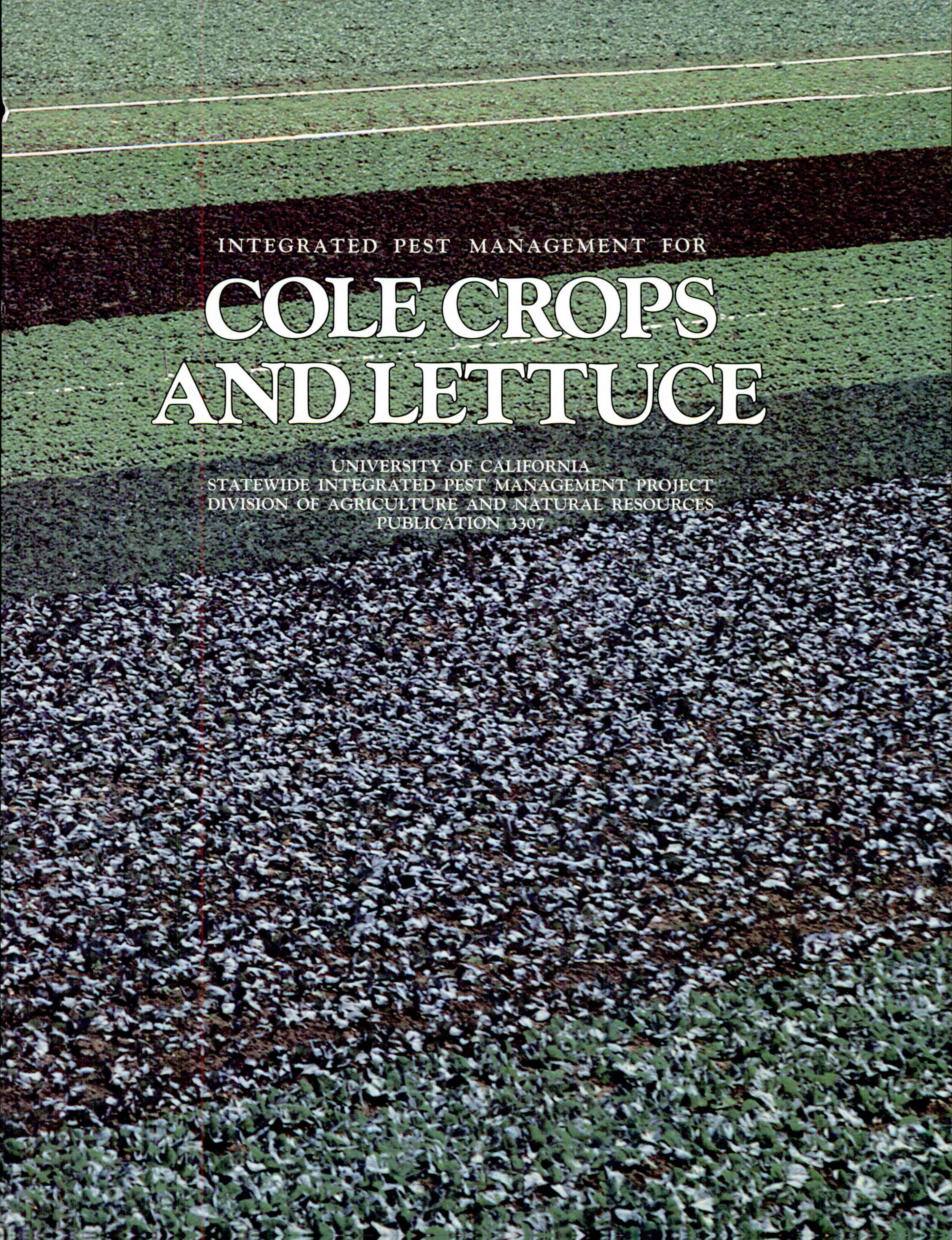

INTEGRATED PEST MANAGEMENT FOR

COLE CROPS AND LETTUCE

UNIVERSITY OF CALIFORNIA
STATEWIDE INTEGRATED PEST MANAGEMENT PROJECT
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
PUBLICATION 3307

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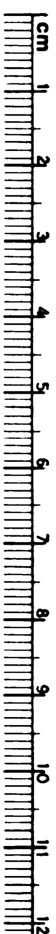

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1992

PRECAUTIONS FOR USING PESTICIDES

Pesticides are poisonous and must be used with caution. READ THE LABEL BEFORE OPENING A PESTICIDE CONTAINER. Follow the label precautions and directions, including requirements for protective equipment. Use a pesticide only against pests specified on the label or in published University recommendations. Apply pesticides at the rates specified on the label or at lower rates if suggested in this publication. In California, all agricultural uses of pesticides must be reported. Contact your county agricultural commissioner for further details. Pesticide laws and regulations change frequently; be sure the publication you are using is up to date.

Legal Responsibility. The user is legally responsible for any damage due to misuse of pesticides, including possible effects of drift, runoff, or residues.

Transportation. Do not ship or carry pesticides with food or feed in a way that allows contamination. Never transport pesticides in a closed passenger vehicle or cab.

Storage. Keep pesticides in original containers until used. Store them in a locked cabinet, building, or fenced area where they are not accessible to children, unauthorized persons, pets, or livestock. DO NOT store pesticides with food, feed, fertilizers, or other materials that may become contaminated by the pesticides.

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Protection of Non-Pest Animals and Plants. Many pesticides are toxic to desirable animals, including honeybees, natural enemies, fish, domestic animals, and birds. Crops and other plants may also be damaged by misapplied pesticides. Take precautions to protect non-pest species from direct exposure to pesticides and from contamination due to drift, runoff, or residues. Certain rodenticides may pose a special hazard to animals that eat poisoned rodents.

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Harvest Intervals. Some material or rates cannot be used in certain crops within a specified time before harvest. Follow pesticide label instructions and allow the required time between application and harvest.

Permit Requirements. Many pesticides require a permit from the county agricultural commissioner or other local authority before possession or use. When such materials are recommended in this publication, they are marked with an asterisk (*).

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Crop Injury. Certain chemicals may cause injury to crops (phytotoxicity) under certain conditions. Always consult the label for limitations. Before applying any pesticide, take into account the stage of plant development, the soil type and condition, the temperature, moisture, and wind. Injury may also result from the use of incompatible materials.

Personal Safety. Follow label directions carefully. Avoid splashing, spilling, leaks, spray drift, and contamination of clothing. NEVER eat, smoke, drink, or chew while using pesticides. Provide for emergency medical care IN ADVANCE as required by regulation.

To simplify information, trade names or products have been used. No endorsement of named products is intended, nor is criticism implied of similar products which are not mentioned.

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ISBN 0–931876–70–2
Library of Congress Catalog Card No. 84–72676

Printed in the United States of America

3m–5/92

Contributors and Acknowledgments

This manual was produced under the auspices of the University of California Statewide IPM Project, James M. Lyons, Director, Howard Ferris, Associate Director.

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Special Thanks

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Information in this manual has been derived from research supported by the University of California and the U.S. Department of Agriculture. Thanks to Agriculture and Natural Resources Publications, University of California, for making available editors and artists.

The impetus for compiling this book came from J. T. Trumble, who coordinated the writing of several early manuscripts on pest management in cole crops.

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Table of Contents

Integrated Pest Management for Cole Crops and Lettuce

The purpose of this book is to help growers and pest control advisors apply the principles of integrated pest management (IPM) to California cole crops and lettuce. IPM emphasizes preventive methods that provide economical, long-term solutions to pest problems while minimizing hazards to human health and to the environment.

Cole crops, members of the crucifer family, are varieties of the species *Brassica oleracea* and include cabbage, broccoli, cauliflower, and brussels sprouts. Cole crops are cool season crops; some, however, show more tolerance to heat than others. Cabbage, broccoli, and cauliflower are grown all year in the Salinas Valley, Santa Maria Valley, and the Oxnard Plain; during fall in the southern San Joaquin Valley; and in fall and winter in the Imperial Valley. Brussels sprouts production is largely limited to the coastal areas between San Francisco and the Salinas Valley, where transplants are planted from spring through summer and sprouts are harvested from late summer through winter.

Many head and leaf lettuce varieties, all in the species *Lactuca sativa*, are grown in California. Lettuce, a member of the sunflower family, is slightly more sensitive to heat and cold than are cole crops and is grown during limited periods. In the Salinas and Santa Maria valleys lettuce may be harvested from early April through November. In Ventura County and the San Joaquin Valley head lettuce is harvested in spring and fall. In the Ventura County area leaf lettuce may be harvested from November through April. In the Imperial and Palo Verde valleys, lettuce is harvested from late fall through early spring.

Between planting of seed and harvest both cole crops and lettuce may require as few as 60 or 70 days to mature. Many cultural practices used in both are similar, and they are frequently grown in rotation. Many of the same insects, vertebrates, and weeds may contribute to losses in both, so pest management recommendations often apply to both. With few exceptions, however, the pathogens that attack cole crops and lettuce differ, although a number of general disease prevention practices are recommended for both crops.

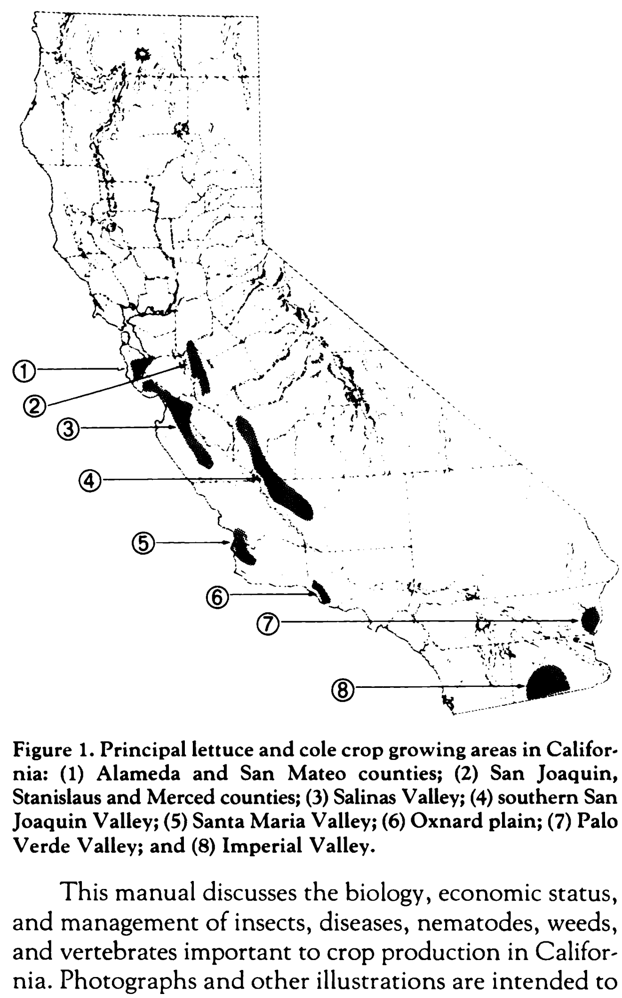


Figure 1. Principal lettuce and cole crop growing areas in California: (1) Alameda and San Mateo counties; (2) San Joaquin, Stanislaus and Merced counties; (3) Salinas Valley; (4) southern San Joaquin Valley; (5) Santa Maria Valley; (6) Oxnard plain; (7) Palo Verde Valley; and (8) Imperial Valley.

This manual discusses the biology, economic status, and management of insects, diseases, nematodes, weeds, and vertebrates important to crop production in California. Photographs and other illustrations are intended to help the reader identify important pests and their damage, an essential first step toward choosing effective control measures.

This manual discusses pesticides in general but not in particular. The constant changes in pesticide registrations make it impractical to include specific recommendations or application rates. Pest control recommendations published by the University of California are listed in the References. For the latest information on developments in pest management in cole crops and lettuce, ask your farm advisor.

Growth Requirements and Development of Cole Crops and Lettuce

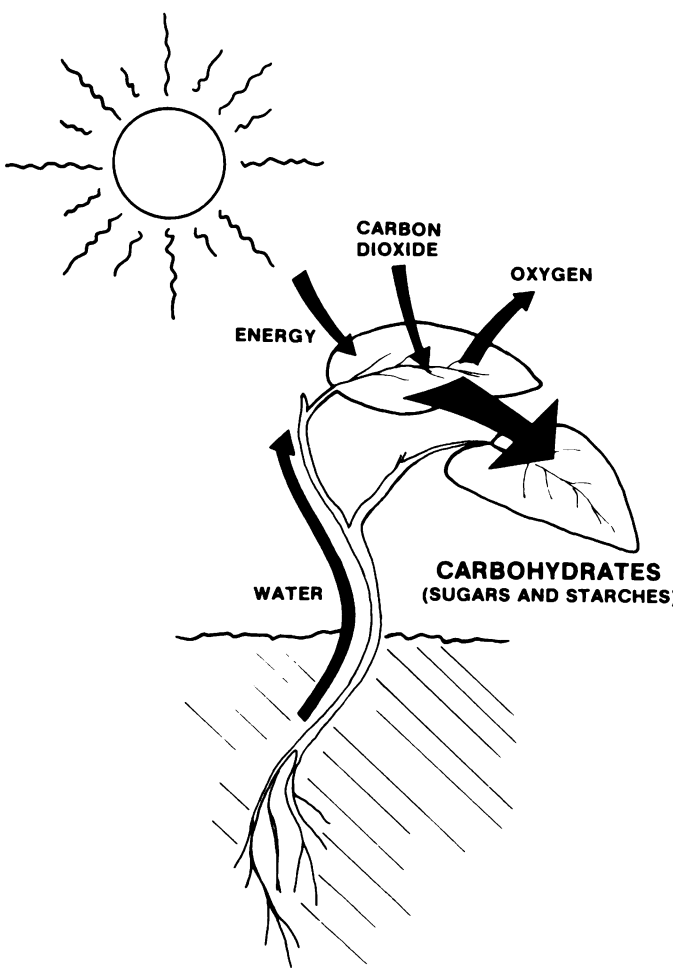


Figure 2. In photosynthesis green plants use energy from the sun to convert carbon dioxide from the air and water from the soil into sugars, their primary food source. In the process, oxygen is released into the air.

Planning a successful integrated pest management program requires an understanding of basic plant biology and how the interaction of the environment with pests and cultural practices affects plant development and crop yields. Without knowledge about a crop's requirements and normal development patterns, one can easily overlook symptoms of stress or confuse those caused by pests with those caused by other factors.

Growth Requirements

All plant growth depends on the capture of solar energy through photosynthesis, which occurs in the plant's green, chlorophyll-containing parts (Figure 2). The sugars and starches produced are immediately used or are stored for growth, maintenance, or repair of tissue damaged by pests or other stresses.

To carry out photosynthesis, a plant needs water, light (as its source of energy), carbon dioxide, various nutrients, and sufficiently warm air temperatures. The supply of water can be partly controlled by irrigation and drainage and the amount of nutrients controlled by adding fertilizers. Temperature and the sun's energy vary according to weather and climate, so they can be manipulated somewhat by planting in a suitable area at the proper time. Weed control also indirectly regulates sunlight, since it prevents weeds from shading crop plants. The amount of carbon dioxide in the outdoor air is fixed, but its levels can be enriched in greenhouses. All the basic requirements for growth must be fully met for plants to have maximum resistance to diseases, compete with weeds, and tolerate damage by insects and other pests.

Nutrients

Cole crop and lettuce plants acquire essential nutrients mainly from the upper foot of soil as they take up water through their roots. Plants deficient in nutrients are less able to tolerate stress and may display symptoms similar to those caused by pathogens. Nutrient deficiencies also limit yields, delay or advance maturity, decrease market and storage quality, and may even change flavors and other plant quality characters. Excessive amounts of some nutrients can also lower quality or impair development. Needed in the largest amounts are nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. The minor (or micro) nutrients, required only in very small amounts but still essential, are iron, boron, manganese, zinc, molybdenum, copper, and chlorine. Most California vegetable crops soils naturally contain enough of most nutrients needed for cole crop and lettuce production. Usually, only nitrogen and phosphorus need to be added on an annual basis.

Water

Only a small fraction of the water used by plants actually remains in plant tissue. Most of it—90% or more—passes from the roots up through the vascular system and evaporates through leaf pores called stomata. This flow supplies water to the leaves for photosynthesis and carries mineral nutrients through the plant.

Evaporation from leaves—transpiration—occurs because the stomata must remain open to expose a moist surface that can absorb carbon dioxide from the atmosphere. Transpiration also serves as a coolant. The rate of transpiration increases when temperature is high, humidity is low, or winds are brisk; these factors therefore influence the amount of irrigation water needed. Factors that promote root growth and prevent root damage can be as important as irrigation in increasing the availability of water to the plant.

Temperature

As long as the requirements for light, water, and nutrients are met, temperature controls the rate of plant growth; within a certain range, plants grow faster at high temperatures. The same relationship holds true for insects, fungi, and other cold-blooded organisms, although actual rates of growth and optimum temperatures for growth vary considerably among organisms. The lower limit for growth is called the developmental threshold; as temperatures increase above the threshold, the rate of growth also increases up to an optimum temperature. Above the optimum, the growth rate declines until the temperature reaches the upper limit for growth (Figure 3).

The effects of temperature on the growth of cole crops and lettuce have not been studied extensively, but the developmental threshold for some cole crops cultivars has been estimated to be below 41° F (5° C). The optimum range for development is about 59° to 68° F (15° to 20° C), and the upper limit for growth is about 77° to 86° F (25° to 30° C). The range for lettuce development is probably slightly higher; even so, temperature requirements for these "cool-season" crops are considerably lower than for many major California crops.

Changes in temperature can stimulate cole crops and lettuce plants to initiate reproductive growth, maintain or revert back to vegetative growth, or not grow at all. For example, bolting in lettuce is induced by high temperatures—generally several days of temperatures above 80° F (27° C). Heads that are already developing become pointed when the rapidly growing seed stem pushes through the head.

In cabbage and other cole crops, prolonged periods of cool temperatures below 50° F (10° C) stimulate seed stem elongation. Heat spells can cause heads or curds of some broccoli and cauliflower cultivars to grow too fast, can produce loose heads and "riceyness" in cauliflower, and can enlarge flower buds and elongate pedicels in broccoli. Cauliflower is especially susceptible to heat damage. Prolonged temperatures over 77° F (25° C) can retard heading in broccoli and cauliflower plants that are still growing vegetatively. Optimum temperatures for vegetative growth are a few degrees higher than those for reproductive growth, but too high temperatures will cause cabbage heads, like those of lettuce, to grow loosely and to fail to cup properly.

Several days of temperatures just above freezing can cause leaves to grow thick and leathery. When temperatures fluctuate from cold to warm, leaf thickness may vary greatly. Frost damage is most frequently associated

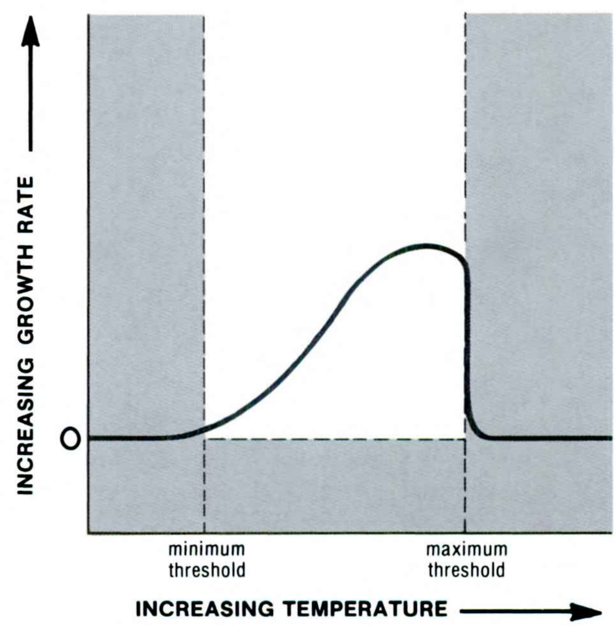


Figure 3. The relationship between temperature and speed of development is similar in plants, pathogens, insects, and other invertebrates. Little growth occurs below a minimum development threshold and very high temperature inhibits growth.

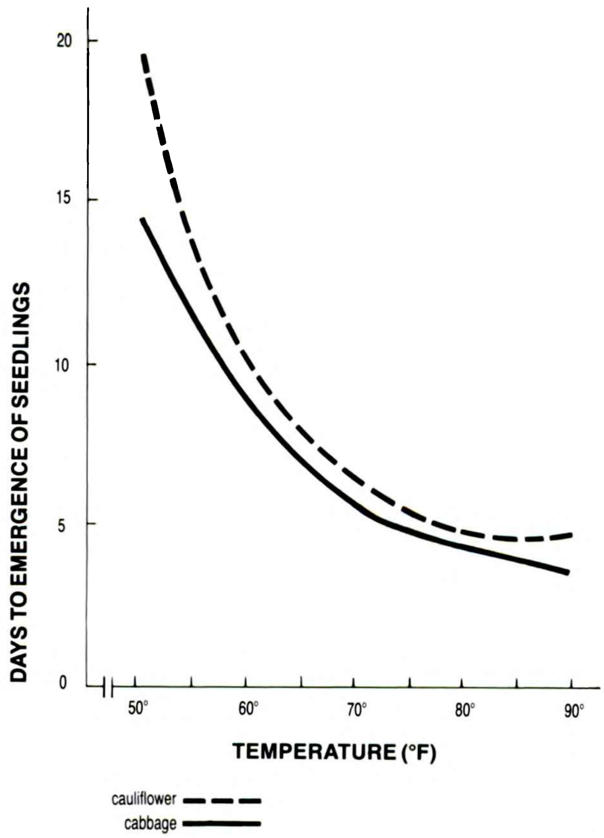


Figure 4. The effect of temperature on emergence of cabbage and cauliflower seedlings.

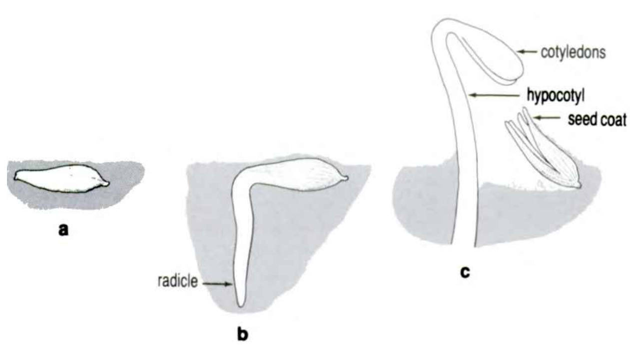


Figure 5. Germination of a lettuce seed: (a) seed shortly after planting, (b) emergence of seedling root or radicle shortly after imbibing water, and (c) emergence of hypocotyl and cotyledons from soil surface. Seed coat is left in soil.

with lettuce grown in the southern desert areas. Frost several days in succession near harvest can seriously affect marketable leaves. A quick drop in temperature can cause the most severe damage because tissues grown under warmer temperatures are more succulent and susceptible to damage. Frost damage is not common in cole crops grown in the coastal areas, but when it does occur, heads of cauliflower and broccoli may be damaged, leaving wounds vulnerable to secondary infection. Wrapper and outer leaves of cabbage may be damaged, but these can be removed with little economic loss. Brussels sprouts are relatively tolerant to cold and can withstand temperatures of 14° F (−10° C) with little damage if the temperatures drop slowly.

Development

Cole crops and lettuce plants pass through three growth phases: seedling development, a rosette period, and heading. Seedling development lasts from germination of seeds to thinning or transplanting. In the rosette period, between thinning and head formation, growth determines the ultimate size of the plant. During heading, the crop assumes its marketable shape—lettuce or cabbage heads, for example. In the case of brussels sprouts, buds in the leaf axils along the stem enlarge to resemble tiny cabbage heads. Broccoli's marketable parts are the flower stalks and buds and cauliflower's are the excessively branched flower stalks that do not develop flower parts until well past the marketable stage. The actual time it takes to develop from one stage to another depends on cultivar, weather, and management practices.

Seedling Development

In California, lettuce, cabbage, and broccoli are generally direct seeded; brussels sprouts are always sown in seedbeds and later transplanted to the field; cauliflower may be transplanted or direct seeded, depending on season and production area. Seedling development is similar in all crops, whether direct seeded or not.

Germination conditions can be critical to lettuce production. Germination of seed requires water, oxygen, and suitable temperatures. Once lettuce seeds absorb water, they germinate rapidly. Optimum temperatures for germination range from 68° to 77° F (20° to 25° C). Above 86° F (30° C), germination is inhibited or in most cultivars prevented. Under high temperatures many seeds that have taken up water will enter a state of dormancy that may prevent them from germinating for a month or more, even if favorable conditions return. However, once the root shoot or radicle has emerged out of the seed, usually about 12 hours after the seed has taken in water, the seedling can tolerate higher temperatures, but it does better if it is cool. When daytime temperatures are hot, growers reduce germination problems by sprinkle-irrigating seeded fields in the evening after temperatures have dropped; germination is then completed by early morning. Plants will emerge 3 to 7 days later, depending on the temperature. Some recently developed techniques, such as seed priming, can increase germination at high temperatures.

The optimum temperature for cole crop germination is about the same as for lettuce: 68° F (20°C). At 50° F (10° C) cabbage seedlings take 2 weeks to emerge above the soil; at 68° F (20° C) only a week is required (Figure 4). Because seedlings and germinating seeds are particularly susceptible to damage from insects and diseases, they should be planted under temperature and soil conditions that will hasten growth and limit exposure to pests.

After the young root has grown an inch or so into the soil, the seedling begins to grow upward. The first two leaves to emerge above the soil are the cotyledons or seed leaves. Food stored in the cotyledons is used during the seedling's early development; these leaves eventually decrease in size, wither, and fall off. The first true leaves emerge soon after the cotyledons, and the plant begins to carry out photosynthesis. The early true leaves also drop off after a few weeks of growth. As the true leaves continue to grow, the taproot grows deeper into the soil and the first lateral roots form in the upper 8 inches (20 cm) of soil. Some roots of mature plants may grow as deep as 5 to 6 1/2 feet (1.5 to 2 m), but 70 to 80% of the roots are in the top 12 inches (30 cm) of soil. Much root growth is lateral, most roots attaining a thickness of no more than 1/50 inch (0.5 mm). As with other crops, the actual depth of the root system is affected by soil type, preplant cultivation, moisture supply, method of irrigation, oxygen supply, and adequacy of drainage. A strong root system helps avoid problems associated with moisture stress later in the season. During early growth stages, direct-seeded plants have a stronger taproot and are better anchored than are transplants, whose root growth is mostly lateral because the taproots are often damaged during transplanting.

When to thin or transplant is largely a matter of choice for the producer. Thinning of direct-seeded fields usually occurs at the three- to four-leaf stage or about 3 to 8 weeks after planting, depending on temperatures. Transplanting typically occurs a bit later, when plants are larger and have several more leaves. For example, head lettuce is transplanted at about 3 weeks, whereas brussels sprouts may be 5 to 8 weeks or older.

Thinning or Transplanting to Heading

Both lettuce and all cole crops continue vegetative growth for some time by elongating the stem before branching. New leaves continually form at the growing point as the stem elongates. Eventually the lengthwise

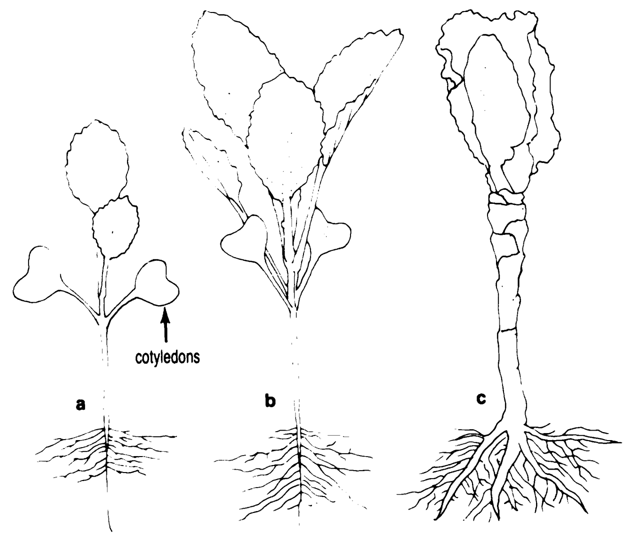


Figure 6. Development of cabbage plant: (a) seedling, (b) young plant several weeks old, (c) beginning of heading with outer leaves removed and cotyledons having fallen off.

vegetative growth is arrested, but the stem continues to thicken. Lettuce stems are relatively short, and stems of marketable heads seldom reach a length of 4 inches (10 cm). Among cole crops, cabbage stems are the shortest; cauliflower and broccoli stems may be as long as 12 inches (30 cm). Brussels sprouts stems are tall; some may be more than a meter long.

Although the lengthening of the stem soon slows markedly, the growing point continues producing leaves, which grow out in a rosette of leaves on very short petioles or stalks. The first leaves unfold normally. Later leaves begin to unfold only partially, signaling the beginning of heading in cabbage and lettuce and reproductive growth in broccoli and cauliflower. Depending on weather and cultivar, 5 or more weeks after thinning or transplanting are required to reach the heading stage. Brussels sprouts cultivars take at least 2 months after transplanting to achieve marketable sprouts.

Heading: Cabbage and Lettuce

Heading begins in crisp head lettuce and cabbage when the rosette leaves start to grow more upright. As new leaves form and expand within the rosette's center, their margins become temporarily entrapped against the upright leaves. In the early stages of head formation, these temporarily entrapped leaves finally unfold, become upright, and roll outward to form the wrapper leaves. As more leaves are produced in the center, they become increasingly entrapped until they remain folded in the center to form the compact mature head. This growth pattern can be easily visualized if you examine a cross section of a cabbage or lettuce head. Crisp head lettuce is usually round, but cabbage heads may range from flat topped to conical, depending on the cultivar. Heads are ready for harvest when they achieve full size and are firm. Plan to plant when environmental conditions during development will not stimulate bolting or growth of flower stalks. Flower stalk initiation in cabbage is stimulated by prolonged cold temperatures below 50° F (10° C), and bolting in lettuce is stimulated by several days of temperatures above 80° F (27° C). In both cases, duration of temperatures is more important than severity.

In leaf lettuces, which do not form compact heads, the plants remain continuously in the rosette stage. Newly formed leaves change their growth orientation from flat to upright.

Sprout Formation: Brussels Sprouts

After the stem has achieved at least two-thirds of its final height in brussels sprouts and the apical rosette is formed, the axillary buds above each leaf on the stem begin to enlarge into small heads. Normally the lower buds begin to enlarge and reach desired size first, but enlargement of sprouts is more uniform if the growing point is removed from the top of the plant. After one month or more of enlargement, brussels sprouts are ready to be harvested.

Curd and Head Formation: Cauliflower and Broccoli

Most broccoli and cauliflower cultivars grown in California are annuals that produce heads or curds after forming about 20 to 26 leaves and do not require cold stimulus. Biennial or winter cultivars, planted in September, start heading in late winter after several days of temperatures below 50° F (10° C). Premature heading or buttoning can occur in annual cultivars of young broccoli and cauliflower plants beyond the juvenile stage if they are exposed to several days of cold temperatures. The result is small, unmarketable heads. Buttoning can also be caused by insufficient water, a shortage of nitrogen, excessive salt, or weed competition; these cause the plant to stop growing or greatly reduce its vegetative growth. To avoid cold-induced buttoning, growers must adjust planting times in the desert areas, where chilling may occur, so that plants will either be large enough to yield a marketable head or they will be too immature for premature heading when cold temperatures are likely to occur. Buttoning may also occur in cauliflower if plants are more than 6 inches high at transplanting.

Curding or heading in annual cultivars can be held back by temperatures above 77° F (25° C). Plants in which heading has begun may revert back to vegetative growth in high temperatures, reducing curd size and development of leaves or bracts within the head, and causing other irregular growth. At temperatures between 68° and 77° F (20° and 25° C), flowering parts continue to grow, but the cauliflower curds and broccoli inflorescences grow so quickly that their market quality is poor. Curds and heads are also much more sensitive to freezing than plants in vegetative stages.

Broccoli flower stalks are branched into many short clusters, and the beads in broccoli heads are actual flower buds that bloom with maturity. The cauliflower head is made up of excessively branched flower stalks that do not develop into buds or flowers until long after harvesttime. The cauliflower curd is hidden by foliage at first, becoming visible after it is about 2 inches (5 cm) in diameter. At the approach of maturity, leaves are sometimes tied with a rubber band or broken over the cauliflower curd to keep sunlight from turning the white surface yellow or green. Broccoli flower clusters are not covered by leaves. Cauliflower must be harvested before the curds become loose and the true flower stems beneath the head elongate and form flowering stalks. Broccoli is harvested while the bud clusters are still compact and the buds are tightly closed and green.

Managing Pests in Cole Crops and Lettuce

Integrated pest management programs treat pests as part of the total production system, which includes not only the crop and its pests but also their physical and biological environment. The goal is to coordinate pest management with production practices to achieve economical and long-lasting solutions. The emphasis is on anticipating and preventing problems.

Four components are essential to any IPM program:

- pest identification
- field monitoring
- control action guidelines
- effective methods for prevention and control

Each field calls for a slightly different set of production and pest management methods for greatest profitability, and each field's requirements change from season to season. Climate, soil type, crop and pest history, cultural practices, the cultivar grown, and the nature of the surrounding land all affect pest problems. The general discussion of management practices that follows can help you tailor a program to the specific needs of your crop and location.

Pest Identification

Most pest management tools, including pesticides, are effective against only a certain range of pest species, so accurate pest identification is essential. Different methods or pesticides may be needed even for closely related species. The mere presence of invertebrates does not necessarily mean that they are causing economic damage. Many species are beneficial or innocuous; others cause damage only during certain stages of crop development. Before treating a pest problem, be sure that damage symptoms are those typically assocated with the pest. Remember, certain nutrient deficiencies or chemical toxicities can cause symptoms similar to those caused by pathogens or invertebrates, so these should be carefully diagnosed before taking a corrective action.

The descriptions and photographs in this manual will help you recognize pests commonly found in California cole crops and lettuce fields. Check other references cited in the text for additional information. Remember some pest problems can only be diagnosed reliably by experienced professionals; don't hesitate to seek their help. Your farm advisor, pest control advisor, or agricultural commissioner's office can assist you or direct you to professional diagnostic services.

Field Monitoring

Field monitoring provides information on daily or seasonal field conditions that can be used to predict and evaluate potential pest problems. Because conditions vary even between neighboring fields, every field must be monitored. Regularly check the pest species present, the crop's maturity and health, weather and other environmental conditions, and, when appropriate, population levels of pests and beneficial organisms. Keep written records. Simple tables and graphs of data help define patterns, and maps help identify local problems and pest movement. To help determine future control measures, use this information, together with records of control measures used, dates when cultural practices were carried out, previous crops planted in the field, and other field observations. This manual's insect and weed sections describe methods for monitoring each pest and include samples of record forms.

Weather affects development of both crop plants and their pests. Good weather information is useful in timing cultural practices and in predicting pest outbreaks. Differences in terrain, vegetation cover, elevation, and other local conditions may cause considerable variation in weather within a few miles.

Daily reports of high and low temperatures, relative humidity, wind conditions, and, in some areas, evapotranspiration information are offered by local newspapers, radio stations, and some farm advisor offices. The National Weather Service broadcasts continuous local and regional weather information in California over two very high frequency (VHF) FM radio stations at 162.40 and 162.55 megahertz. (To get these broadcasts, equip your radio with a special receiver.) The broadcasts include agricultural weather forecasts, climatological information, river conditions, and agricultural advisories as well as emergency warnings of hazardous conditions. This information is taped and repeated every 4 to 6 minutes 24 hours a day. You may also want to set up your own weather station to record changes in temperature, humidity, precipitation, or wind conditions in your own fields.

Control Action Guidelines

Control action guidelines indicate when managment actions, especially pesticide applications, are needed to avoid eventual losses caused by pests. Guidelines for invertebrate pests are often expressed as numerical thresholds indicating the population levels that will cause economic damage. Guidelines for weeds, diseases, nematodes, and vertebrates are usually based on the history of a field or region, the stage of crop development, weather, pest distribution, and other field observations. These guidelines are helpful only when used with accurate pest identification and careful field monitoring. The specific guidelines for each pest given in this manual are provisional and will be revised when additional information becomes available.

Management Methods

The preferred methods in an IPM program are those that protect the crop while interfering as little as possible with long-term maintenance of the production system. The cheapest and most reliable way to deal with pest problems is to anticipate and avoid them. When pesticides are needed, choose materials and application methods that are effective without adversely effecting other organisms.

Cultural Practices

Many normal cultural practices can be manipulated to minimize pest damage. Making these adjustments is often the most economical and reliable long-term defense against pests. Field selection, cropping sequence, land preparation, planting methods, cultivar selection, fertilizer application, and irrigation all have an impact on pest problems. The following outline of production methods is intended to help you anticipate possible problems and choose among alternate methods according to conditions in your area.

Field Selection. Pest management is cheaper and easier on land that is well suited for the crop. If possible, choose a field with deep, uniform soil. Sandy streaks and other irregularities interfere with irrigation and make applying herbicides more difficult since rates must be adjusted for soil type. Root-knot nematodes are more likely to cause economic damage on sandy soil; however, fumigation for nematodes and other soil-inhabiting pests is easier on this soil type. Light soils do not store as much water as medium-to-heavy soils and are less suitable for such moisture-loving cole crops as broccoli and cauliflower. Clay soils require careful water management, and root development may be adversely affected in fields with shallow hardpans, compacted layers, or high water tables.

Check the soil and irrigation water for salinity, excess sodium, boron, and other potentially toxic minerals. Also test for nutrient deficiencies and correct before planting. Check soil pH; acid soils favor clubroot of cole crops. If the field has a history of clubroot and a pH below 7.2, add lime before planting cole crops. Farm advisors often know which areas in their districts have had clubroot problems. Always submit samples to a laboratory for analysis to confirm soil or water toxicity problems. Residues from some herbicides used in other crops—for instance, legumes and grains—can sometimes damage seedlings of cole crops and lettuce, so be sure to check the herbicide use records for the field if these crops were grown previously. Remember: Tailwater from other crops can also carry harmful herbicide residues. Be sure the climate is suitable for growing your crop. All the cole crops and lettuce are sensitive to high temperatures. Cauliflower is especially sensitive.

Avoid fields heavily infested with weeds that are hard to control with herbicides used in your crop. For lettuce these might include common groundsel, prickly lettuce, and sowthistle. In cole crops special problems include common groundsel, sowthistle, London rocket and other mustards, and cheeseweed. Check field records from previous years for disease and nematode losses and choose suitable management practices. Consider planting a rotation crop to keep difficult to control pests and weeds from building up.

Land Preparation. Well-prepared fields and seed beds are easier to irrigate and cultivate properly. As a result, weed control is more effective and efficient, and there is less chance of root diseases and other disorders associated with waterlogging of the soil. Start by properly grading the land, especially where furrow irrigation is used. Provide good drainage at the tail end. If the field has compacted layers, break them up with subsoiling equipment while the soil is dry. Don't work soil that is too wet; this may cause campaction. Beds that are 9 inches (22.5 cm) high rather than the normal 6 inches (15 cm) will provide better drainage and will offer protection against corky root of lettuce and other diseases favored by oversaturated soils; use 9-inch beds where you expect special problems. Unlike other cole crops and lettuce, brussels sprouts are planted on only slightly raised beds. Make the final bed tops flat and uniform; the average clod diameter should be about 1/2 inch (1 cm). Soil-applied herbicides and fumigants are less effective in soil with large clods. Don't pulverize the soil too finely, however, as very fine soil is subject to crusting.

For most uniform growth in double row beds, list the beds in a slightly northwest to southeast direction. With true north-south beds, the east side is slightly warmer than the west because of prevailing winds in California, and plants on that side will grow faster. During winter, the south side of east-west beds will be warmer because of the sun's low position; north-south beds are satisfactory at this time.

In fields heavily infested with common groundsel, sowthistle, or Sclerotinia rot of lettuce, consider deep plowing. Seeds of groundsel and sowthistle and the sclerotia or resting bodies of Sclerotinia rot of lettuce cannot germinate and survive when buried deep below the soil surface. If buried to a depth of 6 inches in an irrigated field, most groundsel and sowthistle seeds will die after about a 6-month burial. Sclerotinia sclerotia buried 10 to 12 inches in soil cannot grow far enough to infect lettuce plants and are soon attacked and destroyed by bacteria and other soil microorganisms. Plow to a depth of 16 inches (40 cm) and completely invert the soil. After deep plowing be sure the field is adequately leveled. Deep plowing is not effective against long-lived weed seeds or large-seeded weeds that can germinate from a great depth, but these are often not as serious a problem as groundsel and sowthistle.

Cultivar Selection. Select a cultivar that produces a marketable product of high quality under local growing conditions. The projected time of maturity when the cultivar is planted on a given date in a given area is equally important. Not only do cultivars vary in adaptation to climate, but they may also vary in ability to produce uniform maturity of plants sown at the same time. For example, cauliflower sown in the same field may mature over a 4- to 8-week period, requiring four to six separate harvests. Most growers prefer to limit harvesting to two or three trips through the field, so varieties with more reliably uniform maturity are preferred; hybrids are popular for this reason. Bolting resistance and ability to germinate under hot temperatures are important characteristics in choosing lettuce varieties to be grown under hot temperatures. Some cultivars are more sensitive to herbicides than others. If you suspect that herbicide damage is occurring, try leaving part of a row untreated.

In selecting a cultivar, resistance to pathogens and other pests should also be considered. Adaptation to local growing conditions is important for this reason because vigorous, healthy plants can tolerate limited damage by insects and pathogens and the competition of weeds. For some crops, cultivars with resistance to specific diseases have been developed. Tolerance to lettuce big vein is available for lettuce. Downy mildew resistance was available in lettuce cultivars for several years, but new strains of the fungus developed that overcame resistance. Among cole crops, many cabbage cutivars resist Fusarium wilt, and some broccoli cultivars resist downy mildew. Serious efforts have been made to develop clubroot resistance, but available cultivars are not resistant against many strains of the pathogen. Always seek up-to-date information on pest resistance in available cultivars.

Planting Methods. Cole crops and lettuce may either be directly sown in the field, or they may be sown in seedbeds or in a greenhouse and transplanted as seedlings. Brussels sprouts are always transplanted in California, largely because of the high cost of seed and length of the growing season. About a third of the cauliflower crop is transplanted, especially the winter crop planted in September. Most broccoli, cabbage, and lettuce is direct seeded. A few growers transplant these crops to get a crop in early or to get an extra crop each year on their land. Transplanting damages the seedling taproot and plants require a few days to recover before resuming growth.

Direct-seeded crops may be planted to a stand or thinned 4 to 5 weeks after emergence. Direct-seeded cauliflower, cabbage, and lettuce crops are usually thinned;

spacing isn't as important in broccoli, so some growers plant to a stand, but most plant lightly and thin lightly. Plants should be thinned at the 4- to 5-leaf stage. Thinning provides an opportunity to weed.

Planting depth is important. Lettuce seeds are tiny and should be sown not more than 1/2 inch (1 cm) deep and usually less. For cole crops seeds, which are somewhat larger, optimal sowing depth still should be about 1/2 inch or less. Where soils are likely to dry out, deeper planting may be desirable.

Raised beds make cultivating and irrigating easier and are recommended for all crops, even when furrow irrigation isn't used. Height of the bed may vary; six inches (15 cm) is normal, but taller beds may provide better drainage under certain circumstances. Broccoli, lettuce, and cabbage are planted with two rows to a bed; broccoli is spaced 5 to 8 inches (12 to 20 cm) apart, cabbage 9 to 12 inches (22 to 30 cm), and lettuce 11 to 13 inches (27 to 33 cm). Cauliflower may be planted two rows to a bed, 12 to 15 inches (30 to 38 cm) apart, or in a single row slightly off the center of the bed. Spacing is especially important with cauliflower because plants get too tall and elongated if they are crowded. Only one row of brussels sprouts plants is planted along a bed.

The proper time to plant varies with region, crop and cultivar, and available markets. In the central coastal areas, most cole crops are planted all year, and planting times are determined according to the availability of a field or a market. An exception is brussels sprouts, which are only transplanted from April through early August. Biennial cultivars of cauliflower and broccoli require an early fall planting so that plants can get chilled at the proper time. Annual varieties of broccoli and cauliflower will produce premature heads (buttoning) if they are exposed to temperatures below 50° F (10° C) for several days. Adjust planting times in desert areas and other areas where chilling may occur so that plants will either be large enough to yield a marketable head or will be too immature for premature heading when cold temperatures occur. Lettuce bolts too rapidly in summer in hot southern desert areas and grows too slowly to be harvested in cool winters of central coastal areas.

Before you plant, be sure soil and air temperatures are warm enough to give moderately rapid emergence (Figure 4, page 10). Slowly emerging seedlings are likely to suffer more serious damage from insects, diseases, and weed competition.

Hot temperatures adversely affect germination, too. Seeds of some lettuce cultivars enter a heat-induced dormancy when exposed to temperatures above 79° F (26° C) after absorbing water. To avoid this problem in the southern desert, plant into dry soil (dry seeds aren't affected by heat) and sprinkle irrigate in the evening after temperatures have dropped. By the time temperatures rise to their peak the next day, seeds will have started germination and will be past the heat-sensitive stage. Ask your farm advisor or seed supplier for information about when to plant cultivars.

Irrigation. Correct decisions regarding amounts of irrigation are essential. Too little water can result in small plants, slower growth, and premature bolting. Excessive irrigation or poor soil drainage may contribute to development of certain diseases including bottom rot, corky root, and downy mildew of lettuce, and black rot and Phytophthora stem rot of cole crops. Uneven distribution of water can contribute to weeds and diseases, thereby thwarting uniform maturing of the crop.

Good water management can help prevent problems. First, design your irrigation system and prepare fields to promote even water distribution and good drainage. Be sure that fields are properly graded and have adequate tailwater ditches to prevent water from standing in low areas. Break up compacted areas, reduce clod size, and carry out other operations to increase water penetration. A loose or cloddy bed will not conduct water by capillary flow as well as a firm bed. Irrigate to meet the needs of your operation and the growth stages of your plants.

A good procedure in most situations is to sprinkle irrigate from planting to thinning or up to the rosette stage and then switch to furrow irrigation until harvest. Solid set sprinkler irrigation is best for germination because all seeds in the field are wet at about the same time, so germination and maturity will be more uniform; it also helps to keep soil aggregated and provides an environment less conducive to damping-off of seedlings. Sprinkler irrigation will leach excess salts from the top of the soil bed to below the rooting zone of seedlings if soil is wet to a depth below the root zone. Keeping the surface soil wet will prevent upward movement of salt. Furrow irrigation can carry the salts up toward the salt-sensitive seedling roots, but if done properly in a well-graded field, it should move the salts beyond seedling roots toward the center of the bed. Sprinklers can make use of some preplant herbicides easier by eliminating the need to incorporate them. Unfortunately, in older plants, sprinklers can increase some disease problems, such as downy mildew, black leg, or black rot of cole crops, and can promote germination of weeds. Splashing from sprinkler irrigation can dirty the leaves of lettuce and favor such diseases as mildew, anthracnose, and Sclerotinia. For these reasons and because sprinkler irrigation is more expensive, it is usually advisable to furrow irrigate after the rosette stage. Brussels sprouts, however, are usually sprinkler irrigated throughout their growth.

When using sprinklers, especially for germination, don't apply water faster than it can infiltrate the soil. Choose an application rate that does not permit runoff or surface puddling; then let the sprinklers run long enough to apply the required amount of water. It is easier to get uniform application of water at an acceptable rate by using moderate sized sprinklers, close spacings, small nozzles, and adequate, uniform water pressure. University of California Agriculture and Natural Resources publication 2265, *Solid Set Sprinklers for Starting Vegetable Crops*, provides details about application rates for different soil types and situations (see References).

Linear sprinkler systems often provide good uniformity; they move over the field releasing water at a controlled rate. Never sprinkle on windy days when it is impossible to apply water uniformly. Wait until the wind dies down in the evening and irrigate then. If wind has made sprinkler application uneven, you may have to apply additional water to soak upwind areas.

Scheduling Irrigations. Knowing when to irrigate and how much water to apply is critical to crop production. Irrigating according to the calendar can lead to serious damge from over or under watering if weather and soil conditions aren't considered. Begin by finding out how much water is available to the crop when the soil is at field capacity (Figure 7). The amount of available water depends on soil texture and on rooting depth of plants. Before planting, use a soil tube or auger to examine the soil profile and estimate the available water in your field using the method shown in Figure 8. The approximate water-holding capacities of various soils are shown in Table 1.

The quantity of available water the crop can use before an irrigation is advised is called the allowable depletion. The allowable depletion for most cole crops and lettuce is estimated to occur when 40% to 50% of the

Table 1. Available Water-holding Capacity for Various Soil Textures.

	INCHES OF AVAILABLE WATER PER FOOT OF SOIL DEPTH AT FIELD CAPACITY	
	Range	**Average**
Very coarse to coarse textured sand	0.5–1.00	0.75
Moderately coarse textured sandy loams and fine sandy loams	1.00–1.50	1.25
Medium to very fine textured sandy loams to silty clay loams	1.25–1.75	1.50
Fine to very fine textured—silty clay to clay	1.50–2.50	2.00
Peats and mucks	2.00–3.00	2.50

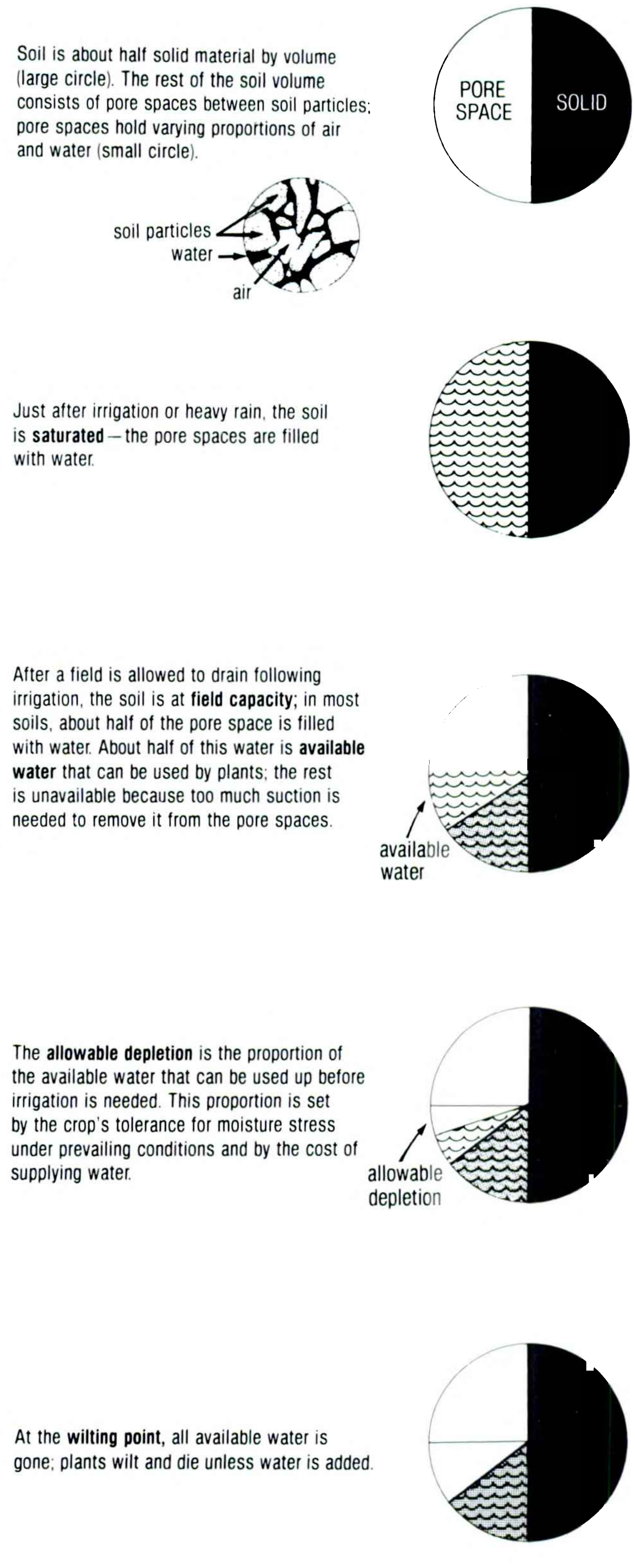


Figure 7. The soil reservoir.

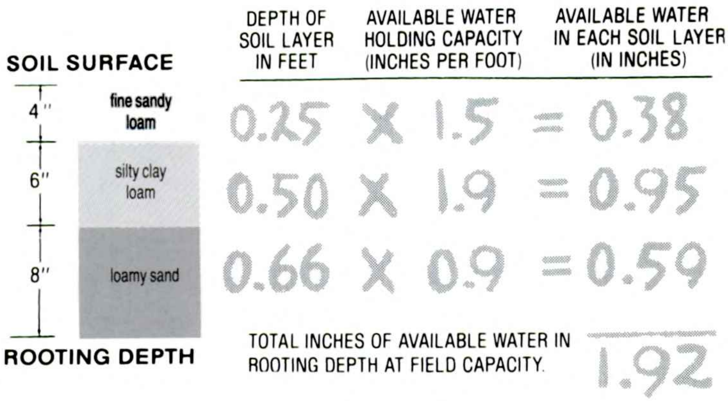


Figure 8. To calculate how much available water the soil can hold at field capacity, first examine the soil profile to find out whether there are layers of different soil textures in the rooting depth of the crop. For each soil layer, multiply the depth of the layer in feet by the available water-holding capacity of that soil layer (see Table 1). Add the results from all layers to get the total available water-holding capacity for the soil profile.

available water has been depleted. These figures are estimates and have not been derived experimentally. To determine when the soil is nearing the allowable depletion level, monitor soil moisture in the field at least weekly and estimate how much moisture is left.

The easiest way to estimate soil moisture is to take soil core samples from several places in the field and evaluate the soil's moisture content using the "feel" method described in Table 2. Take samples from one-third, one-half, and two-thirds of the way down runs if you are furrow irrigating. Because cole crops and lettuce obtain most of their water from the upper foot (30 cm) of soil, focus routine monitoring on that zone. Usually, irrigation is needed when the first foot of soil reaches the allowable depletion level. When plants are young and shallowly rooted, check the soil in the top few inches where most roots are located. Monitor moisture at deeper levels, too, especially where there is a high or fluctuating water table and where there are compacted soil layers. To locate the top of the water table, sink a soil tube or auger 3 feet deep (90 cm) and preferably 4 feet (120 cm) and allow at least an hour for water to percolate into the hole. Measure the distance from the soil surface to the water level; this is the depth of the water table. Crop consultants or local water agencies can help you locate the water table. If the water table is close to the root zone either delay irrigation or add only enough water to supply the upper soil layers without raising the water table.

Tensiometers and other special equipment may be useful for monitoring soil moisture in some situations. Always check instrument readings against direct observation of soil moisture before applying water. Also, watch for the reduced growth, wilting, and abnormally dark leaves that may indicate water stress; these symptoms indicate irrigation has been delayed too long, and water is needed immediately.

If evapotranspiration (ET) data are available for cole crops and lettuce in your area, back up your soil monitoring program by recording how much water is used daily. Aside from runoff and deep percolation, most water used in irrigation is lost by evaporation from leaves (transpiration) or from the soil surface. The combination of evaporation and transpiration is called evapotranspiration or ET.

Table 2. Judging the Depletion of Soil Water by Feel and Appearance.[a]

Coarse-Textured Soils	Inches of Water Needed	Medium-Textured Soils	Inches of Water Needed	Fine-Textured Soils	Inches of Water Needed
Soil looks and feels moist, forms a cast or ball, and stains hand.	0.0	Soil dark, feels smooth, and will form a ball; when squeezed, it ribbons out between fingers and leaves wet outline on hand.	0.0	Soil dark, may feel sticky, stains hand; ribbons easily when squeezed and forms a good ball.	0.0
Soil dark, stains hand slightly; forms a weak ball when squeezed.	0.3	Soil dark, feels slick, stains hand; works easily and forms ball or cast.	0.5	Soil dark, feels slick, stains hand; ribbons easily and forms a good ball.	0.7
Soil forms a fragile cast when squeezed.	0.6	Soil crumbly but may form a weak cast when squeezed.	1.0	Soil crumbly but pliable; forms cast or ball, will ribbon; stains hand slightly.	1.4
Soil dry, loose, crumbly.	1.0	Soil crumbly, powdery; barely keeps shape when squeezed.	1.5	Soil hard, firm, cracked; too stiff to work or ribbon.	2.0

[a] The feel and appearance of soils change as they dry out. Starting at field capacity (top), the numbers in each column are the approximate amounts of water needed to restore one foot of soil depth to field capacity.

If you know how much available water is in the soil at field capacity after irrigation and how much water is lost through ET each day, you can then estimate when the next irrigation is needed by adding up daily ET totals until they approach the allowable depletion. University of California Agricultural and Natural Resources publication 21199, *Basic Irrigation Scheduling*, contains information on how to keep a water budget (see References).

Contact your local irrigation district or farm advisor's office for help in obtaining and using suitable ET data. As yet, newspapers and radio stations do not carry ET data for cole crops and lettuce. ET data averaged over a period of years can help in planning a crop's total irrigation requirements. Monthly ET averages for broccoli, cauliflower, and lettuce grown in California coastal areas are shown in Tables 3, 4, and 5.

To make the most efficient use of water, use flow meters, weirs, or other measurement devices to track how much water is applied and how much runs off after irrigation. With this information, you can estimate the total amount of water needed to return the soil to field capacity from a given level of depletion. Remember: Uniformity of application affects the total amount needed; water wasted in one part of the field may mean another part will remain too dry.

Irrigating Through the Growing Season. In practice, there are several possible ways to begin irrigating your field. The most common is to plant into a dry field and sprinkler irrigate to start germination and continue sprinkling every day or two until the crop emerges. When soil is very dry, especially in summer, irrigating before preparing the field will make it easier to break up clods during tillage. Preirrigating also helps leach out salts, an important practice in low desert areas with saline water. Only bring equipment into the field when the soil is dry enough to resist compaction. When planting lettuce in hot weather, turn sprinklers on just before sunset and run them during the night to obtain optimum germination.

Another system designed to promote weed control in cole crops and used in central coastal areas involves irrigating the field up to field capacity before planting but after fertilizing, discing, and firming beds. Then the bed surface is lightly tilled to remove crust and germinating weeds. Afterwards the crop is seeded at a depth of 1/2 to 3/4 inch (1 to 2 cm). During summer in the central

Table 3. Normal Crop Water Use — Broccoli.

REGION AND GROWING PERIOD		ESTIMATED MONTHLY EVAPOTRANSPIRATION (INCHES)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Central Coast Interior Valleys	2/1–5/15		1.3	2.7	4.4	2.6								11.0
	3/15–7/1			1.0	2.6	5.3	6.1							15.0
	8/15–12/1								1.4	2.6	3.4	2.2		9.6
	10/15–3/1	1.6	2.1								1.0	1.4	1.4	7.5
Central Coastal Plains	2/1–5/15		1.4	2.5	3.9	2.2								10.0
	3/15–7/1			.9	2.3	4.3	4.9							12.4
	8/15–12/1								1.1	2.1	3.0	2.2		8.4
	10/15–3/1	1.8	2.2								.9	1.4	1.4	7.7
Southern Coastal Plains	8/15–12/15								1.2	2.7	3.4	2.6	1.1	11.0
	9/15–1/15	.8								.8	2.2	2.6	2.1	8.5

Table 4. Normal Crop Water Use — Cauliflower (Direct-Seeded).

REGION AND GROWING PERIOD		ESTIMATED MONTHLY EVAPOTRANSPIRATION (INCHES)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Central Coastal Plains	5/15–8/1					1.1	3.2	5.2						9.5
	8/1–11/15								2.1	3.4	3.3	1.2		10.0
	12/1–5/1	1.5	2.2	3.1	3.9								1.0	11.7
Southern Coastal Plains	8/15–12/15								1.2	2.7	3.4	2.6	1.1	11.0
	9/15–1/15	.8								.8	2.2	2.6	2.1	8.5

Table 5. Normal Crop Water Use — Lettuce.

REGION AND GROWING PERIOD		ESTIMATED MONTHLY EVAPOTRANSPIRATION (INCHES)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Central Coast Interior Valleys	12/15–4/15	1.5	2.0	3.3	2.0								.6	9.4
	3/15–7/15			1.4	3.5	5.4	6.1	3.1						19.5
	8/15–11/15								2.2	4.0	3.6	1.2		11.0
Central Coastal Plains	12/15–4/15	1.6	2.1	3.1	1.8								.6	9.2
	3/15–7/15			1.3	3.1	4.4	4.8	2.5						16.1
	8/15–11/15								1.7	3.2	3.2	1.2		9.3
Southern Coastal Plains	3/15–6/15			1.3	3.1	4.5	2.4							11.3
	8/15–11/15								1.8	3.4	3.3	1.3		9.8
	9/15–12/15									1.4	2.7	2.6	1.1	7.8
	11/15–2/15	1.8	1.1									1.0	1.9	5.8

coast, cole crops will germinate rapidly on the available moisture, and the thin layer of dry soil on top forms a mulch that prevents germination of weed seeds on the soil surface. Deep-seeded weeds will not emerge until after the crop has formed several leaves. The field is mechanically cultivated when the crop reaches the three-leaf stage, and the first irrigation follows immediately after. Because lettuce is seeded so shallowly, it cannot survive without irrigation long enough to use this method. The program is not used in the Imperial Valley.

Two or three irrigations are usually required between thinning and harvest in central coastal areas and up to eight are needed in the Imperial Valley. If plants become stressed for water, they are less able to tolerate damage by nematodes, root diseases, and insects, and they compete poorly with weeds. An exception is fields infested with the pathogen that causes corky root of lettuce; if such fields must be planted, they should be irrigated as infrequently as possible between thinning and rosette stage to promote deep root growth; a normal irrigation schedule is resumed after heads begin to form. In all crops, common practice requires final irrigation a few days to a week before harvest to assure turgidity of the harvested crop.

Table 6. Cool Season Crop Yield Responses to Nutrient Levels in Soil Samples[a]

	Phosphorus (P)	Potassium (K)	Zinc (Zn)
	Nutrient Levels in Parts per Million (ppm)		
Lettuce			
Crop yield reduction likely if less than	15	50	0.5
Crop yield reduction unlikely if more than	25	80	1.0
Cole Crops			
Crop yield reduction likely if less than	10	50	0.5
Crop yield reduction unlikely if more than	20	80	1.0

[a] Soil nutrient levels measured as $NaHCO_3$ extractable P, exchangeable K, and DTPA extractable Zn.

Fertilizing. Most California soils contain sufficient quantities of most nutrients to produce lettuce or cole crops. However, nitrogen almost always must be added to provide good color and growth, but it must not be so high that growth becomes too lush. Frequently phosphorus and occasionally potassium may also need to be supplemented. Deficiencies of micronutrients sometimes occur, especially in boron, molybdenum, and zinc, so if you suspect deficiencies, have soil and plants analyzed.

Avoid overfertilizing; excessive additions of nutrients, especially the micronutrient boron, can injure plants. Excess nitrogen can cause hollow stems in broccoli and cauliflower and generally rank vegetative growth. In combination with hot weather, excess nitrogen can spur such rapid growth of lettuce plants and cabbage that they begin to show symptoms of tipburn (see page 77).

At least once a year have soil samples analyzed for available levels of potassium, phosphorus, and important micronutrients. Table 6 shows their critical and deficient levels. There are no reliable methods for determining availability of nitrogen for plant needs based on soil tests. Take soil samples before planting and early enough to add fertilizers before planting if necessary. In some situations, nutrients may be supplied during crop growth, but applied phosphorus, potassium, and zinc cannot usually be effectively utilized after the crop has emerged. A soil analysis may also identify other mineral imbalances, including excess salinity and unfavorable acidity or alkalinity. Soil analysis is especially valuable for fields with little information on crop history. A directory of commercial laboratories equipped to carry out nutrient analysis is available from the University of California Agriculture and Natural Resources publications or through your farm advisor's office (see References). Agriculture and Natural Resources publication 1879 contains information on interpreting soil and plant tissue nutrient analysis.

Analysis of plant tissue may help in finding out whether nutrient deficiencies are responsible for slow growth or other symptoms. It is also useful for checking accurately the crop's nitrogen status. Although deficiencies of phosphorus and potassium cannot be readily corrected in the field, plant tissue analysis can help you plan a fertilizer program for the next crop. Again, obtain the services of a qualified commercial laboratory to carry out these tests.

Table 7 lists deficient and sufficient levels for nitrogen, phosphorus, and potassium in various crops at specific growth stages. Sufficient and deficient levels of nutrients in leaf tissues vary significantly between growth stages, so be sure samples are taken at the stages indicated. Many nutrient deficiencies cause plants to develop distinctive symptoms. These symptoms are described on page 80. Always confirm suspected nutrient deficiencies or toxicities with a soil or leaf analysis. Other disorders can produce similar symptoms.

Nitrogen applications are usually made several times during the crop's development. Other nutrients are usually applied before planting. Nitrogen (and , if necessary, phosphorus, potassium, and micronutrients) is either applied preplant or at the time of planting or transplanting, usually as a band application. Preplant broadcast applications are also practical. A second application of nitrogen is applied most often after thinning as a sidedress, and the final application of nitrogen only, if needed, is sidedressed about the time heading begins. The proper rates to apply depend on nutrient content of the soil, soil type, time of year, and other factors specific to the field. Manure can be another source of nutrients with the added benefits that organic matter offers. However, it may contain salts or weed seeds that cause problems. If you use manure, apply it well in advance of planting the crop. A farm advisor can help you plan a fertilizer program suited to your needs.

Sanitation. An IPM program should include such sanitation practices as eliminating refuges, food sources, breeding and hibernation sites, and alternative food sources that maintain pests after the crop is harvested. Pathogens, insects, and nematodes can maintain or build their populations on crop culls or closely related weeds that remain in the field after harvest. Preventing introduction of pests is an equally important aspect of sanitation. Soil carried on equipment or introduced with transplants or manure may contain nematodes, plant pathogens, root-dwelling insects, and seeds or other reproductive parts of weeds. Surface water may be contaminated with many of the same pest organisms. Weeds surrounding the field may harbor diseases or insects that can invade the field when the crop is planted; fencerow weeds are also a major source of weed seeds. Some pest organisms, especially weeds and viruses, can be introduced with crop seeds; thus it is important to buy seed certified disease and weed free.

Table 7. Deficient and Sufficient Levels of Nutrients in Leaves of Cole Crops and Lettuce at Various Developmental Stages.[a]

	NO_3-N (ppm)	PO_4-P (ppm)	K %
BROCCOLI[b]			
Midgrowth			
Deficient	7000	2500	3
Sufficient	9000	4000	5
First Buds			
Deficient	5000	2500	2
Sufficient	7000	4000	4
BRUSSELS SPROUTS[b]			
Midgrowth			
Deficient	5000	2000	3
Sufficient	7000	3500	5
Late Growth			
Deficient	2000	1000	2
Sufficient	3000	3000	4
CABBAGE[c]			
At Heading			
Deficient	5000	2500	2
Sufficient	7000	3500	4
CAULIFLOWER[b]			
Buttoning			
Deficient	5000	2500	2
Sufficient	7000	3500	4
LETTUCE[c]			
At Heading			
Deficient	4000	2000	2
Sufficient	6000	3000	4
At Harvest			
Deficient	3000	1500	1.5
Sufficient	5000	2500	2.5

[a] Tissue concentrations of water extractable NO_3-N, 2% acetic acid-soluble P (PO_4-P), and total K (dry weight basis).
[b] For broccoli, brussels sprouts and cauliflower, use midrib of young, mature leaf for samples.
[c] For cabbage and lettuce, use the midrib of wrapper leaves for samples.

Specific sanitation practices are discussed in the pest discussions in the later parts of this book. Of particular significance are practices incorporated into the lettuce mosaic virus control program and those used to prevent spread of nematodes, clubroot, and cabbage maggots.

Rotation. You can limit populations of certain pests by rotating to crops that will not support them. Cultivation of certain crops may discourage pests because they will not provide adequate nutrition, have life histories unsuitable for pest survival, or require cultural and chemical practices that limit or are hostile to those pests. Rotating crops provides the opportunity to use herbicides that are highly effective against groundsel, prickly lettuce, sowthistle, and mustards; these weeds may be difficult to control with herbicides available for use in cole crops or lettuce. Avoid using herbicides or rates that may be phytotoxic to future plantings of cole crops or lettuce or other succeeding crops. Rotation can be especially useful in managing corky root of lettuce, black rot and black leg of cole crops, and cyst nematodes. Growing a green manure cover crop such as cereal rye every 3 years can keep a field in top shape.

In many areas, economic considerations make it difficult to rotate to such crops as tomatoes, dry beans, sugarbeets, or small grains, which could enhance pest management and overall soil health. However, some feasible rotations exist. For example, cole crops may be rotated to lettuce, celery, beans, carrots, or spinach, and lettuce may be rotated to cole crops, celery, carrots, spinach, or beans, providing good management of several important pests. Rotation is discussed in detail in the chapters on weeds, diseases, and nematodes.

Biological Control

Predators, parasites, and pathogens attack and kill certain pests in vegetable crop fields. These natural enemies occasionally exert significant control of some insects. The most commonly observed natural enemies are aphid parasites, which leave behind the crusty mummies of aphids they have killed. Loopers, cabbageworms, and other caterpillars are also often killed by parasites or various naturally occurring insects and diseases. Predator populations in these short-lived crops are sporadic, but minute pirate bugs, ladybeetles, syrphid fly larvae, and bigeyed bugs are occasionally active. Use of biological control is limited because of the short time crops are in the field, high cosmetic standards, and these crops' low tolerance for insect contamination. Frequent use of insecticides can kill natural enemies, so the feasibility of relying on biological control is restricted. In some cases natural control is sufficient to keep pests below damaging levels before heading. To gain maximim benefit from biological control, choose insecticides, rates, and application methods that are least disruptive to the activities of natural enemies.

Natural enemies and competitors can also affect populations of weeds, nematodes, vertebrates, and the microorganisms that cause diseases in plants. Little is known, however, about how to take advantage of biological control to manage these pests. Future research may lead to greater use of biological control in lettuce and cole crops.

Pesticides

Properly used, pesticides can provide convenient, economical protection from pests that otherwise would cause significant losses. Often they are the only feasible means of control. However, careless or excessive use can result in poor control, crop damage, and hazards to human health and the environment.

In an IPM program, pesticides are used only when field-collected information indicates their need. Some pests, such as aphids and caterpillars, require population samples and using the numerical control action thresholds discussed later in this book. For other pests, such as nematodes, treatments are largely preventive, so you will need field monitoring records of crops previously grown in that field and price outlooks for the crop. Eliminating unnecessary treatments can reduce costs and potential hazards.

Sometimes a pest can be treated with one of several chemicals; the choice depends on the degree of control necessary, the effect on other pests, natural enemies or wildlife, and economic and legal restrictions. Most pesticides are available in several formulations and can be applied at various rates and by various methods to obtain desired control safely and economically. Before choosing a pesticide, check with your farm advisor for the most recent University of California pest control recommendations for cole crops and lettuce. Always read the pesticide label; it outlines safety precautions, legal requirements, and registered uses for each product.

Pesticide Resistance. Pesticide-resistant strains of a pest are able to withstand application of a pesticide at a rate that at one time killed most individuals of that species (Figure 9). Resistance generally develops most quickly under the selective pressure of repeated pesticide application. Resistance has been reported in aphids, tobacco budworms, leafminers, loopers, and other pests in lettuce and cole crops. Once resistance has developed, other pesticides or higher dosages may be required to reduce pest populations below economically damaging levels, often substantially increasing pest control costs. Relying on a number of different control methods and avoiding repeated applications of the same material slow development of resistance.

Pest Resurgence and Secondary Outbreak. Pest resurgence and secondary pest outbreaks occur when pesticides kill or otherwise disrupt the activities of natural enemies or competitors of pests. When natural enemies are killing a substantial portion of a pest population, removing the enemies with pesticides causes the pest population to return—a phenomenon called pest resurgence. When a pesticide application disrupts natural control of a pest not previously a problem, it is called a secondary pest outbreak. For example, leafminers are not commonly of economic importance except when their natural enemies are killed by insecticides applied to kill other pests.

A problem similar to secondary outbreak can occur when herbicide applications kill most of the weed species present but allow a few tolerant species to survive. With competing weeds removed, the tolerant species grow more abundantly. This is the situation in many lettuce fields where sowthistle and groundsel have increased because of repeated use of relatively selective herbicides.

Phytotoxicity. Phytotoxicity is injury to plants caused by toxic substances. Herbicides are the most widely recognized cause of phytotoxicity, but other pesticides, adjuvants, fertilizers, and air pollution may also injure plants. Examples of phytotoxic symptoms are pictured on pages 78–79. Herbicides, formulated deliberately to be phytotoxic, may injure crop plants as well as weeds. They are successful only when applied properly and precisely. An application at the wrong rate, at the wrong time, with the wrong material, or under the wrong environmental conditions can kill or severely damage crop plants. Phytotoxicity can also occur when certain mixtures of herbicides and other chemicals are applied together or soon after one another. Proper herbicide application is discussed in more detail in the weed section of this book.

Although people seldom realize it, insecticides commonly cause phytotoxicity. Damage is often not visible, but certain insecticides reduce photosynthesis, transpiration, and overall productivity of lettuce plants, even when applied at registered rates under recommended conditions. Although the yield loss is not enough to warrant eliminating treatments for economically damaging levels of insect pests, preventive or repeated treatments applied when pest levels are not damaging could reduce, rather than increase, yield. Visible phytotoxicity may occur when maximum rates of two insecticides are applied together for treatment of caterpillars and aphids at the same time. Avoiding maximum rates and weekly treatments and reducing surfactant additions can prevent most of these problems.

Pesticide Residues. Certain pesticides remain in the soil or on the crop for a relatively long time. If label restrictions are not carefully followed, applications may leave

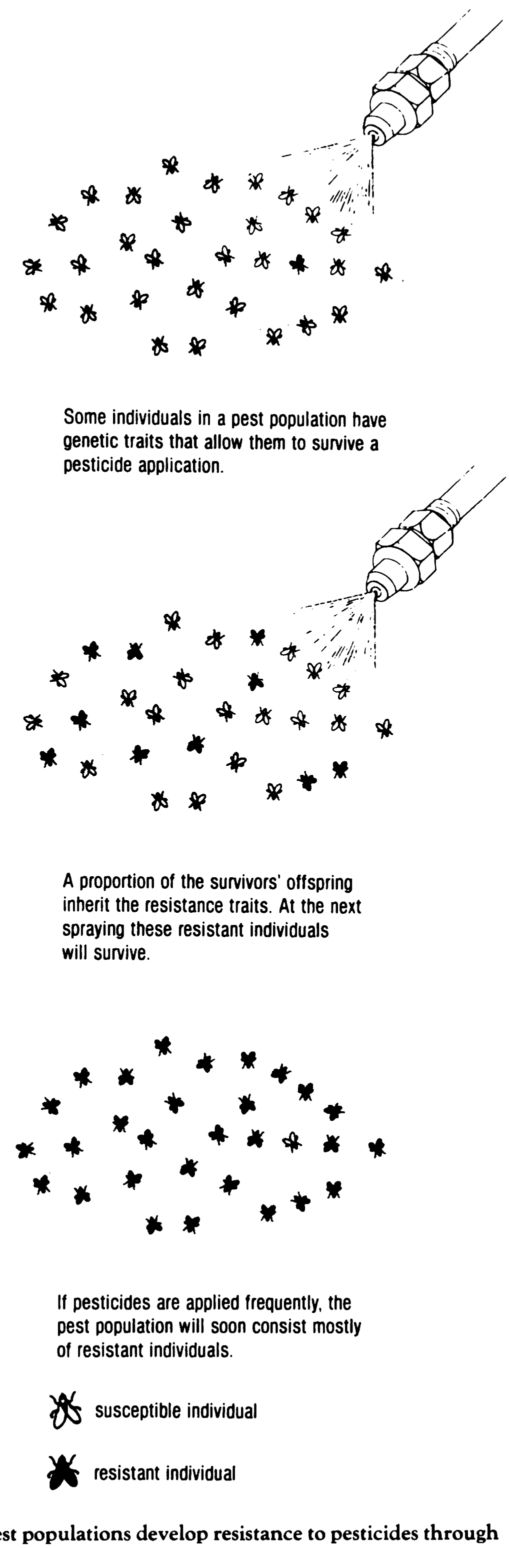


Figure 9. Pest populations develop resistance to pesticides through genetic selection.

illegal residues on harvested produce. Certain herbicides used in lettuce can leave residues that can harm subsequent rotation crops, especially grains. Before applying any pesticide, learn its use limitations. Before planting, become aware of what pesticides were applied to previous crop; some may injure cole crops or lettuce or have restrictions that do not allow a rotation with these crops.

Hazards to Human Health. Some pesticides used in cole crops and lettuce are hazardous to humans. Most at risk are applicators and harvesting or hoeing crews who may enter the field soon after an application. Others who spend time in the field, such as field workers and irrigators, may also be exposed. Residents nearby may suffer pesticide poisoning when sprays drift from the field onto yards, roadways, and other public areas. Minimize health problems by following label directions and state and local regulations, wearing appropriate protective clothing, confirming the availability of emergency health care, and avoiding drift and unnecessary use of pesticides. Several University of California Agriculture and Natural Resources publications, including numbers 21062, 2768, and 4070, discuss health hazards and safety precautions in detail (See References).

Hazards to Wildlife and Domestic Animals. When applying pesticides, consider the impact they could have on wildlife or domestic animals that might pass through the field or feed on culls. Fish may be killed if pesticide-contaminated water drains into streams or rivers. To minimize these problems, follow label requirements, the requirements of the local county agricultural commissioner, and the standards of the local regional water quality control board.

Hazards to Bees. Bees do not normally forage in lettuce and cole crops, but they may be attracted by flowering weeds or the honeydew produced by aphids. Unfortunately, many insecticides used in cole crops and lettuce are toxic to bees; avoid using them when honeybees are foraging. Consult University of California Agriculture and Natural Resources publications 2883 and 2287 for information about protecting bees from pesticide poisoning. (See References).

Insects

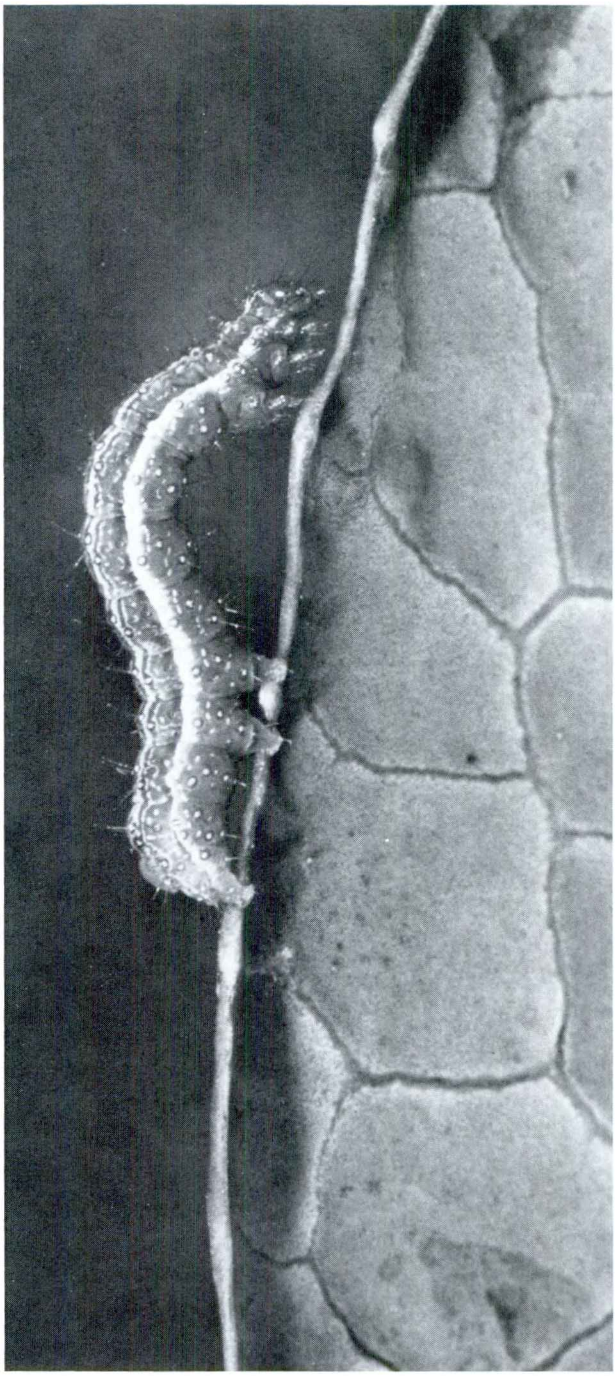
Insect outbreaks in cole crops and lettuce often relate to time of planting and adjacent crops. Generally, aphid populations increase during the cooler growing seasons—fall, winter, and spring— and drop when temperatures rise in summer. Lepidopterous pests, on the other hand, are most numerous during the warmer growing periods of summer and early fall. However, both groups can damage crops throughout the year in most California vegetable-growing areas. Variations in weather and climate can significantly affect calendar dates when pests occur in different regions and in different years in the same regions.

There is a different spectrum of pests in the central coast's cooler growing regions than in the warmer desert areas or even in the southern coastal areas. Some pests, such as the cabbage maggot on cole crops, the alfalfa looper, and the lettuce root aphid, are pests principally along the central coast. Other insects that may cause major losses in the desert—the tobacco budworm, white-flies, and several seedling pests—do not cause economic losses in either the central or southern coastal areas.

Many desert area pests move into lettuce from cotton, alfalfa, and sugarbeets. Fields planted where cotton is not grown or planted well after cotton has been defoliated are rarely infested with tobacco budworm and have a lower incidence of whiteflies and infectious yellows disease. Seedling pests such as crickets, fleabeetles, and darkling beetles are most often associated with desert lettuce that is planted while high temperatures still prevail in late summer or early fall and in fields close to cotton plantings. On the other hand, beet armyworm outbreaks are more closely associated with alfalfa and sugarbeet fields.

In all areas, crop residues in neighboring fields can be a major source of insect invasions. In many cases, especially when someone else is managing the adjacent land, you can do little to avoid these invasions other than to delay planting, not plant at all, or prepare to control problems when they arise.

The amount of economic damage that insect pests can inflict depends on the crop's maturity, so control action thresholds and management options in an IPM program must change as plants grow. Guidelines in this manual relate to three plant developmental stages:



- seedling development (Stage I)
- growth between thinning and heading (Stage II)
- head or curd formation (Stage III)

Common pest species for each stage are listed in Figures 10, 11, and 12.

Seedling Development—Stage I

Small seedling plants between germination and thinning or transplanting are very susceptible to insect damage. When large numbers of insects migrate into a field, they can destroy much of a stand in a few days. Pests that may attack seedlings of lettuce or cole crops include various caterpillars—loopers, cutworms, armyworms, tobacco budworms, and corn earworms—as well as aphids and flea beetles, and less commonly, crickets, darkling beetles, symphylans, springtails, or earwigs. In cole crops the cabbage maggot and the seedcorn maggot can also be important pests of seedlings.

COLE CROPS' INSECT DAMAGE—ALL REGIONS

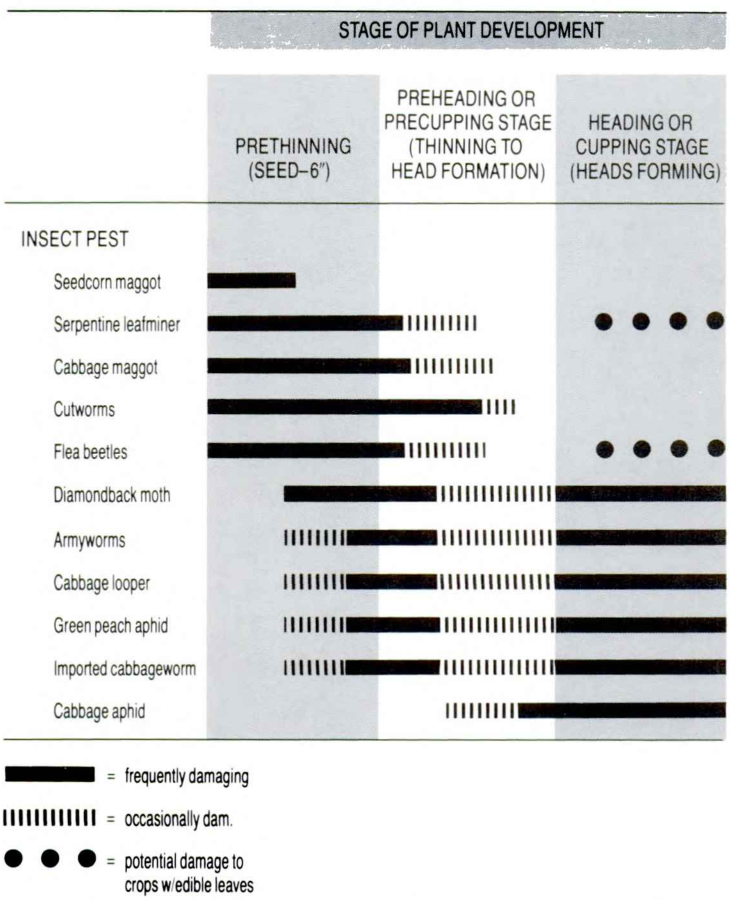


Figure 10. Crop stages when major insect pests are most damaging in cole crops.

Rapid removal of culls and other crop residues can slow invasion of new plantings by seedling pests. In some cases, other preventive methods are available. However, once seedlings begin to show stress due to insect feeding, they must be treated to prevent severe stand losses. Baiting or spot treatments will sometimes provide sufficient protection. In transplanted crops, the first few weeks after transplanting are also critical; seedlings must be protected until they form strong root systems.

Intermediate Growth—Stage II

Between thinning and head formation (Stage II), cole crops and lettuce plants can tolerate moderate insect populations. You have the most flexibility in making decisions during Stage II, which may be as short as 3 weeks in broccoli and lettuce under warm growing conditions or as long as several months in brussels sprouts. Because most leaves and stems grown during this time do not go to market, moderate damage will not cause economic loss as long as it does not delay maturity or stunt overall growth. Just before heading, however, plants must be clean. Once heads begin to form, insects can crawl into protected areas and escape control, so treat just before Stage III if you find significant populations of aphids or caterpillars.

Limiting insecticide treatments during Stage II has several benefits. The first is the obvious economic benefit of eliminating unnecessary insecticide applications. In addition, treatments generally kill natural enemies of insect pests. For example, predators and parasites may help regulate populations of caterpillars during Stage II, so insecticide usage can cause secondary pest outbreaks or pest resurgence, which will require additional treatments. Where possible, use the microbial insecticide *Bacillus thuringiensis* to control loopers, imported cabbageworm, and diamondback moth; it will not kill natural enemies.

Another reason for limiting insecticide use in lettuce is the adverse effect insecticides have on crop yield. Repeated applications of certain insecticides can reduce the plant's ability to carry out photosynthesis and transpiration. Weekly treatments of some organophosphates during the growing season may significantly reduce head size. With frequent treatment, yield loss due to pesticide usage will outweigh any benefits gained through insect control. If you follow the treatment guidelines in this manual, the number of treatments should stay well below levels that could damage crops. No information is available on the possible phytotoxic effects insecticides may have on cole crops.

Head or Curd Formation—Stage III

To meet high quality standards at the marketplace, all cole crops and lettuce must be almost free of insects and insect parts. Damage to or contamination of marketed portions of the plant—heads, curds, or sprouts—must be kept to a minimum. Control action thresholds from heading to harvest are very low. Cabbage aphid in cole crops and green peach aphid in lettuce are common contaminators because they can move inside the head or between leaves where they cannot be reached with insecticides or washed out during processing. Caterpillars may eat large holes in leaves or bore into heads or curds, rendering them unmarketable and contaminating the crop with their frass and bodies.

Monitoring for Insects

Insect populations often migrate to and build up rapidly in vegetable crops, so regular monitoring is essential. Monitoring should begin in nearby weeds for cutworms and other seedling pests even before seedlings emerge. Continue twice a week until harvest. After the crop has been thinned, weekly monitoring may be enough in the coolest part of the year. When populations appear to be approaching economic levels, check more often.

The most important monitoring activity in cole crops and lettuce is inspecting leaves, stems, heads, or roots for insects and their damage. Pheromone traps, which use sexual attractants as lures, are available for corn earworm, tobacco budworm, black cutworm, beet armyworm, armyworm, alfalfa looper, and cabbage looper, but at present there is no way to relate trap catches to the need for treatment. Similarly, yellow and purple sticky traps can be used to monitor adults of cabbage and seed corn maggots and yellow waterpan traps for green peach aphids, but there is no reliable system for using these catch counts.

Tools you will need in the field include a hand lens of at least 10× power for identifying small insects and eggs, a sharp pocket knife for slicing open damaged plants, a shovel for digging up wilted plants to examine them for root damage, and containers, such as glass vials or plastic bags, for collecting insects to take to the laboratory or to a farm advisor for identification. Always carry a notebook or monitoring form and a pencil to record your observations and monitoring results.

To monitor for insects, follow a path that zigzags through all quadrants of the field and examine a plant every few yards. Figure 13 shows a sample pattern. Choose plants randomly—a difficult step because samplers are often drawn to large or noticeably damaged plants. You can ensure random sampling by walking 50 paces into the field, stopping, and then finding the plant closest to your foot. Call this plant number one and count down the row to the tenth plant; plant number ten will be the plant you will sample. If you are to check several plants at each stop instead of just one, use the

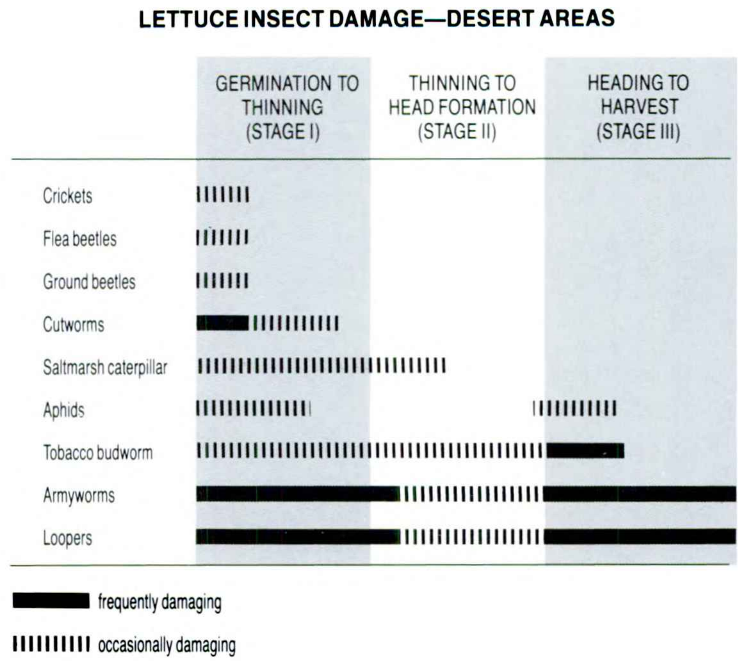


Figure 11. Crop stages when major insect pests are most damaging to lettuce in desert areas.

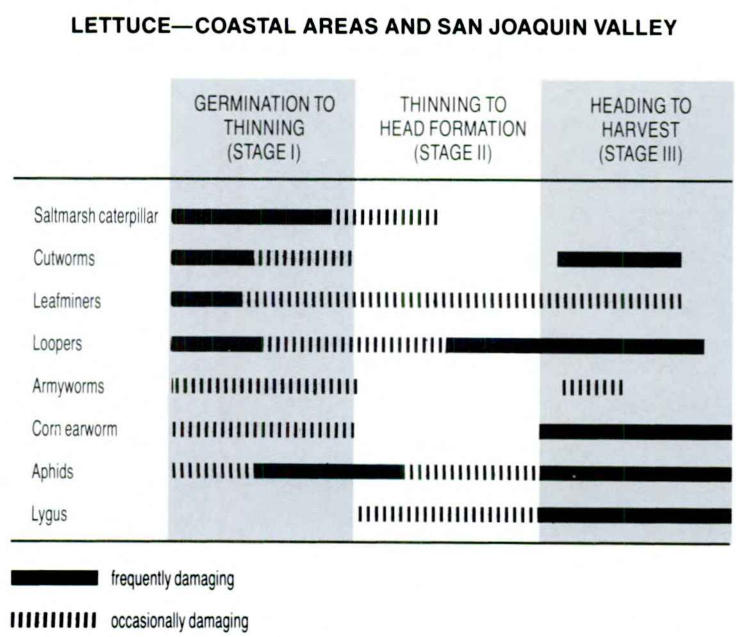


Figure 12. Crop stages when major insect pests are most damaging to lettuce in coastal areas and the San Joaquin Valley.

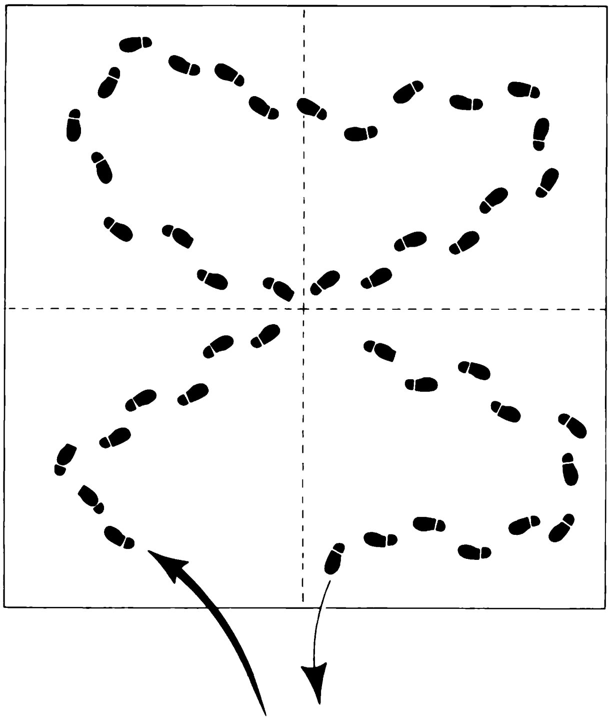


Figure 13. Typical zigzag sampling pattern for monitoring insects in cole crops and lettuce. Follow a different pattern each time you check the field, but be sure all quadrants are represented. Take separate samples along field edges or in areas with poor stands to detect invading pests.

same procedure to find the first one, then check the required number of adjacent plants. Step off a fixed number of paces—20 or 30—between each sample site and then count down the row from the closest plant each time to find the sample. As you move from site to site, zigzag through as much of the field as possible. Always include some samples from the head, tail, and middle of irrigation runs.

No experimental data show how many sampling sites are needed for most lettuce and cole crop pests, but researchers recommend dividing each field into four or more equal parts and taking as many samples as time permits from each part. Small fields may require less than four quadrants. Divide large fields into more areas or take more samples from each area. Sample field edges and areas with poor stands separately; some insect infestations begin in these areas, and some may be limited to those areas.

It is most efficient to sample for aphids, caterpillars, and other pests at the same time. Control action thresholds for most lepidopterous pests on both cole crops and lettuce combine counts for most species including loopers, armyworms, imported cabbageworms, cutworms, earworms, and budworms, so count them together. Note those species present and predominant; *most insecticides are not equally effective on all species.* Keep separate records for each species. At each sampled plant, complete counts and observations for caterpillars before starting counts for aphids or other pests. If sampling for one pest dislodges or disturbs other pest species, check for the second pest on an adjacent plant. Keep written records of your monitoring results on a form (Figures 14 and 15). Monitoring guidelines for caterpillars follow; see discussions on individual pests for details on monitoring for other insects.

Monitoring and Control Action Guidelines for Lepidopterous Pests. Loopers, cabbageworms, armyworms, corn earworms, tobacco budworms, cutworms, and other caterpillars that feed on leaves and heads of cole crops and lettuce are assessed together in the integrated pest management program. Check at least 25 plants for caterpillars in each quadrant of a 40- to 80-acre field twice a week. In fields where the crop is heading (Stage III), stop at five different locations in each quadrant and sample five plants at each location. In each quadrant of Stage I and Stage II fields, check 25 individual plants randomly every few yards as you follow the standard zigzag sampling path through the field. Fields smaller than 40 acres may require fewer samples. Check field edges separately for invading pests.

If a plant has holes made by caterpillars, search the general area near the hole and the crown of the plant for the caterpillar and carefully identify the species. In cabbage or lettuce heads, caterpillars may burrow into the head, so open damaged heads to find the larva. Feeding holes can also give you an idea of the seriousness of the damage, and they may indicate what parts of the field have infestations. Damage symptoms and feces can also be a clue as to which species are present, but do not rely on them for positive identification; damage alone does not justify treatment.

Even if there are no feeding holes, check each plant carefully for eggs and larvae, especially near the crown of seedlings and on the outer leaves of older plants. Earworms and budworms usually lay eggs on the outer leaves of the top half of the head. Loopers lay eggs primarily on the underside of lower leaves. Armyworm and cutworm eggs are often in the lower parts of the plant, but most are easy to spot because, except for certain cutworm species, they are laid in distinctive egg masses. After hatching in lettuce, armyworms and cutworms tend to move toward the center of the plant, so their damage is not as obvious as that caused by loopers and *Heliothis* species. You may also find pupae; for instance, diamondback moth caterpillars pupate on the outer and lower leaves of cole crops and are often abundant. Record the number of pests you find, their state of development, and the species. Don't include parasitized or diseased pests in your counts, but record the percentage of diseased or parasitized caterpillars. Pull larvae apart as shown on page 49 to detect parasites. Also note the presence of important predators.

Control Action Guidelines. Treatment thresholds vary according to stages in crop development. Treat seedling plants during Stage I if plants show stress due to caterpillar feeding. Treat lettuce seedlings if you find more than one healthy larva for every ten plants and no signs of a declining population due to biological control. If you find eggs on seedlings, wait until they start to hatch before spraying; most insecticides are more effective against larvae than they are against eggs. Waiting will also allow you to check for control by predators and parasites.

Be careful to identify caterpillars correctly. For instance, if the predominant species is a cutworm and the infestation is limited to field edges or one area of the field, spot baiting may suffice. If damage is due to loopers or diamond back moth and caterpillars are still small, the microbial insecticide *Bacillus thuringiensis*, which is less toxic to natural enemies, may be the best material to use.

During Stage II, between thinning or transplanting and the heading or rosette stage, plants become more tolerant of caterpillar feeding. Midway between thinning and heading as many as nine small-to-medium larvae per plant in cole crops or one-half larva per plant in lettuce can be tolerated. In the first week after thinning, however, treatment may be needed at these levels if all larvae are large. Natural enemies can often keep pests below these thresholds, so search carefully for beneficials and modify treatment levels to take maximum advantage of biological control. Treat just before heading if any caterpillars are in the field.

Keep the crop insect free after heading (Stage III). Watch for eggs or first instar larvae and treat as soon as you find a significant number. One larva per 25 plants can be used as a treatment guideline during Stage III. Older larvae will move into heads or under plants where insecticide applications cannot penetrate, so treat as soon as eggs hatch. Continue monitoring to determine whether more treatment will be needed.

Pesticide applications are most effective when caterpillars are most active and are in the upper portions of the plant. In timing applications, consider also weather and properties of the specific insecticide.

FIELD ____________________

DATE ____________________

DATE PLANTED ____________________

COMMENTS ____________________

____

MAP OF FIELD: indicate sampling pattern, quadrants, problem areas, and north edge of field.

Quadrant	# plants sampled	% damaged	# larvae	species[a]	stages[b]	predators, parasites, disease
____	____	____	____	____	____	____
____	____	____	____	____	____	____
____	____	____	____	____	____	____
____	____	____	____	____	____	____
TOTALS	____		____			

LARVAE/PLANT FOR FIELD ____

[a]SPECIES
A = armyworms
CUT = cutworms
CE = corn earworm
DB = diamondback moth
ICW = imported cabbageworm
L = loopers
SM = saltmarsh caterpillar
TB = tobacco budworm

[b]STAGES
E = egg
SL = small larva
ML = medium larva
LL = large larva
P = pupa

Figure 14. Record sheet for monitoring for caterpillars in cole crops and lettuce.

Cole crops seedlings may also be seriously damaged by cabbage maggots, seedcorn maggots, and diamondback moths.

Seedling Pests

Cole crops and lettuce seedlings are very susceptible to injury from insects and certain other invertebrates. Major pests—including armyworms, loopers, budworms, earworms, and aphids—sometimes inflict serious damage on seedlings, but there are also a number of pests that primarily attack seedlings. These include cutworms, flea-beetles, leafminers, crickets, darkling beetles, wireworms, earwigs, springtails, symphylans, and slugs and snails.

Cabbage Maggot

Delia radicum

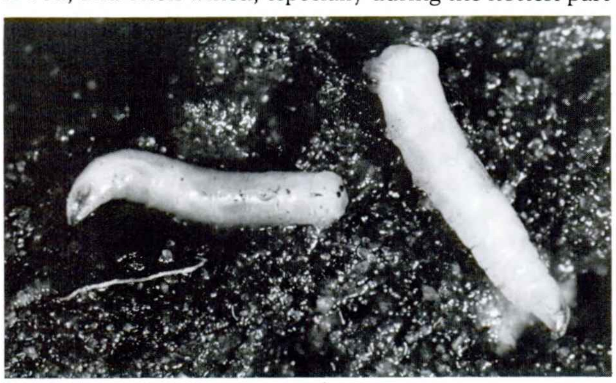
Cabbage maggots may seriously damage seedling stands of brussels sprouts, cabbage, and other cole crops in some areas along California's central coast. They are rarely a problem in southern California or in the lower San Joaquin Valley. Young plants between seedling emergence and about a month after thinning or transplanting are most vulnerable.

Description and Seasonal Development

Adult cabbage maggots are dark gray flies about half as long as the common housefly. Females lay small white eggs in cracks in the soil near plant stems. When the eggs hatch in a few days, the larvae burrow down to the roots. The larvae, small, legless, white maggots, are usually less than 1/3 of an inch long when full grown. Their head end is pointed and the rear is blunt with a dozen short, pointed, fleshy processes arranged in a circle around two brown, buttonlike spiracles. Cabbage maggots are usually found in dense colonies feeding on feeder roots and also boring into the taproot. The roots of a single infested plant may contain as many as a hundred larvae. Maggots feed for 3 to 5 weeks and then pupate in the roots or in the soil surrounding the infested plant. Pupae are brown and egg shaped. After 2 or 3 weeks, adult flies emerge from the pupae and push through to the soil surface. Cabbage maggots have at least two to three generations each year along the central coast where cool moist conditions enhance development. Cabbage maggots can be active all year but may overwinter as pupae in the soil.

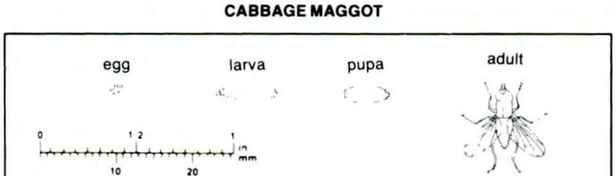
Damage

Maggots damage and destroy the root systems of cole crops. Their injury also provides entryways for pathogens that cause blackleg and bacterial soft rot. Heavily infested roots may be riddled with tunnels and rotten. If you try to pull up infested plants, the weakened taproot will sometimes break off. Affected plants are stunted, yellowed, and often wilted, especially during the hottest part of the day. The youngest plants are most susceptible. Healthy plants attacked after they are well established can usually tolerate a moderate cabbage maggot infestation. Cauliflower and brussels sprouts are less vigorous than are the hybrid cultivars of broccoli and usually sustain more damage. Crops planted in winter and spring usually suffer the greatest losses.



The head end of the cabbage maggot is pointed, and the rear is blunt with numerous short pointed fleshy processes. Cabbage maggots cannot be distinguished from seedcorn maggots without a microscope.

CABBAGE MAGGOT



In some years, cabbage maggots may crawl up the stem or be kicked up in weed cultivation and bore into the lowest sprouts. Any resulting economic damage can usually be removed by selective harvesting.

Management Guidelines

For transplanted crops, good management starts in the seedbed. Maggots can move into the field on infested transplants. Where cabbage maggot is a perennial problem, consider growing transplants in fumigated soil in the greenhouse or under frames of clear plastic or organdy. Greenhouse seedbeds can be treated with an insecticide, but treatment is not as foolproof as fumigating soil in an enclosed area. Fumigation also controls nematodes and other pests that may spread to transplants and then to the field on infested soil or plants. However, greenhouse-grown seedlings may become infested with maggots or other pests when plants are moved out of the greenhouse to harden before transplanting.

Applying an effective insecticide in a band at the base of the plant at the time of transplanting or planting is the best way to prevent damage in the field. Spring-planted or transplanted crops in areas where cabbage maggot causes economic injury every year should always be treated at this time. Sprays applied after planting or transplanting do not give satisfactory control. In transplanted crops in problem fields, use both the seedbed and the transplant treatment.

Female adults are attracted to the moisture gradient at the seed row for egg laying. Eliminating this gradient by attaching a set of drag chains behind the planter during seeding will reduce damage to direct-seeded seedlings.

After crops are in the field, watch for wilting or reduced growth, usually the first sign of a cabbage maggot infestation. Often, affected plants are lighter green than surrounding plants. Other pests and stresses can cause wilting, so pull up wilted plants and check roots and soil for maggots or pupae. If young larvae are present in several rows while the plants are still seedlings, insecticides may be drenched into the soil, but such treatments are difficult, costly, and may not be adequate. Replanting may be a more practical option. If roots are tunneled and rotten but no maggots are present, the maggots have probably left the roots to pupate, and insecticide treatments will be of no value. Older plants, if not attacked by midgrowth Stage II, can often outgrow moderate cabbage maggot populations, especially if they are maintained with a careful irrigation schedule. Disc under crop residues in infested fields immediately after harvest. Crop residues can provide an overwintering site.

Various techniques used experimentally to sample for cabbage maggots may be modified eventually for commercial use. To sample for eggs, mark a circle with a 5-inch (12.5 cm) diameter around the plant's stem, dig out the soil within the circle to a depth of 1 inch, and then drop the soil into a container of water. After mixing, allow the soil to settle, and small white maggot eggs will float to the surface. If you find more than 25 eggs per cauliflower plant or more than 50 eggs per cabbage plant, economic damage may occur. Maggot populations are often clumped in local areas around the field, so take many samples throughout the field.

Adult flies can be monitored with purple sticky traps. Some years cabbage maggot flies seem to emerge, mate and lay eggs in distinct generations. Knowing when they are active and laying eggs might help you predict when your crop is likely to be infested. For instance, it may be possible to transplant after the flight or apply a preventive treatment when eggs are expected to hatch. However, no predictive programs are currently available. Ask your farm advisor for the latest information on cabbage maggot management.

Seedcorn Maggot
Delia platura

Seedcorn maggots may infest newly sprouted seed and seedlings of cole crops and numerous other crops including corn, cotton, beans, beets, turnips, peas, radishes, and potatoes. Morphologically, seedcorn maggots cannot be distinguished in the field from cabbage maggot larvae. However, unlike cabbage maggots, they do not attack plants after the very early seedling stages. Seedcorn maggots are most prevalent under cool spring conditions, especially after very wet winters when decomposition of crop residues is slow. They occur in coastal areas and the San Joaquin Valley.

The seedcorn maggot's life cycle is similar to that of the cabbage maggot. Female flies lay their eggs singly or in clusters in the soil near plant stems. They prefer soils with a high proportion of organic matter. Eggs hatch in about 10 days, and the larvae feed for 1 to 3 weeks on seeds and germinating seedlings and then burrow into the soil to pupate. In areas where winters are cold, seedcorn maggots overwinter as pupae. In most California vegetable-growing areas, seedcorn maggots have numerous generations and are active for most of the year; their populations decline in summer.

Failure of seed to germinate or seedlings to emerge is usually the first sign of an infestation. Dig up the soil and seeds in rows that failed to emerge and look for seedcorn maggots. Other insects and disease may also kill germinating seedlings, so always search the soil for maggots before treating for other pests. Once the stand is established and seedlings have developed a few leaves, seedcorn maggots usually cause no economic damage.

Prevention is the best management strategy. Seedcorn maggots prefer to lay their eggs in moist, organically rich soil. If you are using manure, let it age and incorporate it well before planting a cole crop. Disc under cover crops at least 2 weeks before planting. Attaching a set of drag chains behind the planter during seeding will significantly reduce damage by seedcorn maggots as well as cabbage maggots. The moisture emitted from the seed row attracts female flies for egg laying. The drag chains eliminate this moisture gradient. Drag bars will also work, but chains are better.

Agromyzid Leafminers
Liriomyza spp.

Leafminers, often present in the field, occasionally cause economic damage to seedlings or marketed leaves of cabbage and lettuce. The principal leafminer species include the serpentine leafminer, *Liriomyza brassicae*, on cole crops; the pea leafminer, *L. huidebrensis*, and *L. trifolii* on lettuce; and the vegetable leafminer, *L. sativae*, which attacks both crops. Leafmining by the larvae is the principal cause of damage. The mines reduce the plant's photosynthetic capacity, render edible leaf portions unmarketable, and provide an entrance for pathogenic organisms.

Liriomyzid leafminer adults are small, shiny, black flies with a bright yellow triangular spot on the upper thorax between the wings. Females lay white, oval eggs within the leaf. Both male and female leafminer flies often feed at egg puncture sites.

After 2 to 4 days, larvae hatch and begin mining between the upper and lower surfaces of the leaves. The winding, whitish tunnels they create are initially narrow, but they increase in width as the larvae grow. Larvae emerge from the leafmines after completing three instars and pupate on the leaf surfaces or, more commonly, in cracks in the soil. Adult flies emerge from the pupae after about 8 to 11 days. The entire life cycle can be completed in less than 3 weeks when the weather is warm. Many generations are produced each year in both northern and southern California.

Management Guidelines. Natural enemies, primarily parasitic wasps in the *Diglyphus* genus, often control leafminers. Parasites are often killed by insecticides applied to control other pests, and a secondary outbreak of leafminers is not uncommon. Choose selective insecticides or baits, especially when treating for seedling pests.

Regularly check young seedlings for leafmines. Most mines occur on the cotyledons and first true leaves. Turn leaves over; some mines are most obvious from the underside.

If leafminer populations build to high levels when seedlings have only four or five leaves, chemical treatment may be necessary. Treat if you find in your overall field samples an average of one or more mines per leaf. Broccoli or cauliflower plants with six or more leaves are rarely damaged by leafminers, regardless of population numbers. However, if edible parts are mined, especially cabbage or lettuce leaves, chemical control may be justified later. Remember: By choosing selective materials to control other pests, you can often prevent leafminer outbreaks.

Other Seedling Pests

Start monitoring for other seedling pests before seedlings emerge. Check bordering weedy areas or fields for pests or evidence of their damage. If possible, destroy these reservoirs several weeks before you plant. Avoid mowing or plowing under reservoirs at the time of seedling emergence; this will just drive more of the pests into the seedling field. Harvesting an adjacent, infested crop will do the same thing.

Check seedling fields at least twice a week. Thoroughly inspect all border areas for invading pests, and zigzag through the field to check for eggs of moths and other pests that may fly in. Control action thresholds for seedling pests in lettuce are low. In the case of cutworms, armyworms, loopers, earworms or budworms, treatment is recommended when population levels of all species combined reach one larva per 10 lettuce plants. Thresholds for lepidopterous pests in cole crops have not been established, but the same guidelines could be used.

Cutworms

All cole crops and lettuce are subject to attack by cutworms, which include several species of moth larvae that clip plant stems near or just below the soil. The three most common species attacking cole crops and lettuce in California are the black cutworm, *Agrotis ipsilon*, the variegated cutworm, *Peridroma saucia*, and the granulate cutworm, *Feltia subterranea*.

The larvae usually bury themselves just beneath the soil surface or hide under dirt clods or plant debris during the day and emerge to feed at night. Large cutworms, up to almost 2 inches (5 cm) long, can destroy several plants each night; heavy infestations can remove most of a stand.

Adult cutworm moths have dark grey or brown front wings with irregular spots or bands and lighter hind wings (see photo on page 53). Females lay hundreds of white eggs, either singly or in clusters (depending on species), on leaves or stems close to the soil. After hatching, young larvae may feed on leaf surfaces for a while, but older larvae drop to the ground, tunnel into the soil, and emerge at night to feed. Some cutworm species are subterranean and remain beneath the soil until they emerge as adults. The only subterranean species known to occur in lettuce and cole crop areas is the glassy cutworm, *Crymodes devastator*, which is occasionally seen in the southern San Joaquin Valley. A feature that distinguishes many cutworm species from most other lepidopterous pests in these crops is their habit of curling into a C-shape when they are disturbed.

Cutworms typically cut off seedlings or young plants at or just below ground level. Usually several plants in row will be wilted or cut off, often in isolated areas of the field. Losses can be especially serious in fields seeded to a stand or just thinned. Cutworms occasionally bore into lettuce or cabbage heads causing damage similar to that caused by other caterpillars that enter the head. Some species may also damage leaves.

Management Guidelines. Even before you plant a field or before the crop emerges, check for cutworms in surrounding weeds. After the crop is up, check for a row of four or five or more wilted plants with completely or partially severed stems. Once you find damaged plants, look for cutworms by digging around the base of plants and sifting the soil for caterpillars. You won't normally find cutworms on the soil surface during the day. A good time to find them is at dawn or at night with a flashlight.

Cutworms often recur in the same fields and in the same parts of fields from year to year. Areas that have had a dense stand of weeds, or crop residue disced in soon before planting, or located near an alfalfa field often have high populations. Damage is worst where large numbers are present before planting. Baits are available for control of most species, but they will not control subterranean species like the glassy cutworm. Baits are more effective when other food is limited, so check for cutworms and get the bait out before the crop emerges, especially where cutworms have caused damage before. Once seedlings are up, treat as soon as you find several severed plants in the same row.

Cultural controls can help prevent cutworm damage. Remove weeds from field margins and plow fields at least 10 days before planting to destroy larvae, food sources, and egg-laying sites. Several natural enemies attack cutworms but none is effective enough to provide reliable control.

Flea Beetles

Flea beetles occasionally infest cole crops and lettuce seedlings. They are most common in spring but may occur anytime, especially in fields that are weedy or surrounded by weeds. The species that occur in these crops in California include the striped flea beetle, *Phyllotreta striolata*, the potato flea beetle, *Epitrix cucumeris*, the western black flea beetle, *P. pusilla*, and the western striped flea beetle, *P. ramosa*.

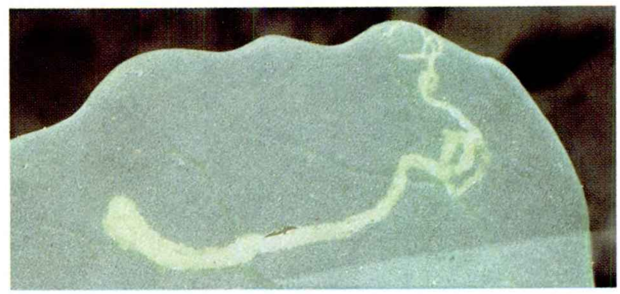
The adults, small, hard beetles with enlarged hind legs, cause most of the damage. The different species vary in color and markings. When disturbed, they jump like

The black cutworm is greasy gray to brown with several black bumps or tubercles on each segment. This species may tunnel beneath the soil, dragging parts of plants with it.

The granulate cutworm may vary in color but is lighter than the black cutworm and does not tunnel into the soil.

Cutworms frequently roll into a C-shape when disturbed. The variegated cutworm is the species shown here.

The leafminer adult is a tiny yellow and black fly. This photo shows the vegetable leafminer, *Liriomyza sativae*.



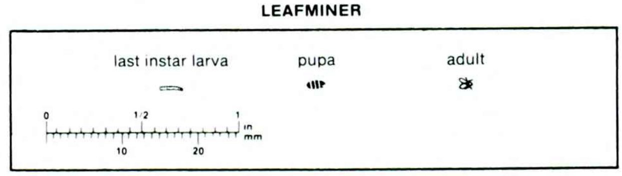
Leafminer mines begin as threadlike, white lines that widen gradually as the larva feeds and grows.

This mine has been opened to show the legless leafminer maggot.

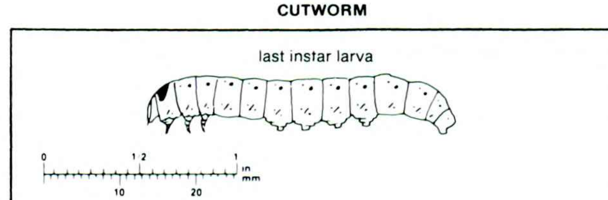
Parasitic wasps in the *Diglyphus* genus frequently kill leafminer larvae within leafmines. This *Diglypghus* pupa has been removed from a leafmine.

EARL OATMAN

LEAFMINER

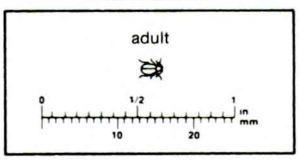


CUTWORM



Flea beetles are small beetles that feed on the underside of leaves.

FLEA BEETLE



EARL OATMAN

Small pits or irregularly shaped holes are typical of flea beetle damage.

This predaceous ground beetle (*Amara* sp.) should not be confused with darkling beetles. The tips of their antennae are not usually enlarged as are those of darkling beetles.

fleas, often travelling considerable distances. They feed on the undersides of leaves causing numerous small, round, or irregularly shaped holes or pits. Large populations of beetles can kill or stunt seedlings. On older plants flea beetles feed on the lower, older leaves, but they do not usually cause economic damage once seedlings are well established.

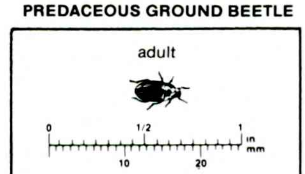
Flea beetles lay their very small eggs in the soil around the plant, on the leaves, or in cavities hollowed out in the stems. The larvae are small, slender, white worms that feed on the foliage, mine the leaves, or attack the roots, depending on the species. Length of the larval stage is variable, frequently lasting up to a month. Flea beetles pupate in the soil.

Management Guidelines. Monitor newly emerged seedlings at least weekly for flea beetle damage until plants are well established. Relatively low populations can cause economic damage when plants are in the cotyledon or first-leaf stages. Treat if you find several damaged rows. Often spot treatment of outside rows or borders will be enough. Baits are not effective.

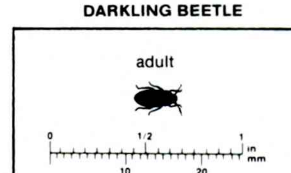
If populations are high enough, flea beetles can cause severe losses just after thinning, so treat infested fields before thinning. Once plants have five leaves, they can tolerate several flea beetles per plant without damage. Older plants are even more tolerant to feeding and will not be damaged unless populations achieve extreme densities. When insecticides are necessary, one treatment is usually sufficient.

Darkling beetles are dull bluish black or brown. They never have color patterns on the back. Like *Blapstinus* species shown here, most species have the segments at the tip of the antenna slightly larger than segments at the base.

PREDACEOUS GROUND BEETLE



DARKLING BEETLE



Cultural controls can substantially reduce populations. Remove weeds along field margins and deeply disc plant residue in infested fields after harvest. Some flea beetles have a wide range of hosts, so choose rotation crops carefully. Natural enemies apparently do not effectively control flea beetles.

Field Crickets *Gryllus* spp.

Crickets are pests only occasionally; their damage is usually confined to sprinkler-irrigated lettuce fields in the low deserts. However, when they do occur, they can quickly destroy most of a field. Problems are usually limited to fields planted closely to cotton in August or early September in desert areas. Moving out of cotton and desert flora, large numbers will migrate to seedling lettuce if it is available. Most damage occurs at night. Crickets hide during the day in soil cracks, ditches, and weeds. Apply baits around field edges to control threatening populations.

Darkling Beetles *Blapstinus* spp.

Darkling beetles chew off seedlings or feed on foliage. They usually invade fields from weedy areas or from such crops as cotton, alfalfa, or orchard ground cover, so damage often begins at the edges of a field. The beetles are most active at night but occasionally run on the ground in the daytime. They often hide under clods or debris during the hot parts of the day. To prevent beetle invasions from an adjacent field, fill a ditch full of water to keep them out. If treatment is needed, a bait placed around the edges of the field will usually provide adequate control.

Darkling beetles can be confused with predaceous ground beetles, which may be black or brown like darkling beetles, but they are usually shiny, and the tip segments of their antennae are rarely enlarged. Some predaceous ground beetles have prominent patterns of lighter colors; they feed mostly on caterpillars and other insects.

Wireworms

Wireworms are the soil-dwelling larvae of click beetles, family Elateride. Some species injure seedlings by feeding on roots or boring into stems. Wireworms, slender, cylindrical, and usually yellowish, resemble mealworms. When present in significant numbers, they can be found by checking soil in the root zone. Damage is most common where the soil has a high organic content, as in fields that have recently been in or are adjacent to pasture, fallow land, or alfalfa. Soil fumigants and certain other pesticides kill wireworms, but special controls are seldom needed. Flooding a field for several weeks also reduces populations.

False Wireworms

False wireworms are the larvae of beetles in the genus *Eleodes*, family Tenebrionidae. They occasionally feed on sprouting seeds and seedlings of lettuce or cole crops, usually in fields that have been fallow or in pasture and that have not been intensively farmed in recent years. The larvae may be dark brown to yellow and resemble true wireworms, but they have longer, thicker antennae and front legs. False wireworm adults are dark to black beetles with smooth or ridged wing covers. When disturbed, they have a peculiar habit of placing their heads on the ground and elevating the hind part of their bodies as though standing on their heads. Adults do not normally cause serious economic damage. Control is the same as for true wireworms.

Earwigs

Earwigs, common garden insects in the order Dermaptera, have pincerlike forceps on their posteriors making them easy to identify. Nocturnal, they hide during the day and are generally a problem in commercial crops only in areas near buildings, trash, or other refuges. Damage is limited to feeding on young seedlings. Baits are available for their control.

Springtails

Springtails, in the order Collembola, are among the most primitive insects. They are usually less than 1/8 inch (0.5 cm) long, entirely wingless, and with a forked appendage at the tip of the abdomen used for springing into the air. Like garden symphylans, they are associated with heavy soils with high organic content. They often occur in the same parts of a field every year. Springtails are difficult to control; rototilling beds before planting offers some control. Preplant soil fumigation will also kill springtails.

Garden Symphylan *Scutigerella immaculata*

Garden symphylans, also called garden centipedes, feed on roots of various crops and weeds. They may damage seedlings before or after emergence and may slow growth of larger plants. Occurring mainly in soils with good structure and a high organic matter content, they return to damage the same relatively small areas every season; infestations spread slowly. Infested soil can be treated with soil fumigants and with certain insecticides, but treatments are not always completely effective. Continuous flooding for 3 weeks or more during summer helps reduce infestations, as does discing in a crop of sorghum.

Snails and Slugs

Snails and slugs may invade cole crops or lettuce fields under cool and moist conditions along the coast and in the coastal valleys. Fields next to citrus groves, canals, and drainage ditches often are the most seriously affected. Seedling or more mature plants may be damaged. Removing trash, lush weedy growth, and other daytime shelter may help limit their numbers. For control, disc under several rows of the crop or apply recommended baits along field edges where pests enter.

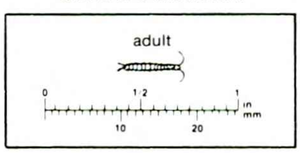
Cabbage Aphid
Brevicoryne brassicae

The cabbage aphid, a key pest of all cole crops throughout California, does not infest lettuce. Although high populations can stunt plants, their contamination of produce is the major concern.

Wireworms are long, cylindrical, soil inhabiting larvae. False wireworms have longer, thicker antennae and true legs.

Garden symphylans are slender and white; they have 10 to 12 pairs of legs and a pair of antennae. They run rapidly when exposed to light.

GARDEN SYMPHYLAN



Snails may injure mature or seedling plants of lettuce or cole crops.

Description and Seasonal Development

The cabbage aphid is green gray with a waxy "bloom" that gives colonies a grayish white appearance; some growers call it the "gray aphid." The pest forms dense colonies around the plant's youngest leaves and flowering parts, in the centers of cabbage heads, or on young brussels sprouts. It is not as common on seedlings as is the green peach aphid.

Throughout California's vegetable-growing areas, this pest usually has a simple life cycle with adult females giving birth throughout the year to live offspring. When cole crops are not in the field, populations can survive on weeds in the mustard family. Up to 21 generations per year have been reported in areas with climates similar to that of southern California. In areas of cold winters, the aphid overwinters in the egg stage.

The cabbage aphid may be found all year, particularly in the Salinas Valley, where cole crops are always in the field and the climate is mild. Along the southern coast, where summers are warmer, populations drop in July and August, build up in fall, peak during winter, and drop by late spring when it gets warm.

Both winged and wingless adults occur. Winged adults are gray green with a black thorax and without the thick, waxy coating characteristic of other individuals of this species. Their short cornicles and general shape distinguish them from winged green peach aphid adults. More winged individuals are produced when local populations become dense or the food source deteriorates. The winged form provides the pest with a means for rapid dispersal when conditions become unfavorable.

Damage

Cabbage aphids usually do not affect seedlings, but they begin to build up after thinning or transplanting. Large colonies may stunt or kill plants, especially when plants are small, but the main problem associated with cabbage aphid is contamination. Cabbage aphid colonies in heads of cabbage, broccoli, cauliflower, or brussels sprouts cannot be removed before processing or marketing. When aphid populations are high, their feeding often distorts leaves, causing them to curl. Aphids in these protected areas often escape pesticide treatments, and control becomes more difficult.

Management Guidelines

Prevention. Cultural practices and biological agents can reduce aphid infestations and delay or prevent the need for pesticide use. Small colonies are sometimes destoyed by lady beetles, syrphid fly larvae, or other predators, or fungal disease especially in spring. Aphid parasites are also active in cole crops, and the "mummies" produced when the parasites pupate within the dead aphid's body are good indicators that parasites are present. *Diaeretiella rapae* is the most important parasite of the pest in California. Unfortunately, natural enemy populations rarely build up fast enough to keep heavy aphid infestations below economic levels after Stage II. Hyperparasites on *D. rapae*, insecticides, short crop life, and environmental and biological factors partly account for the lack of good biological control.

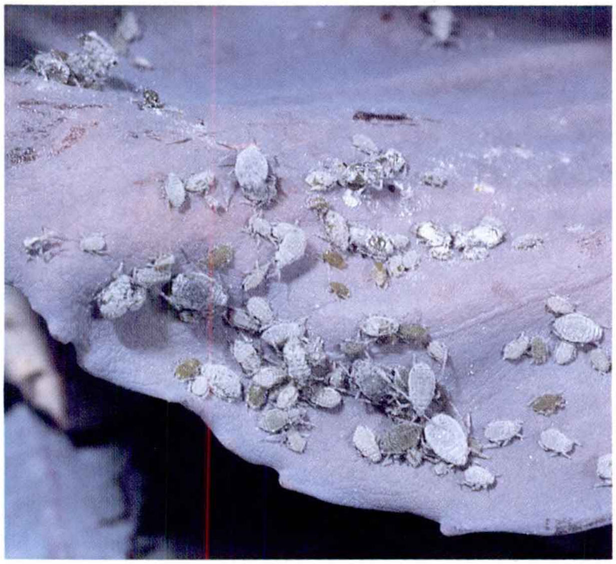
Cultural practices that can limit cabbage aphid populations include removing host plants that harbor aphids between crops. Destroy crop remnants immediately after harvest and remove or control alternate hosts, including mustards and related weeds, around field borders. Infestations on brussels sprouts can start in seedling beds before transplanting, so be sure transplants are clean.

Monitoring. Check each field for cabbage aphids at least twice a week. You can check for green peach aphids at the same time, but count and record them separately.

Aphids tend to be most prevalent along the upwind field borders and edges next to other crucifer crops or weeds, so take the first half of your samples in these areas. If you don't find any aphids along the field edges, you may not need additional samples. If you do find aphids, take the rest of your samples in a zigzag pattern that includes random areas in the center of the field. Aphid populations are often clumped, so check all quadrants of the field. Check approximately the same number of plants as you are sampling for lepidopterous larvae (see page 28).

When sampling brussels sprouts fields, you need only determine if cabbage aphids are present on each plant and follow the sequential sampling program outlined here. In cabbage, broccoli, and cauliflower, check the youngest, highest, and innermost leaves in young plants. After heading, check the flowering parts of broccoli and cauliflower and pull back some of the wrapper leaves to check cabbage. Also look for natural enemies of aphids, including parasites; count aphid mummies, syrphid fly larvae, and the lady beetle larvae and adults. Record these counts on a form (Figure 15).

Control Action Guidelines. An IPM program's goal is to delay using insecticides for as long as possible while maintaining yields and quality. Most fields require at least one application against aphids at preheading; however, if you can delay applications until just before head formation, you will save the expense of additional applications and may also be able to maintain the natural enemies that will keep caterpillar pests, including loopers, imported cabbageworms, armyworms, and diamondback moths, below economically damaging levels. Because cabbage aphid populations are often clumped, you may also



Cabbage aphid colonies are usually dense and covered with a waxy gray bloom.

FIELD ____________

DATE ____________

DATE PLANTED ____________

STAGE OF PLANT DEVELOPMENT ____________

PESTICIDE APPLICATIONS ____________

COMMENTS ____________

____

MAP OF FIELD: indicate sampling pattern, quadrants, problem areas, and north edge of field.

quadrant or field edge location	# plants sampled	average # aphids per plant	aphid species[a]	natural enemies		other pests[b]	

[a]APHID SPECIES

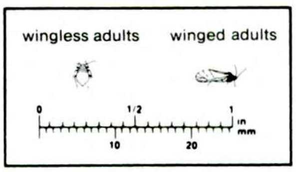
CA = cabbage aphid
GPA = green peach aphid
PA = potato aphid
TA = turnip aphid

[b]OTHER PESTS

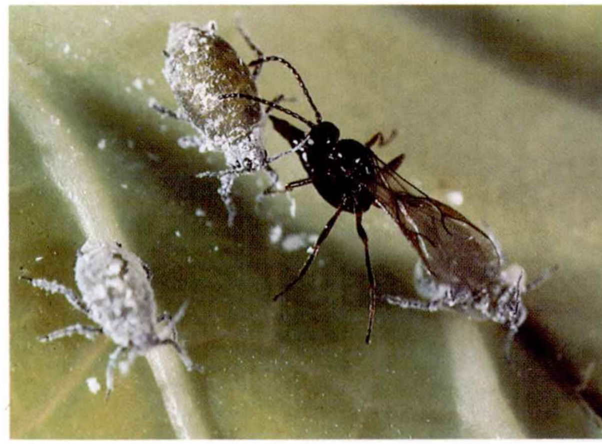
Write in species in your field; these might include:
LRA = lettuce root aphid
CM = cabbage maggot
LM = leafminers

Figure 15. Record sheet for monitoring aphids and other insects in cole crops and lettuce.

CABBAGE APHID



Because of its coating of wax, some growers call the cabbage aphid the "gray aphid." Freshly molted individuals lack the gray wax.



A major natural enemy of the cabbage aphid is the parasitic wasp, *Diaeretiella rapae*, shown here laying an egg in an aphid.

Some cabbage aphid adults are winged. They have a black thorax and are not covered with wax. Their short cornicles distinguish them from adults of the green peach aphid.

Parasitized aphids form tan, crusty skins called mummies, and the wasp develops inside, killing the aphid. The holes in these mummies indicate that an adult wasp has emerged.

When colonies are dense, cabbage aphids can severely distort growth of cabbage heads.

Cabbage aphids, such as the tan ones in this photo, are often killed by fungal diseases when high humidity favors their development.

be able to limit application to one or two borders or areas of the field and preserve natural enemies in other areas.

Broccoli and Cauliflower. Seldom a problem on seedlings, cabbage aphids may increase rapidly after plants are thinned. Between thinning and head formation, broccoli and cauliflower can tolerate fairly high populations without yield losses unless plants are stressed for other reasons. So, for these crops, wait until populations increase to nearly 100 aphids (including green peach aphid and turnip aphid) per plant before treating during this period. If infestations are limited to field edges, border or spot treatments may suffice.

Once heads begin to form, cabbage aphids must be controlled, even if only a few are present, since even a few can make heads unfit for market. As soon as they move into sheltered areas in the heads, aphids are difficult to control, especially if insecticides are applied at low volume. Parasites and predators that migrate into the aphid-infested heads are equally detrimental as contaminants after head formation. Once treatments begin, check the field weekly, and treat again as soon as aphids reappear.

Cabbage. Cabbage plants require more careful attention than do other cole crops. Infestations that occur before heading can cause severe damage by distorting head development. Throughout growth, the plant's overlapping leaves provide excellent shelter for cabbage aphids. Begin treatment as soon as more than 1 to 2% of the plants in the field are infested with one or more aphids. Continue checking and reapply pesticides when populations again rise to this level.

Brussels Sprouts. Presence-absence sampling makes it easier to determine whether brussels sprouts require treatment for cabbage aphids before sprout formation. To use it, sample at least 13 randomly selected plants for each block that can be sprayed separately. Take five samples along the field border and the rest scattered through the center of the field. For each plant, simply record whether the cabbage aphid is present or absent. After checking 13 plants, consult Table 8; if the number infested exceeds the "treat" level or is at the "don't treat" level, stop sampling and take appropriate action. If the number of infested plants falls between the "don't treat" and "treat" levels, continue sampling until counts are either equal to or below the "don't treat" level or equal to or above the "treat" level. If you take 50 samples and still don't reach a determination, stop sampling and wait until the next sampling date to make a decision. After treating, continue sampling and follow the same guidelines for treatment.

After sprouts form, continue checking the fields and treat as soon as you find one or more infested plants for every 40 checked. Aphid-contaminated sprouts are not marketable.

Table 8. Sequential Sampling Decision Lines for Cabbage Aphids on Brussels Sprouts.[a]

Number of Plants Sampled	NUMBER OF PLANTS WITH APHIDS		
	Don't Treat	Continue Sampling	Treat
13	0	1–4	5
16	1	2–4	5
18	1	2–5	6
23	1	2–6	7
25	2	3–6	7
28	2	3–7	8
33	2	3–8	9
34	3	4–8	9
38	3	4–9	10
43	4	5–9	10
44	4	5–10	11
49	4	5–11	12
50	4	5–11	12

[a] Continue sampling until you make a clear decision to treat or not treat.

Green Peach Aphid
Myzus persicae

The green peach aphid is the most important leaf-feeding aphid pest on lettuce. On cole crops, it rarely requires treatment, even though substantial populations may occur.

Description and Seasonal Development

The green peach aphid is pale green to yellow and has no waxy bloom, making it easy to distinguish from the cabbage aphid. Its shape and color are distinctive to the trained eye. An easy way to tell it from other aphids commonly occurring on lettuce is to check the base of the antennae under a hand lens. The green peach aphid is the only lettuce aphid whose frontal tubercles at the base of the antennae grow toward each other instead of diverging (Figure 16). Both winged migrant and wingless adult forms occur.

On cole crops this species is usually found scattered on the oldest leaves. The aphid is common on seedlings, young plants, and lower leaves of older plants, but it is seldom found in heads of broccoli, cauliflower, cabbage, or brussels sprouts.

On lettuce, populations start on the lower, older leaves and frequently move up the plant. In heavy infestations, they may be found throughout the plant. Colonies are not clustered, as is the case with the potato aphid, but spread uniformly on the leaves. Green peach and potato aphids often occur together on the same lettuce leaves.

On cole crops, green peach aphid colonies are usually confined to lower leaves.

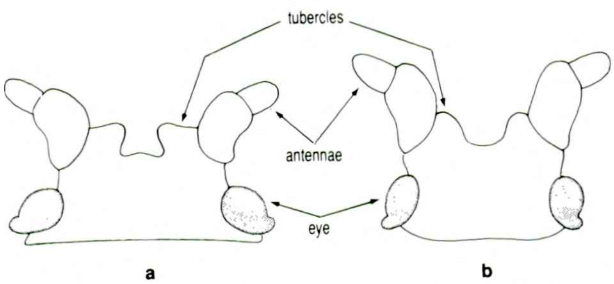


Figure 16. The green peach aphid has converging antennal tubercles as illustrated in a. The diverging tubercles of the potato aphid are shown in b.

The green peach aphid can be distinguished from other aphids occurring in these crops by looking at the frontal tubercles at the base of the antennae. It is the only one with tubercles growing toward each other rather than diverging.

Like other aphids on these crops, the green peach aphid has a simple life cycle throughout California's major lettuce and cole crops regions. Females give birth to live offspring all year without mating. When vegetable crops are not available, the aphid lives on a wide range of weed hosts. In areas of frequent freezing temperatures, including California's northeastern mountain areas, the aphid has male and female sexual forms that produce eggs for overwintering on deciduous fruit trees. However, no eggs are known to be produced in California's cole crop and lettuce-growing areas.

In the central coastal areas, populations peak in spring and fall and decline in summer and winter. Spring populations build up on weed hosts in uncultivated areas during March and April and migrants fly into crop plants as weeds mature in April and May. With more winter rainfall, weed growth in uncultivated areas is more luxuriant and aphid populations are likely to be higher. However, lady beetle populations often fly to the wild plants and clean up the aphids before they migrate to crops.

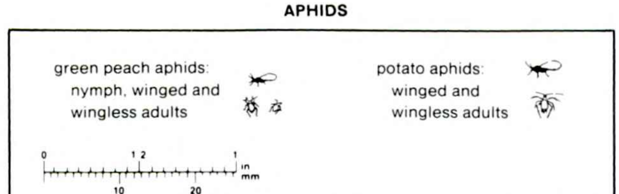
In the southern coastal areas, populations peak in September to November and again in March to April; they are highest during fall and lowest during hot, dry summers. In the San Joaquin Valley, populations are usually highest in April and May and decline in summer. Although they may increase again in fall, they usually do not reach springtime levels in these areas. In the southern desert areas, green peach aphids achieve their highest population levels in January and February.

Damage

High numbers of aphids can stunt seedlings or transplants of either cole crops or lettuce. In cole crops, green peach aphids rarely cause economic losses in older plants, but losses in lettuce are occasionally serious. In lettuce they may move into the plant, contaminating heads bound for market. Removing the wrapper leaves can help where infestations are moderate, but if populations are high, heads cannot be salvaged.

The green peach aphid is a vector of several viruses that affect lettuce. Lettuce mosaic virus used to be the most serious, but a lettuce-free period, virus-free seed, and cultural controls have reduced it as an economic problem in

APHIDS



California over the last decade. Other viruses of lettuce spread by green peach aphids include beet western yellows and turnip mosaic; neither currently causes serious economic problems. These diseases are discussed in more detail in the disease section of this book.

Management Guidelines

Prevention. The same general predators that attack other aphids also prey on green peach aphids. Epidemics of a disease caused by the fungus *Entomophthora aphidis* may also kill portions of the green peach aphid population under some conditions. Parasites, including *Lysiphlebus testaceipes*, *Aphidius matricariae*, and *Aphelinus semiflavus*, attack this pest. On cole crops, *Diaeretiella rapae* also parasitizes green peach aphids. Natural enemies rarely provide adequate control of high field populations of the aphid in spring or fall crops.

Prompt removal of culls and other crop residues helps slow reinvasion of fields and may limit sources for the viruses that the green peach aphid may spread. The aphid has so many alternate hosts that complete elimination of reservoirs is impossible.

Monitoring. Check each field at least twice a week. Plants located at the edges of fields, especially along the upwind borders, are usually the first to become infested, so sample those first to detect new migrations. Also take some samples scattered around the center of the field to assess developing populations. Be sure to check all quadrants of the field. Like other aphids, green peach aphid colonies are clumped, especially in the early stages of colonization, so you may not find them if you sample only a few plants. Check approximately the same number of plants as you are sampling for lepidopterous pests, following a pattern similar to that shown in Figure 13.

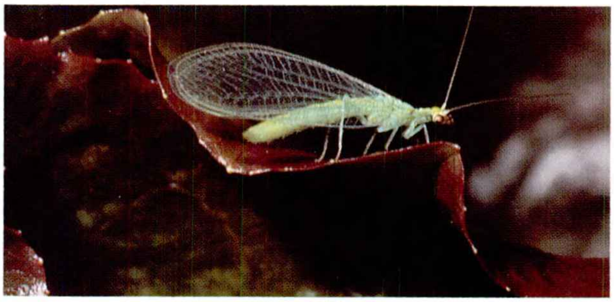
On cole crops, green peach aphids prefer the undersides of the oldest leaves. On broccoli, about 50% of the population can be found on these leaves; check the oldest leaf on each sampled plant, and tally the number found.

Although infestations start on the oldest leaves on lettuce, green peach aphids spread rapidly through the plant when populations expand. Once they have moved to younger leaves, economic damage may have already occurred.

Control Action Guidelines. The aphid's tendency to move into heads of lettuce and its potential for spreading virus diseases make it a much more serious pest in lettuce than in cole crops. Guidelines differ for the two crop groups.

Cole Crops. Because these aphids remain mostly on the older, nonmarketed leaves of cole crops, low-to-moderate

Both winged and nonwinged adult green peach aphids occur. Winged green peach aphids have longer antennae and cornicles than cabbage aphids.



Lacewings sometimes feed on aphids in lettuce. This is the adult of the green lacewing.

The predaceous larvae of syrphid flies feed on all species of aphids, including the green peach aphid.

The convergent lady beetle can often decimate aphid colonies in the spring. The predaceous larva is shown here.

populations can be tolerated on older plants. Young seedlings or transplants can be killed by high numbers, so treat infested young plants if they show stress due to feeding by aphids. Green peach aphids will be controlled at preheading if applications are made to control cabbage aphids and, also, if certain materials are applied to control lepidopterous pests.

Lettuce. If high populations develop on seedlings, treat as soon as plants appear stressed. During Stage II, before heading, moderate numbers of aphids can be tolerated. Insecticides applied at this time to control aphids will also kill natural enemies of various caterpillar pests, so avoid treating unless populations exceed 20 aphids per plant. Just prior to heading, however, treatment is required if a significant percentage of plants are infested to keep aphids from spreading into the center of the head where they are more difficult to control. Continue monitoring to see whether another treatment is required—one application may be enough. Many fields may not require a preheading spray for aphids. Treatments for lepidopterous larvae will usually control green peach aphid during the heading period. Because insecticide applications will not control 100% of the aphids in the field or later immigrating aphids, they cannot be relied upon to limit spread of aphid-vectored viruses. Populations of green peach aphids in some areas are resistant to some insecticides registered for their control. Ask your farm advisor for information.

Potato Aphid
Macrosiphum euphorbiae

The potato aphid is a pest in lettuce, but it is not economically important in cole crops. Often occurring in mixed colonies with green peach aphid, it does not generally occur in southern desert areas.

Both pink and green forms of the potato aphid occur. The potato aphid is much bigger than the green peach aphid; the adult has much longer cornicles and cauda. Potato aphid colonies are composed of adults with offspring closely clustered around them and they are usually on the youngest leaves. Green peach aphids spread out and do not occur in dense colonies unless numbers are very high.

The potato aphid is not known to transmit any diseases to lettuce. The damage it does cause is similar to that caused by green peach aphid. Management guidelines, general predators, and monitoring and control action thresholds are the same as for the green peach aphid in lettuce.

Turnip Aphid
Hydaphis erysimi

The turnip aphid is occasionally found on cole crops, especially in southern coastal areas, but it is rarely of economic importance. It prefers to feed on turnips and radishes.

Similar in shape and size to the cabbage aphid, the turnip aphid lacks the waxy bloom that covers cabbage aphid colonies. Turnip aphids are much more evenly distributed over plants than are cabbage aphids, which usually occur in tight colonies on the youngest leaves. Turnip aphid populations seldom require treatment. Applications made to control other aphid pests will control the turnip aphid as well.

Lettuce Root Aphid
Pemphigus bursarius

Although the lettuce root aphid is an occasional pest of lettuce, damage may be severe in infested fields. Most losses involve fields near Lombardy poplar trees, where the aphid overwinters. Most prevalent in coastal areas, it also occurs in interior valleys. It is not present in the southern desert.

Description and Seasonal Development

The aphid occurs on lettuce roots in clustered colonies covered with white powdery wax. Its short antennae are less that a third of the length of its body, and its cornicles are undeveloped. These features distinguish the root aphid from the aphids that feed on lettuce leaves.

The aphid usually overwinters as an egg on the bark of the Lombardy poplar. The eggs hatch in spring and emerging aphids move to new stems or leaf petioles to feed and form galls. Feeding stimulates development of new petiole tissue and after 25 to 30 days, the aphid is enclosed within a gall. It matures into a stem mother and gives birth to 100 to 250 young aphids inside the gall. Many mature into winged forms that leave the poplar tree and move into nearby lettuce fields to feed and reproduce, giving birth to live offspring on lettuce roots. Asexual reproduction continues on lettuce and related weeds through several generations. Winged, as well as nonwinged, adults are produced, enabling aphid colonies to move easily from field to field when crops are harvested.

Although most damage occurs within 1 1/2 miles of poplar trees, by the end of the season root aphids may have dispersed as much as 5 miles from the nearest poplar tree. When conditions become unfavorable in fall,

These aphids are the pink form of the potato aphid. Green forms also occur. Note the diverging tubercles at the base of the antennae and the long antennae, cornicles and cauda on the adult (upper right).

aphids migrate back to the poplar trees and produce sexual forms that mate and lay eggs on the poplar tree's bark. If host plants are in the field and the weather remains dry, the aphid can spend the winter in the field on lettuce or on related weed roots without going through the egg- or gall-producing stages.

Damage

The lettuce root aphid damages roots, impairing the plant's ability to take up water and nutrients, so the first evidence of infestation is wilting leaves. Outer leaves are most affected, and wilting is most obvious during the hottest part of the day. If you pull up the plant, you will see masses of white, wax-covered aphids on the roots. Infestations starting on the smaller rootlets later move into the entire system, including the taproot.

When infestations are heavy, heads fail to mature properly, remain soft, and are reduced in size. Roots turn brown and die on severely infested plants; plants soon collapse and die.

Management Guidelines

Where possible, avoid planting lettuce near Lombardy poplars, and never plant poplar windbreaks near potential lettuce fields. Where feasible, remove existing Lombardy poplar trees.

Some varieties of leaf lettuce resist lettuce root aphid; if possible, plant these varieties in fields with frequent root aphid problems.

At present, the only available pesticide effective against the root aphid must be applied as a band over the seed row at planting and incorporated immediately by sprinkler irrigation. One application will protect the crop until harvest. Treat fields near Lombardy poplars that have suffered lettuce root aphid damage in the past. No

Lettuce root aphid occurs in colonies on lettuce roots. The proliferation of wax in areas around the roots makes these infestations easy to identify.

Lettuce root aphids have shorter antennae than leaf-feeding aphids, and their cornicles are undeveloped.

The spring migrant generation of root aphid develops in galls formed on the petioles of Lombardy poplar leaves. The aphids have emerged from these galls.

insecticides are available for treating fields once the aphids infest lettuce. Ask your farm advisor for the latest University of California recommendations regarding available pesticides and recommended rates. The root aphid is resistant to parathion, an insecticide formerly effective against it.

Once lettuce root aphids invade the field, the crop may survive if it grows fast enough. Avoid stressing infested plants and maintain optimum water levels. Prevent cracking of the soil; cracks provide a way for aphids to enter the soil and colonize roots. After removing an infested crop from the field, work the soil deeply and allow it to dry thoroughly before replanting lettuce. Rototilling alone will not eliminate the problem.

Whiteflies

Whiteflies, tiny, sap-sucking insects, have recently become numerous on several crops in desert areas. They seldom damage lettuce or cole crops, but one species, the sweetpotato whitefly, *Bemisia tabaci*, spreads the virus that causes infectious yellows, a disease that can devastate a lettuce crop. The disease causes the typical yellows disease symptoms, including interveinal yellowing and stunting of plants. Symptoms and disease cycle of infectious yellows are discussed in more detail in the chapter on diseases.

The sweetpotato whitefly has a broad host range and moves into newly planted lettuce fields in fall from weeds, cotton, squash, or melon fields. Whiteflies normally do not breed on lettuce, so fields planted close to alternate hosts probably suffer the most damage. Alternate hosts for the virus include many weeds and crops including cucurbits and sugarbeets.

Adult whiteflies are about 1/16 inch (1.5 mm) long, and their wings and body are coated with a powdery wax that makes them appear dull white. When disturbed, the adults fly or jump. They suck the sap of host plants and transmit the virus as they move from infected to noninfected plants to feed. The virus can be transmitted in as little as 10 minutes of feeding.

Although whiteflies may lay their football-shaped eggs on lettuce, their immature stages do not normally develop on lettuce, and all larval development occurs on other plants. Whitefly larvae lose their legs and antennae after their first molt and remain fixed at the same feeding site until they become adults. The second and third instars are flattened and oval and resemble small scale insects. They suck large amounts of sap out of the plant and excrete large quantities of sticky honeydew on the leaves where they are feeding. A black sooty mold often grows on the excreted honeydew. Whiteflies develop rapidly and have many generations a year.

Several parasitic wasps effectively control whiteflies, but heavy use of synthetic pyrethroids and other insecticides in cotton in desert areas often kills the natural enemies, allowing whiteflies to increase to extremely high levels. Because the parasites attack only the immature stages of whiteflies, they do not effectively reduce populations in lettuce fields, but they can reduce them in neighboring fields.

Lettuce growers have few options for managing whiteflies. Insecticides are not effective. However, certain cultural practices may reduce invasion by whiteflies or spread of infectious yellows virus. Plant your earliest lettuce as far as possible from cotton or melon fields. Destroy crop residues from cotton, melons, and other crops that may harbor whiteflies after harvest. Removing weeds that host the whitefly and the virus could also reduce incidence of infectious yellows. Whitefly populations in desert areas decrease in mid-October and November; whenever possible, delay planting to avoid infestation.

Loopers
Trichoplusia ni and *Autographa californica*

The cabbage looper, *Trichoplusia ni*, is among the most destuctive pests on both cole crops and lettuce, occurring throughout California's vegetable-growing areas and feeding on many crops including tomatoes, cotton, and celery. A related species, the alfalfa looper, *Autographa californica*, occurs in lettuce along the central coast in spring. The cabbage looper is the predominant looper along the central coast in fall. The two species are difficult to distinguish, and damage symptoms and management guidelines are the same.

Description and Seasonal Development

Cabbage looper moths lay dome-shaped eggs singly, mostly on the undersurfaces of older leaves. The larvae have two sets of legs in the front of the body and three sets of fatter, unjointed prolegs at the rear. They move or "loop" by holding on with the front legs, arching the middle portion of the body to bring the prolegs or "hind legs" forward, and then extending the front of the body while holding on with the prolegs.

The youngest larvae feed primarily on the undersides of lower leaves, skeletonizing them between veins. Older larvae may move deeper into the plant. On cabbage they often feed at the base of the head, sometimes burrowing through several layers of leaves. On lettuce, they may also burrow into the head from the top. On brussels sprouts, older larvae may chew through the outer leaves of the sprouts. In cauliflower and lettuce they migrate into the head, contaminating the head with their bodies and their frass.

After feeding for 2 to 4 weeks, larvae spin cocoons and pupate, usually while attached to leaves. Adult moths emerge after about 10 days in warm weather and are active mostly at night. Cabbage looper moths have brown, mottled forewings marked in the center with a small, silver white figure 8.

The cabbage looper continues to develop all year in southern California's coastal areas and in the southern desert areas. Populations are a problem in fall, whereas the alfalfa looper may cause problems in spring.

Damage

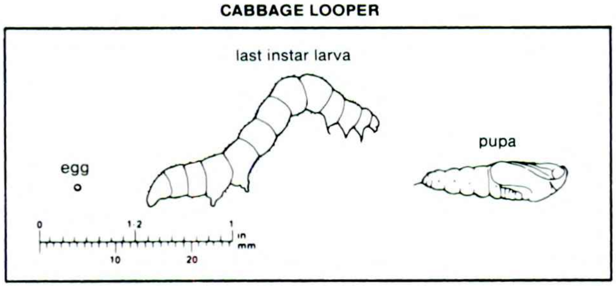
Loopers damage plants by eating ragged holes in leaves, boring into heads, and contaminating heads and leaves with their bodies and their frass. High populations can chew seedlings severely enough to kill them or slow growth enough to inhibit uniform maturing of the crop, but most economic damage occurs after heading. Young plants between thinning and heading can tolerate substantial feeding by loopers and other caterpillars without loss of yield or quality. Heads contaminated with loopers or tunneled into by loopers are not marketable.

Management Guidelines

The cabbage looper and the alfalfa looper have many natural enemies which frequently keep loopers below economic levels, at least until heading if they are not killed by insecticide applications. IPM programs for lettuce and cole crops should make maximum use of these natural enemies by limiting treatments, especially between thinning and heading.

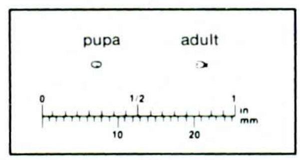
In some areas an important biological control agent is a nuclear polyhedrosis virus that occurs naturally in the field. Bodies of loopers killed by the virus are dark, soft, and shapeless with their body contents often spilling onto the leaves. Another important natural enemy in southern California, the tiny parasitic wasp, *Trichogramma pretiosum*, attacks looper eggs and eggs of certain other caterpillars. Eggs parasitized by *Trichogramma* turn black, as

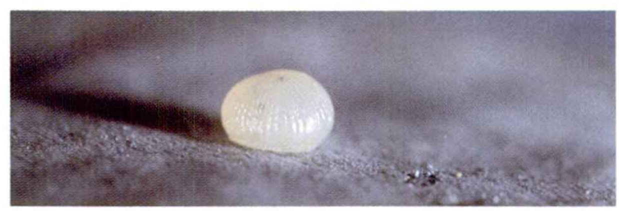
CABBAGE LOOPER



The adult sweet potato whitefly is coated with a powdery wax that makes its wings appear dull white. The larger oval bodies are pupae; adults have emerged from T-shaped slits in some of them. The smaller ones are larvae.

WHITEFLY





Looper eggs are broader and more flattened than eggs of the corn earworm, and the ridges on the egg surface are much finer.

Loopers arch their backs as they crawl. Cabbage loopers usually have a narrow, white stripe along each side and several narrow lines down the back.

Loopers can damage cap leaves of mature cabbage or lettuce heads.

Presence of loopers is often indicated by piles of their yellow green feces.

Outbreaks of nuclear polyhedrosis virus often occur naturally in the field, leaving the limp bodies of dead loopers hanging from leaves often oozing their body contents.

Loopers, parasitized by the wasp *Copidosoma truncatellum*, curl into an "S" shape after spinning their cocoon and fail to pupate. Numerous small wasps emerge from each larva.

the parasite matures inside, and are easy to distinguish from normal eggs that remain white except for a black spot that appears just before hatching. Other parasites that attack looper caterpillars include the tachinid fly, *Voria ruralis*, and three wasps, *Hyposoter exiguae*, *Copidosoma truncatellum*, and *Microplitis brassicae*.

Monitoring. You can spot locations where loopers have been feeding by looking for plants with moderate sized holes on their outer or lower leaves. If you turn over the damaged leaves, you will often find the looper feeding at the edge of the hole or on leaves deeper in the center of the plant. Feces are also a good indicator that loopers are present. You can often guess the size of the larva by the amount and size of the fecal pellets or by the size of the holes in leaves.

EARL OATMAN

The parasitic wasp, *Microplitis brassicae*, has emerged from this looper and formed a pupa at its posterior end.

EARL OATMAN

Tachinid flies may parasitize loopers, cabbageworms and other caterpillars.

EARL OATMAN

This looper has been repeatedly "stung" by a tachinid adult below the surface of the looper's cuticle.

Monitor for eggs and larvae of loopers while checking for other caterpillar pests that feed on leaves and heads. Check fields twice a week once seedling emergence begins. When populations appear to be increasing, check more often. Follow the monitoring guidelines for caterpillars on page 28.

Be sure to check for virus-killed or parasitized loopers, and record their numbers separately from those of healthy loopers. If looper populations are close to the treatment threshold, delay treatment if natural enemy populations are high. Also note the stage of looper development.

Control Action Guidelines. Treat seedlings or small plants if populations of medium-sized to large loopers are large enough to stunt growth. Do not treat well-established plants in Stage II unless you find more than nine small to medium larvae per plant in cole crops or more than one-half larva per plant in lettuce. If larvae of other lepidopterous species are present, also include them in this total. Treat just before heading or at brussels sprouts formation if counts show more than one looper or other caterpillar in 25 plants.

Where possible, use the microbial insecticide *Bacillus thuringiensis*, which does not adversely affect beneficial insects and will help control other lepidopterous foliage feeders as well. (It does not control beet armyworm.) *Bacillus thuringiensis* is most effective on small larvae. If large larvae appear on plants or if populations develop after heading, an application of an alternate material may be necessary. Choose insecticides carefully and avoid repeated applications on lettuce because some commonly used insecticides cause phytotoxicity and yield losses that exceed losses caused by insects. See the latest University of California insect control recommendations or your farm advisor for recommended materials.

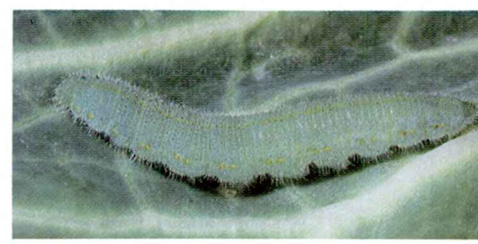
Imported Cabbageworm
Pieris rapae

The imported cabbageworm, called the cabbage butterfly in its adult form, is primarily a pest of cruciferous crops. It occasionally feeds on lettuce seedlings, but economic damage is uncommon. The damage it causes on cole crops is similar to that caused by cabbage looper. The pest occurs thoughout the cole crop growing regions, often with cabbage looper. However, it is rarely an economic problem in the desert or in the San Joaquin Valley.

Description and Seasonal Development

Imported cabbageworm adults are white to yellowish white butterflies with one to four black spots on their wings. They are often seen fluttering around the field during the day. Females attach their rocket-shaped eggs primarily on the undersides of leaves. The eggs are white to

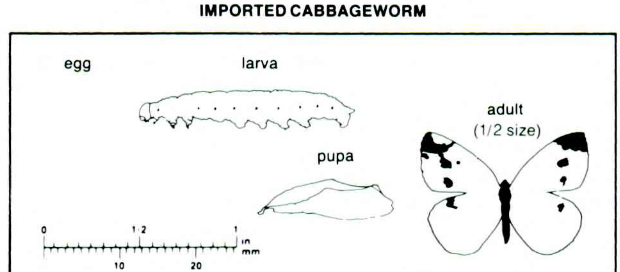
The adult of the imported cabbageworm is a white to yellow butterfly with one to four black spots on the upper surface of its wings. Here, two are mating.



The rocket-shaped eggs of the imported cabbageworm are usually found on the undersides of leaves (left). Imported cabbageworm larvae are very hairy; older larvae often have a faint yellow or orange stripe down their backs and broken stripes along the sides (right).

Pupae of the imported cabbageworm are attached to cole crop leaves by a few strands of silk.

IMPORTED CABBAGEWORM



EARL OATMAN

This imported cabbageworm pupa has been parasitized by *Pteromalus puparium*. Exit holes indicate the parasites have matured and emerged.

EARL OATMAN

The pupa of a parasitic tachinid fly can be seen within the body of this cabbageworm.

pale yellow or orange. The hairy, green young instars are easy to confuse with other tiny caterpillars, but they move more slowly. Older instars are dark green with a faint orange stripe down the back and pale yellow, broken stripes on each side. Many tightly packed hairs give the larvae a velvet-textured appearance.

The caterpillars are sluggish, but they eat voraciously. Young caterpillars chew holes in both the outer and inner leaves; older caterpillars move toward the center of the plant, often feeding at the base of the wrapper leaves or boring into heads of cabbage. They frequently feed on the upper surface of the leaf near the midrib. Larvae feed for 2 to 3 weeks, mature to about 1 inch (2.5 cm) long and then attach themselves to stems or other nearby objects to pupate. The pupal stage lasts about a week in summer.

The imported cabbageworm is active throughout the year in California's vegetable-growing areas and has three to five generations a year. In southern California, it is most numerous in fall and spring. In the Salinas Valley, it is common from spring through fall.

Damage

The damage imported cabbageworm causes is similar to that caused by cabbage looper. The caterpillars chew large, irregular holes in the leaves, bore into heads, and drop greenish brown fecal pellets, which contaminate the marketed leaves and heads. Seedlings may be destroyed or crop maturity may be delayed, but older plants between thinning and heading can tolerate some damage. The most serious losses occur when the imported cabbageworm bores into heads or feeds on marketable leaves.

Management Guidelines

Between thinning or transplanting and heading, cole crops can tolerate considerable damage from the imported cabbageworm and other caterpillars that eat leaves. During this period the strategy is to sample frequently enough to assess population development accurately and to avoid unnecessary insecticide treatments that may disrupt biological control. Once plants begin to head, imported cabbageworms can cause serious economic damage, even when they are present in low numbers, so insecticide applications are required at much lower population densities. If cabbageworm populations build up on seedlings, damage can occur quickly so these must be watched closely.

The imported cabbageworm has several natural enemies that help keep populations below damaging levels under some circumstances. In southern California the most common is the wasp, *Pteromalus puparum*, which attacks the pupae. Larvae are parasitized by *Apanteles glomeratus*, *Microplitis plutella*, and several tachinid flies. *Trichogramma* species occasionally parasitize imported cabbageworm eggs, but are not as common on this species as they are on the cabbage looper. Viruses and bacterial diseases often also reduce imported cabbageworm populations.

Monitoring. Check for cabbageworms, loopers, and other lepidopterous larvae at the same time. Follow the guidelines on page 28 and record your results. Damaged plants often indicate locations in the field where larvae may be feeding, but the damage may be confused with damage caused by loopers. The greenish brown fecal pellets are also a good indicator of cabbageworm presence. Small cabbageworms feed primarily on the undersides of leaves, blending into their surrounding so well that they are often hard to find. The rocket-shaped eggs may be easier to locate than the youngest larvae. Large worms feed toward the center of the plant, often along the midribs of leaves. If you see large numbers of the white imported cabbageworm butterflies, examine the field for eggs; you can expect to find small larvae several days to a week later.

Control Action Guidelines. The control action guidelines for imported cabbageworm are the same as those for cabbage looper on cole crops. Treat seedlings or small plants if populations of cabbageworms and loopers are large enough to stunt growth. Do not treat older plants between thinning until heading, unless you find more than nine small-to-medium lepidopterous larvae per plant in cole crops. Treat just before heading or at brussels sprouts formation if counts show looper or other lepidopterous larval populations to be more than one in 25 plants. Treat again if monitoring indicates populations are again rising to this level.

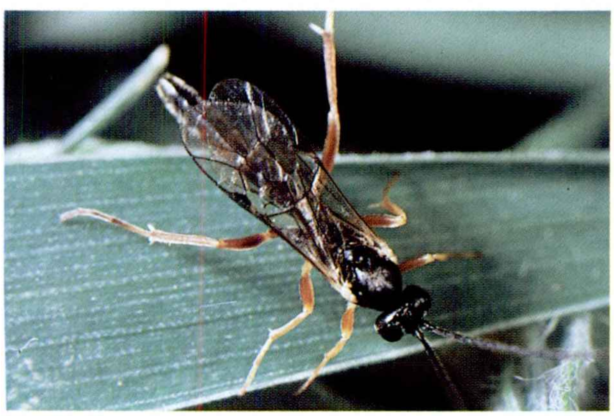
Where possible, use the microbial insecticide *Bacillus thuringiensis*; it gives good control of the imported cabbageworm and does not adversely affect beneficial insects. It will also help control other lepidopterous foliage feeders as well. *Bacillus thuringiensis* is most effective on small larvae. If large larvae appear on plants or the population is high, application of an alternative material may be necessary. See the latest University of California insect control recommendations or your farm advisor for recommended materials.

Beet Armyworm
Spodoptera exigua

Beet armyworm is a major pest of lettuce and an occasional pest of cole crops, especially in southern California. It feeds on many other crops, including sugarbeets, beans, tomatoes, cotton, and alfalfa, sometimes migrating from these crops onto lettuce in fall. Certain weeds, including redroot pigweed, lambsquarters, and nettleleaf goosefoot, are also favored hosts.

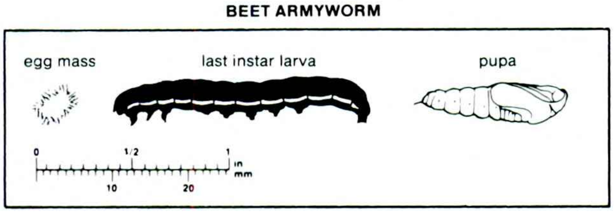
Description and Seasonal Development

Beet armyworm eggs are laid in clumps or masses on leaves of crops and weeds. As the female moth lays the



The *Hyposoter* wasp is one of the most important parasites of the beet armyworm.

BEET ARMYWORM




Beet armyworm eggs are laid in scale-covered, cottony masses on the surfaces of leaves (left). If you remove the cottony covering from the mass, you will see the eggs (right).


Newly hatched beet armyworms often feed in groups (left); this is sometimes an easy way to distinguish them from *Heliothis*. However, they may be found singly as well. Young lettuce plants can be severely damaged when beet armyworms feed at the crown of the plant (right).

Older beet armyworms may vary in color, but usually have many fine, wavy, light colored stripes down the back and a broader stripe down each side. If you look at the body surface under a hand lens, it appears almost hairless.


If you pull apart a parasitized armyworm, a green *Hyposoter* larva will pop out (left). After killing the armyworm, the *Hyposoter* larva spins a black and white cocoon attached to the shriveled skin of the armyworm (right).

eggs, she covers them with white, hairlike scales from her body, giving the egg masses a cottony appearance.

When the tiny first instar larvae first hatch, they feed in groups near the egg mass; they skeletonize the leaf and may completely consume small leaves on seedlings. As they grow older, the armyworms disperse and move toward the center of the plant. They often feed in the crown of young lettuce plants or on foliage and buds of cole crops. On older cabbage and lettuce plants, they often bore up from the bottom into the center of the head and feed on the newly forming leaves at the growing point. Beet armyworms are quite mobile, and a single larva may attack several plants. Larvae are often found in the soil traveling between plants or seeking shade. The dispersal habit results in high mortality of very young armyworms, which may move off plants onto the soil and never return.

Larvae vary in color, but are usually light olive green with many fine, wavy, light colored stripes down the back and a broader stripe along each side. Under a hand lens, the body surface appears smooth and mostly hairless, distinguishing it from corn earworms, imported cabbageworms, and most other caterpillars occurring in cole crops and lettuce. Beet armyworms usually have a dark spot on the side of the body above the second true leg, but the spot sometimes is absent.

Larvae reach maturity in about 2 to 3 weeks in warm weather. The adult moth has mottled brown or gray front wings and lighter gray hind wings. The moths are difficult to distinguish from other nocturnal moths that may occur in vegetable crops.

In the southern desert, the beet armyworm is most prevalent from October through December on fall-planted lettuce. It is also common in late summer and early fall in lettuce grown in the southern coastal areas and in the San Joaquin Valley. In the Salinas Valley, the beet armyworm is sometimes found on lettuce in fall, but economic damage is not common. It is not often of economic importance on cole crops in any area of California.

Damage

Beet armyworms may severely stunt or kill seedling lettuce plants. The caterpillars feed in the crown of the plant, chewing away large portions of the midrib and sometimes the growing point. Potential for damage is not so great between thinning and heading, but once heads form, the pest may bore into the lettuce head, rendering it unmarketable. The damage can be distinguished from that caused by loopers and earworms, which bore into the head from the top and leave holes in the cap leaves. Armyworms bore in from the bottom; often the damage can't be seen from the top.

On cole crops, beet armyworms can destroy seedlings or stunt growth by feeding on buds or large portions of leaves. Serious economic damage to these crops is not common.

Management Guidelines

Cultural and biological controls can help suppress armyworm populations. Disc fields immediately following harvest to kill larvae and pupae. Destroy weeds along field borders; armyworms often migrate from these areas into newly planted fields.

Many natural enemies attack beet armyworms. Among the most common parasites are the wasps, *Hyposoter exiguae* and *Chelonus insularis*, and the tachinid fly, *Lespesia archippivora*. Viral diseases also kill significant numbers.

Monitoring. Start monitoring for beet armyworm even before seedlings emerge. Check for egg masses and young larvae in pigweeds, lambsquarters, nettleleaf goosefoot, and other weeds surrounding the field. If populations are high on weeds, watch especially carefully for infestations on crop seedlings.

Once seedlings emerge, check them at least twice a week for armyworm egg masses and young larvae. Egg masses are easier to spot than are larvae. Once you find an egg mass, check whether the eggs have hatched. You can see the tiny caterpillars through the transparent shells of eggs about to hatch. If the eggs have hatched, but there is no sign of their feeding, predators may be killing the larvae. If there is evidence of feeding, but you do not see larvae, then they have probably dispersed to the plant crown, to the soil, or to other plants. Usually many first instar beet armyworms are killed during dispersal.

Between thinning and heading and after heading, follow guidelines on page 28 for monitoring lepidopterous larvae. Record your results and note the presence of virus-killed or parasitized armyworms. Because armyworms tend to feed in the bottom half of the plant, their damage may be harder to spot in lettuce than that caused by loopers. Don't try to identify pests by observing the damage alone. Search for the caterpillar that caused the damage and positively identify it.

Control Action Guidelines. Seedlings are very susceptible to armyworm damage. Treat if you find one second or third instar larva for every 10 plants. Most insecticides are more effective against young larvae than eggs, so wait until just after most of the egg masses have hatched before spraying. Waiting will also allow you to check predator activities and dispersal mortality of first instars.

Guidelines for armyworms on older plants are the same as for other lepidopterous pests. Do not treat older plants between thinning and heading unless you find more than nine larvae per plant in cole crops or one larva for every two plants in lettuce. Treat just before heading if caterpillars are present in the field.

Insecticides are most effective if they are applied when armyworms are most active. During hot weather in the southern desert and San Joaquin Valley, armyworms are most active just before dawn and right after sunset. In the cool growing seasons along the central coast, the warmest time of day may be the time to spray. Of course, other factors, including wind and local regulations, must also be considered.

Be sure to correctly identify the species of lepidopterous pests. The selective insecticide *Bacillus thuringiensis* that controls loopers, imported cabbageworms, and certain other caterpillar pests is not effective against beet armyworms. Also, beet armyworms are reportedly resistant to certain other insecticides in certain areas. The broad spectrum materials required to control armyworms adversely affect natural enemies that may keep other pests in check. Do not use them early in the season if few beet armyworms are present.

The Armyworm
Pseudaletia unipuncta

The armyworm often damages lettuce in the Salinas Valley. This species is a common pest of wheat, corn, and other cereal crops and often moves into lettuce, spinach, or celery when these crops are harvested. Variable in color, the armyworm is usually dark green or gray and closer to the typical color of yellowstriped armyworm than to beet armyworm. Armyworm has only three thick stripes running down each side instead of the many thin lines on the yellowstriped armyworm and has neither the dark spot on the second segment, typical of the beet armyworm, nor the dark spot on the first legless segment common to the yellowstriped species. First instar armyworms loop; older larvae move in the same way as other armyworms. They are most active at night.

Management guidelines for armyworm are the same as for beet armyworm.

Yellowstriped Armyworms
Spodoptera ornithogalli and *S. praefica*

The yellowstriped armyworm, *Spodoptera ornithogalli*, and the western yellowstriped armyworm, *S. praefica*, occasionally move into fields of seedling lettuce. Damage is similar to that caused by beet armyworm, except mature larvae of the yellowstriped armyworms are larger and can consume more leaf area. Both yellowstriped species prefer to feed on weeds, but they may move in from weedy borders and destroy lettuce around field edges.

The two yellowstriped caterpillars are impossible to distinguish in the field. The yellowstriped armyworm occurs primarily in southern California south of the Tehachapi Mountains, and the western yellowstriped armyworm is more prevalent in California's central and northern parts. Both species can vary in color but generally are purplish brown or black with many fine, light colored stripes and a broad yellow stripe on each side. There is also a large, intense black spot on each side of the body on the first legless segment. These characters make it easy to separate them from the beet armyworm.

Life cycle and management guidelines are similar to those given for beet armyworm.

Corn Earworm
Heliothis zea

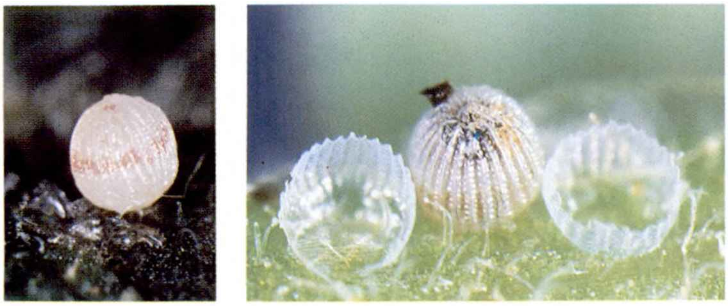
The corn earworm, also known as the bollworm and the tomato fruitworm, can decimate seedling stands of lettuce; it also bores deeply into the center of mature heads, rendering them unmarketable. The pest occurs statewide but causes the most severe damage in coastal areas of southern California. Although it feeds on a wide range of hosts, the corn earworm is not an economic pest in cole crops. The very similar tobacco budworm, *Heliothis virescens*, is the predominant *Heliothis* species in lettuce in low desert areas. Biology and management guidelines for the tobacco budworm are essentially the same as for corn earworm, except that the range of available effective insecticides is more limited for the budworm.

Description and Seasonal Development

Female moths lay their eggs singly on lettuce leaves. Eggs are white when laid but develop a dark red or brown ring around the top within 24 hours. They darken before hatching as the larvae develop inside. Deeper ridges and a more hemispherical shape distinguish corn earworm eggs from those of cabbage or alfalfa loopers.

Along the backs of newly hatched corn earworms are discrete rows of tubercles with one or two hairs protruding from each. Young beet armyworms also have tubercles and hairs, but armyworms are usually found feeding in groups not far from their distinctive egg masses during the first instar. Both species often occur together on seedling plants.

Corn earworms usually develop distinct stripes as they mature, but the overall color of caterpillars is variable. The tubercles and hairs remain obvious on older larvae that are dark colored but are less visible on lighter ones. In addition to the larger hairs and tubercles, corn earworms have tiny short spines covering large portions of the skin that can be seen with a 10× hand lens. These tiny spines distinguish the corn earworm and the closely

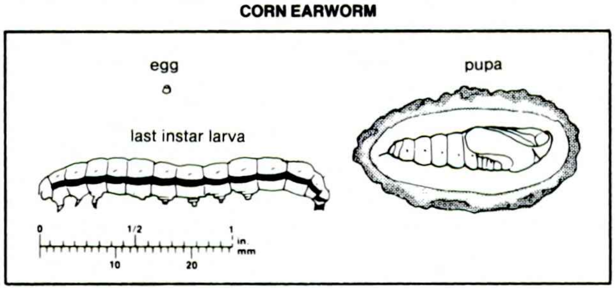


Newly laid earworm eggs are white, but they develop a reddish ring after about 24 hours (left). When the egg is about to hatch, the head capsule of the larva can be seen at the top. Empty shells are transparent (right).

The tiny parasitic wasp, *Trichogramma pretiosum*, lays its eggs in a corn earworm egg. The parasite attacks many other caterpillar pests, including loopers. Eggs parasitized by *Trichogramma* turn black and are easy to tell from normal eggs.

The newly hatched corn earworm has distinctive rows of tubercles and hairs.

CORN EARWORM



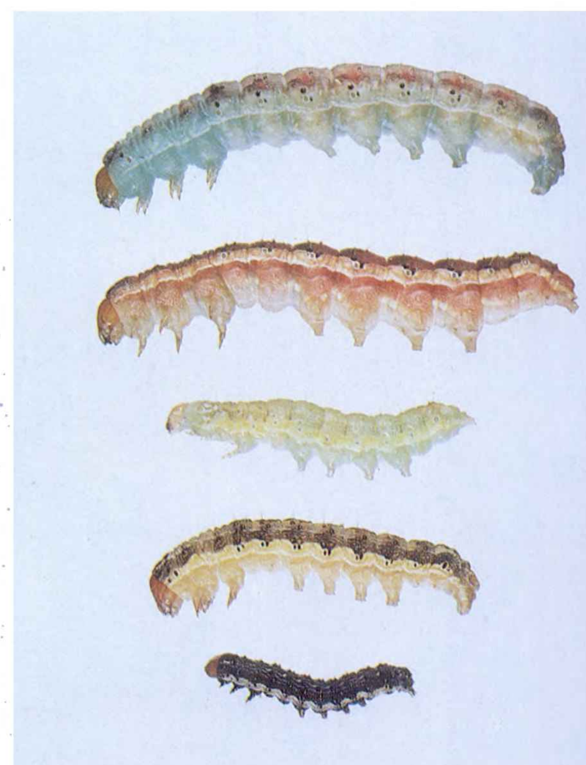
related tobacco budworm from all other caterpillars likely to be found on lettuce.

Corn earworms frequently move into lettuce from surrounding crops. A good example is the migration of earworm moths from corn or cotton, where the pest is known as the bollworm. In southern coastal areas most earworm damage occurs in summer. *Heliothis* is not commonly a problem in lettuce along the central coast or in the San Joaquin Valley.

Damage

The corn earworm can decimate seedling lettuce plants and also bores into lettuce heads, causing damage and contamination. Damage to seedlings is similar to that caused by beet armyworm. Larvae feed in the plant's crown leaving holes and gouges in the midrib and sometimes killing the growing point. Potential for damage decreases as seedlings grow; economic damage is not common between thinning and head formation.

Once heads form, earworms may bore into the head, rendering it unmarketable. Larvae may enter the head from any point, although they usually burrow in from the top half. When burrows begin under or between the wrapper leaves, the infestation may not be noticed until



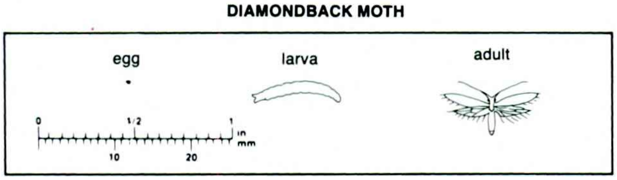
Corn earworms vary greatly in color but usually have stripes. The tubercles and stripes are not as obvious on light colored individuals.

These are the adults of (a) the variegated cutworm, (b) the beet armyworm, (c) the cabbage looper, (d) the tomato fruitworm, (e) the tobacco budworm, and (f) the western yellowstriped armyworm.

The minute pirate bug is a general predator that feeds on corn earworm eggs and young larvae as well as on other small insects.

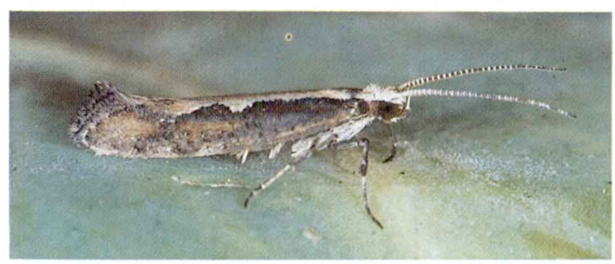
Bigeyed bugs are other general predators that prey on corn earworm eggs.

DIAMONDBACK MOTH



The diamondback caterpillar makes small holes in cole crops leaves. Two prolegs on the last segment are spread apart, forming a distinctive "V" at the caterpillar's rear end.

Pupae of the diamondback moth are often easy to spot scattered on the upper surfaces of leaves. Pupae are covered with loosely spun, white cocoons.



When folded, the wings of the diamondback moth flare up and out at the tips.

EARL OATMAN

These diamondback moth pupae have been parasitized by *Diadegma insularis*. All that remains of the diamondback pupae are the cocoon and some shriveled cuticle.

the head is harvested. Once inside the head, earworms are protected and difficult to control with insecticides.

Management Guidelines

If not disrupted by pesticide applications, the corn earworm's natural enemies can frequently reduce its populations to tolerable levels, particularly between thinning and heading, when plants are not so vulnerable to damage. Common natural enemies in southern California include the egg parasite, *Trichogramma pretiosum*. Eggs parasitized by it turn black and are easy to distinguish from normal eggs. Other natural enemies include the parasite *Hyposoter exiguae*, which also attacks beet armyworms and loopers, and such general predators as minute pirate bugs (*Orius* spp.) and bigeyed bugs (*Geocoris* spp.). Naturally occurring pathogens, including a nuclear polyhedrosis virus, often kill earworms.

Monitoring. As soon as seedlings emerge, check for earworm eggs. Once you find them, check to see whether they are parasitized, hatched, or about to hatch. If they have hatched, look for the caterpillar and feeding damage in the crown of the plant. Pull some of the older larvae apart to see whether they are parasitized.

Between thinning and heading and after heading, follow the guidelines on page 28 for monitoring lepidopterous larvae. Keep written records and note the presence of virus-killed or parasitized earworms. Earworm burrows on the tops and sides of heads are often hard to find. Check for earworms each time you visit the field by pulling back the wrapper leaves or even cross sectioning some heads.

Control Action Guidelines. Lettuce seedlings are very susceptible to earworm damage. Treat if you find a significant number of eggs and larvae on seedlings. Wait until eggs have hatched, because insecticides are most effective on young larvae; waiting will also allow you to check for parasites and predators.

Between thinning and heading, lettuce plants can tolerate up to one-half lepidopterous larva of any species or any size per plant. Once you find one larva for each two plants, treat. Be sure to identify correctly the species in your field. Different rates and more selective materials are available for certain species. Don't treat if you find less than the treatment threshold at this stage. Repeated insecticide treatments are normally required to maintain lower population levels, and repeated applications of many commonly used insecticides cause phytotoxicity and yield loss that can exceed losses caused by insects.

Once heads form, keep earworm populations as low as possible. One larva boring into a head will cause that head to be unmarketable. Treat when you find one lepidopterous larva in every 25 plants. If possible, time ap-

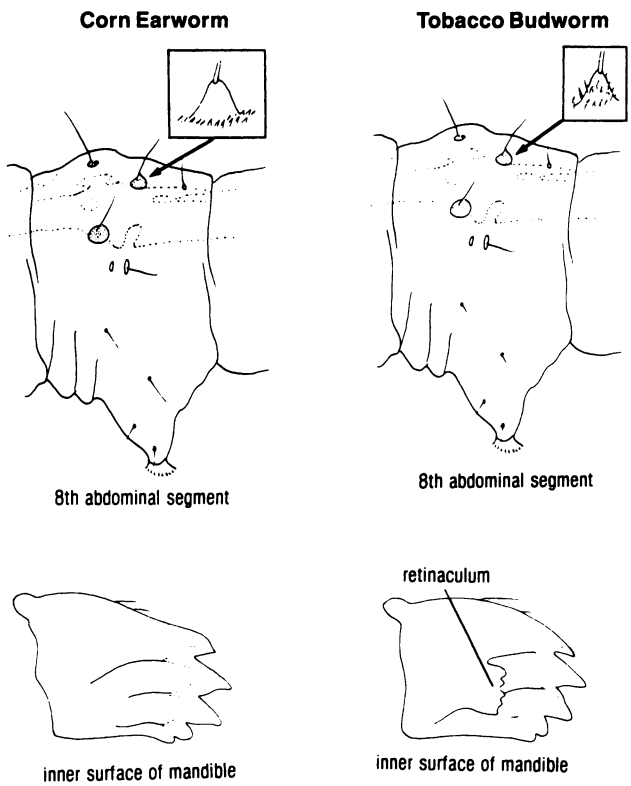


Figure 17. Larger tobacco budworm and corn earworm larvae can be distinguished by examining the eighth abdominal segment and the inner surface of the mandible. Tiny spines cover the mounds or tubercles at the base of abdominal hairs on the tobacco budworm, but they are absent on the corn earworm. A large tooth (retinaculum) can be seen under the microscope on the mandible of the tobacco budworm; it is absent on the corn earworm.

plications to control the caterpillars right after they hatch and before they enter the protected areas within the head.

Tobacco Budworm
Heliothis virescens

The tobacco budworm, closely related to corn earworm, is the primary *Heliothis* species infesting lettuce in the desert areas. It is not known to trouble lettuce in northern California. The budworm has essentially the same biology and life cycle as the corn earworm, causes the same kind of damage, and is similar in appearance. It is most common in lettuce fields planted near cotton; often it only invades the part of a lettuce field adjacent to cotton.

Young larvae of the corn earworm and tobacco budworm cannot be reliably distinguished. Older larvae in the third and later instars can be identified under the microscope by comparing the spines on the base of the abdominal tubercles and by looking for a tooth on the inside of the mandible. These features are shown in Figure 17. Monitoring and control recommendations for tobacco budworm are the same as for corn earworm. The best time to apply insecticides to control budworms is when they are most active—during midday (noon to 4 pm) in the southern desert. At night budworms may leave the plant and go to the soil. In the Imperial Valley, the tobacco budworm has developed resistance to certain insecticides that still control the earworm, so correct identification may be important. Ask your farm advisor about the status of budworm resistance in your area.

Diamondback Moth
Plutella xylostella

Diamondback moths attack only cruciferous plants and do not infest lettuce. They occur year-round throughout vegetable-growing areas along the California coast and in the San Joaquin Valley.

Description and Seasonal Development

These moths usually lay their eggs singly or, less commonly, in groups of two or three on the undersides of leaves. The eggs are minute, scalelike, green white to yellow, and very difficult to spot. The larvae are small compared with other common caterpillar pests in cole crops; mature larvae are only 1/3 inch (less than 1 cm) long with a slender body pointed at both ends. The prolegs on the last segment are spread apart, forming a distinctive "V" at the caterpillar's rear end. Their behavior also distinguishes them from other pests: When disturbed, they wiggle frantically or rapidly attach a silken line to a leaf and drop over the edge.

After emerging from eggs, larvae feed mostly on the undersides of outer or older leaves of older plants, chewing out small holes, or at the growing points of younger plants. They reach maturity in about 10 to 14 days, depending on temperature, and then spin loose white cocoons, which they attach to leaves or stems, and pupate within them.

Adult moths are small and slender, grayish or brownish in general color. Folded, the wings of male moths display three diamond-shaped markings on their back that inspire the name "diamondback moth." The folded wings flare up and out at their tips.

Diamondback moths are often abundant in spring and early summer when loopers and imported cabbageworm are uncommon. In southern California, diamondback moth populations are highest in March and April, again in June through August, and then again in late fall or early winter. The pest has four to six generations a year, varying with local climate.

Damage

Diamondback moth caterpillars chew small holes in leaves and damage the growing points on young plants. Growing point injury causes the most serious losses. Damage to crowns of young plants can severely stunt growth. The larvae may also chew the growing points of developing brussels sprouts or bore into heads of broccoli and cauliflower, causing serious damage and contamination. Damage to leaves is usually not serious, but economic damage can occur if larvae damage the wrapper or cap leaves of cabbage.

Management Guidelines

Natural enemies and insecticides applied to control other pests generally keep diamondback caterpillars below economically damaging levels in most years. The diamondback moth life cycle is well synchronized with its natural enemies. In the southern coastal areas the ichneumonid wasp, *Diadegma insularis*, is the most common parasite. It pupates within the cocoon of the parasitized caterpillar. You can recognize it by the broad white stripe around the pupa. *Trichogramma pretiosum* will occasionally parasitize diamondback moth eggs. Microbial diseases are not a significant cause of mortality.

Pupae are the most visible stage of the diamondback moth, but pest management decisions should be based on numbers of larvae, since larvae are the damaging stage. Record diamondback larvae numbers when you make your twice-weekly samples for other caterpillar pests.

Check fields during the seedling stage, at thinning, and just before heading. In cabbage fields, regularly monitor wrapper leaves for damage after heading. Adult moths frequently migrate from fields being harvested or disced under, so carefully check adjacent fields if populations were high in harvested fields.

Many materials, including the selective microbial insecticide *Bacillus thuringiensis*, are effective. Suitable materials are listed in University of California recommendations. Disc under crop debris immediately after harvest to prevent buildup of diamondback moth and migration to younger plants in adjacent fields.

Saltmarsh Caterpillar
Estigmene acrea

Saltmarsh caterpillars, uncommon in lettuce and cole crops, sometimes build up in neighboring cotton, bean, or sugarbeet fields, other crops, or weeds and move into lettuce or cole crops. Large populations can cause economic losses.

Saltmarsh caterpillars are easy to recognize in the field. Early instars are various shades of yellow brown with long, dark hairs. Older caterpillars, densely covered with black and red hairs, often have yellow stripes running lengthwise down their bodies. Adult moths have white wings with numerous black spots on the upper surface and yellow on the undersides. White eggs are laid in groups of 20 or more on leaf surfaces, but eggs are not commonly found on cole crops or lettuce.

To stop migrating saltmarsh caterpillars, place a physical barrier along the edge of the field. Barriers may include a strip of heavy aluminum foil about 6 inches (15 cm) high set on edge in the soil, a line of irrigation pipe set into the soil so that caterpillars cannot get under it, or a ditch filled with water. A band of residual insecticide applied around the edge of the field can also keep out invading populations. Insecticide sprays are not very effective against the caterpillars in the field.

Diseases

Although few pathogens cause disease symptoms in both cole crops and lettuce, general disease management guidelines apply for both crops. In each growing area and season, only a few diseases are likely to occur on a single crop. Before planting, find out which diseases are likely to occur locally, and whenever possible, review records of disease incidence in the field you intend to plant. Choose cultural practices and crop cultivars that reduce the impact of key diseases.

Diseases caused by pathogenic microorganisms—mostly fungi, bacteria, viruses, or viruslike organisms in these crops—are known as biotic diseases. Environmental stresses and toxic substances can also cause crops to develop disease symptoms; these diseases are often called abiotic disorders and require special management. Abiotic disorders are discussed in the next chapter.

To manage biotic diseases, you must know where a pathogen originates, how it disperses and infects the crop plant, and what environmental conditions favor disease development. Table 9 lists where the pathogen survives when the crop is out of the field for a period, that is, the sources of primary inoculum for diseases discussed in this manual.

Soilborne pathogens can sometimes be managed by management practices such as deep plowing, fumigation, or changing soil pH. Crop rotation can help manage some soilborne pathogens that survive in infected plant residues and have a limited host range, but rotation is not as useful against such pathogens as *Verticillium dahliae* that can infect a wide variety of crops and weeds and have resting stages that survive in soil for a long time. Irrigation practices can limit the impact of many soilborne diseases. In general, soilborne pathogens are spread only by movement of infested soil, plant debris, or transplants, although some have stages that can be dispersed in air or water.

Pathogens that are dispersed by air currents, usually as spores, spread rapidly and may move long distances. Propagules dispersed by water, rain, or irrigation generally are not carried as far. Most air and many waterborne pathogens cause such localized infections as leafspots on aboveground portions of the plant. Economic damage

Table 9. Overwinter Survival of Pathogens Causing Disease in Cole Crops and Lettuce.[a]

Disease	Truly Soilborne	Plant Debris in Soil	Seedborne	Living Plant Reservoir
Cole Crops Diseases				
Damping-off	•			
Clubroot	•			
Fusarium wilt	•			
Verticillium wilt	•			
Phytophthora	•			
Sclerotinia	•			
Black rot		•	•	
Black leg		•	•	
Downy mildew	?			•
Ringspot	•		•	
Alternaria leafspot	•	•	•	
Mosaic or virus diseases				•
Lettuce Diseases				
Damping-off	•			
Sclerotinia	•			
Botrytis rot		•		
Bottom rot	•			
Corky root	•			
Downy mildew				•
Powdery mildew		?		•
Big vein	•			
Anthracnose		?		
Varnish spot	•			
Lettuce infectious yellows				•
Beet western yellows				•
Lettuce mosaic			•	•

[a] • indicates known survival mechanism, ? indicates probable mechanism.

depends on the part of the plant affected. For example, leafspot diseases are more economically damaging to cabbage crops than they are to broccoli or cauliflower because cabbage leaves are marketed.

Management options for diseases resulting from airborne inoculum are more limited than for soilborne diseases because of the wide dispersal that may occur. Crop rotation or fumigation is usually ineffective. Using resistant varieties, if available, offers the best control, but timely application of fungicide sprays may be needed for some diseases.

Several waterborne pathogens—for instance black rot of cole crops, anthracnose, and varnish spot of lettuce—can be spread by splashing water from sprinkler irrigation or rain. A change from sprinkler to furrow irrigation can sometimes reduce their spread.

Most virus diseases of lettuce and cole crops are disseminated and transmitted by certain piercing-sucking insects, primarily aphids or whiteflies, as they feed. Usually only one or a few closely related insect species are involved in the spread of each virus. Because even low populations of aphids or whiteflies can spread these viruses, their control with insecticides is usually not effective in managing disease. A cultural program, involving virus-indexed seed and removal of virus reservoirs, has successfully controlled lettuce mosaic virus, which is seedborne. However, there is no reliable control of most nonseedborne viruses of lettuce. Fortunately, economic losses due to virus diseases in cole crops are rare, but viruses do cause losses in such related species as Chinese cabbage. New cultivars should always be closely observed for susceptibility to viruses.

Several pathogens are introduced in or on seed, including black leg, black rot, and ringspot of cole crops and lettuce mosaic virus. Use disease-indexed seed to avoid introducing these diseases into new fields or areas. Use of this seed is the first critical step in any control program. Laboratory tests are available to help identify seed lots infected or infested with certain pathogens. Once in the field, most seedborne pathogens are spread by wind, water, or insect vectors.

Field Monitoring and Diagnosis

Any plant disease, whether caused by a biotic agent or not, involves a complex interaction between the host plant and its environment. Disease symptoms, their rate of development and the damage produced are influenced by genetic characteristics of the plant, its stage of growth when infection or stress occurs, other stresses occurring at the same time, and environmental conditions, especially temperature and humidity.

Check fields regularly for stress or disease symptoms. Note any pattern in symptoms that occur; for example, do they appear only on scattered plants or are they concentrated in certain parts of the field or are they generally distributed? Record weather, soil conditions, and previous disease outbreaks to help in diagnosis; free water is especially important because most pathogens require water for germination of spores and infection.

When comparing symptoms in the field with illustrations and descriptions in this manual, examine as many affected plants as possible. Look for plants with different stages of disease to determine how symptoms change as the disease progresses. The photographs in this manual may show only some stages. Do not rely solely on a single symptom, such as a leaf spot or yellowing, to identify a disease. Look at all parts of affected plants, including roots and stems. Different diseases may produce the same or similar symptoms if the pathogens involved disrupt the same plant function. Observation of several different symptoms is usually needed to identify a disease.

It is not always possible in the field to identify diseases with certainty. Some pathogens require special laboratory techniques for identification; nutrient deficiencies and some other conditions require plant tissue analysis. Even when laboratory services are needed, however, an accurate set of field notes can help confirm the results.

Prevention and Management

Cultivar Selection. Using resistant or tolerant cultivars is the most convenient way to prevent losses from disease. Resistant cultivars offer protection against a few diseases in both lettuce and cole crops. In lettuce, cultivars resistant to lettuce mosaic virus are available, and cultivars tolerant to big vein are slow to show symptoms and minimize damage from this disease. Downy mildew of lettuce was controlled with resistant cultivars at one time, but new races of the fungus have developed that can overcome the resistance.

In cole crops, cabbage cultivars that resist Fusarium wilt are available; some broccoli cultivars resist downy mildew. Clubroot-resistant cabbage and cauliflower lines have been developed, but no horticulturally acceptable cultivars are available that resist all of the many races of the clubroot pathogen that exist in nature. Seed companies, other industry groups, and farm advisors can help you select resistant cultivars suitable for local conditions.

Field Selection. Several pathogens that affect lettuce or cole crops can remain dormant in the soil or in plant debris for long periods and still cause disease when the crop is replanted. A permanent record of disease problems that occur or have been noted in past crops is essential to future management decisions.

Cultural Practices and Sanitation. The right choice of cultural practices, especially those affecting soil and water management, can minimize losses to disease. Anything that hampers good water management increases chances of encountering certain soilborne diseases. Poor drainage or soil compaction that interferes with water percolation encourages root problems; such practices as deep tillage, uniform bed heights, laser leveling, and cover cropping can alleviate them. Crop rotation is helpful in managing pathogens that have a limited host range and cannot survive in the soil for more than 2 or 3 years. Sanitation, particularly the removal of infected crop debris and weeds, can also deter spread of pathogens. Recommended cultural and sanitation practices are discussed under individual diseases.

Pesticides. Fungicides and bactericides can prevent or reduce damage from some diseases, especially those that occur aboveground. Protective pesticides applied before disease occurs are generally more effective than applications made after it has become established. However, many diseases are sporadic and occur only under favorable environmental conditions, so preventive treatment may not be the most economical control. In these cases, frequently monitor for disease symptoms, especially during periods favorable for disease occurrence, and treat as soon as disease appears. Most applications are foliar sprays. Fumigants are occasionally used to manage clubroot of cole crops as well as nematodes in both lettuce and cole crops. Ask your farm advisor for current information on materials recommended for managing the diseases described in this manual.

Damping-off of Lettuce or Cole Crops
Pythium spp. and *Rhizoctonia solani*

In cole crops and lettuce, damping-off, a common disease of seedlings, is usually caused by *Rhizoctona solani* or any of several species of soilborne fungi in the genus *Pythium*. *Pythium* can also cause a seed rot that kills seeds before they germinate. Seed rot and damping-off occur primarily during cool, wet conditions. Preparation of good seedbeds, use of fungicide seed dressings, careful water management, and choice of planting time can reduce disease incidence.

Damping-off may occur during two phases of development: shortly after seedlings germinate, but before they emerge, and after they emerge. After emergence, lesions most often occur on the lower stem (hypocotyl) at or near the soil surface. The stem tissue collapses and becomes dark and shriveled. Because there is little structural tissue in the stem at this early stage, plants topple over and die. *Pythium* may invade roots as well as the stem, turning them brown. *Rhizoctonia* may invade the cortical tissue and girdle young stems. Often cole crops will remain alive for some time and will continue to grow slowly, but the affected area of the stem does not expand and gives rise to a spindly condition called wirestem.

Damping-off may occur anywhere in a field, but it is usually in fields with high green organic matter with poor drainage or compacted soil. Plants beyond the third- or fourth-leaf stage are not susceptible.

The fungi that cause damping-off are widespread in nature and are found in most cultivated soils. Conditions vary from year to year, so the disease will not necessarily occur in the same fields every year. Most *Pythium* species infect seedlings when temperatures are low and the soil is wet. *Rhizoctonia*, on the other hand, is favored by warmer soils. The pathogen that causes black leg, *Phoma lingam*, may also cause damping-off symptoms in cole crops; it is discussed on page 63.

Damping-off is best controlled by using a fungicide seed dressing, which frequently prevents infection and protects the seedling in its most susceptible stage. Seed treatment is convenient to use and economical, requiring very low amounts of fungicide. Additionally, preparation of good seedbeds and good water management will help reduce losses from damping-off. Before planting, be sure crop residues are thoroughly decomposed. To provide better water control and decrease chances of oversaturating the soil, use overhead or sprinkler irrigation to supply moisture for germination. If possible, avoid planting seed when soil is cold. Seeds germinate faster and seedlings are more vigorous when the soil is warm, as they more quickly reach the stage where they are no longer susceptible. No resistance to damping-off has been found in cole crops or lettuce.

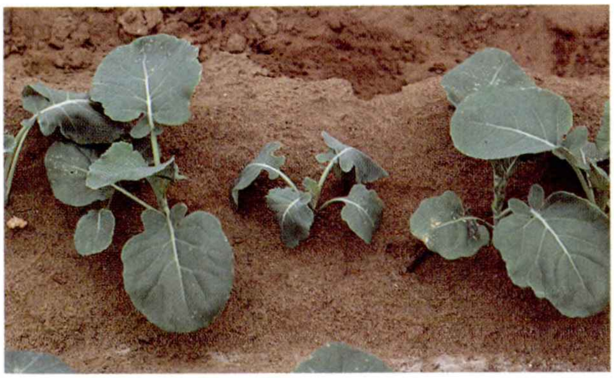
DISEASES OF COLE CROPS

Clubroot
Plasmodiophora brassicae

Clubroot is a destructive disease of cabbage, cauliflower, broccoli, brussels sprouts, kohlrabi, Chinese cabbage, radish, turnip, and rutabaga. It also infects many weeds in the mustard family and such cultivated ornamentals as column stock and wallflower. Serious economic losses in California have mainly been confined to brussels sprouts fields in San Mateo and Santa Cruz counties and broccoli and cauliflower fields in Monterey County; the disease also occurs in a few fields in Alameda and San Joaquin counties.

Symptoms and Damage

Plants may be infected for some time before indicating stress. The first aboveground symptoms are usually a slight wilting or flagging of leaves during the day, espe-



Plants infected with clubroot are often smaller than other plants and show wilting during the day.

Plants from direct-seeded fields of broccoli are often infected with clubroot at the early seedling stage. As a result, they have little chance to develop a root system and their roots are heavily clubbed.

DENNIS HALL

The root systems of plants infected with clubroot after transplanting are more developed, but they still show significant clubbing of roots.

cially on warm days, with recovery at night. Midday flagging continues until permanent wilting occurs.

Roots of affected plants are enlarged into various shapes. Roots of most crucifers infected at a single site are spindle shaped, but multiple infections of the same root cause the extreme swelling and distortion that characterize most brussels sprouts, broccoli, and cauliflower infections. Infected roots crack, and secondary organisms invade them and cause decay. The toxins produced by the secondary organisms cause the tops of transplanted plants to wilt. Direct-seeded crops are usually infected so early that the impact of clubroot alone on the root system will cause wilting.

Seasonal Development

Clubroot fungus persists for many years as spores in soil. Infection is favored by acid soils with adequate moisture, but infections do occur above pH 7.0. Resting spores germinate by producing a zoospore that infects cells of the youngest roots. A few days later, these zoospores produce a second type of zoospore that reinfects the host; the fungus then enlarges and spreads from cell to cell. It induces rapid cell division, abnormal cell enlargement, and completely disrupts the root's growth and structure. Normal development of water- and nutrient-conducting tissue is inhibited, and as the roots die and decay, spores are released into the soil.

The fungus is dispersed from field to field by movement of infected plants, especially transplants, and movement of infested soil on machinery and surface water. It can also be spread in manure from animals fed infected culls or plants.

Management Guidelines

Once in the soil, clubroot fungus remains viable for many years. There is no economical way to eliminate it. Rotation with nonhost crops generally does not provide effective control; however, a 2-year rotation away from crucifer crops and into a cereal has markedly reduced clubroot incidence in brussels sprouts in San Mateo County. The effect of such a rotation on other crops or in other areas is not known. To prevent contamination of clean fields with clubroot spores, wash machinery with high-pressure equipment to remove soil and other debris before moving it from infested to noninfested fields. Do not use tailwater from contaminated fields to irrigate noninfested fields because the fungus can be transported in water. Grow transplants in fumigated plant beds; young plants can be infected for some time without indicating infection and cannot always be detected at transplanting.

Where fields are already infested with clubroot, liming the soil can often provide effective commercial con-

Discontinuous discoloration in the woody, water-conducting vessels of the stem typifies Verticillium wilt. The discoloration is generally darker than that associated with *Fusarium*.

Purpling and reddening of older leaves is the first noticeable symptom of Phytophthora crown rot. A canker develops on the stem near the soil surface.

Plants infected with *Sclerotinia* are often covered with hard black sclerotia and develop a white, cottony growth of mycelium in wet weather.

trol. Clubroot spores do not germinate well in alkaline soil, so adding lime may help reduce disease incidence. However, liming may not be effective in well-buffered soils. Apply lime annually if the soil pH is below 7.2.

Incorporating pentachloronitrobenzene (PCNB) into the soil at planting protects clubbed roots from secondary invaders and may delay their decay until after a crop is made. Economic return from use of PCNB, compared with use of lime alone, will probably be limited to fields (such as those at Half Moon Bay) with a long history of clubroot, very high levels of inoculum, and well-buffered soils. Use PCNB along with regular liming.

Plant breeders and pathologists have tried to develop resistant or tolerant crucifer cultivars, but the many local strains of the fungus have complicated their task. A cultivar tolerant in one field may not be tolerant in another field. Resistance is not available in horticulturally acceptable cultivars.

Phytophthora Stem and Root Rot
Phytophthora spp.

In California, Phytophthora stem and root rot is known to occur on cauliflower, brussels sprouts, and other crucifers in the coastal areas. It is associated with fine-textured soils with slow internal water drainage. The fungi penetrate the roots or stem near the soil line, but the first noticeable symptom, a reddening or purpling of the older leaves, gradually progresses up the plant. The invaded cortical tissue near the soil line develops cankers. The surrounding tissue becomes tan with a dark border, and the discoloration extends into the stem's woody portion. The canker usually progresses until the stem is girdled, and the plant wilts and slowly dies. Infected roots turn brown and die.

Phytophthora megasperma, a common soil inhabitant, attacks several different crops, but little is known about the other species. Control is difficult, but soil management that improves drainage, such as planting high, well-drained beds, and carefully irrigating to avoid prolonged saturation of the soil, will reduce chances of infection. Cauliflower cultivars vary in susceptibility. Use more tolerant varieties in areas where this disease occurs.

Verticillium Wilt
Verticillium dahliae

The Verticillium wilt fungus, found in many cultivated soils throughout California, has a wide host range. It often occurs on brussels sprouts in the north central coastal area and is occasionally isolated from cabbage, cauliflower, and other crucifers grown in California's coastal areas. Of the major cole crops, broccoli seems to be the most tolerant. Other host plants of *V. dahliae* include Chinese radish, tomato, pepper, potato, cotton, and various weeds.

Typical symptoms on cole crops are stunting and irregular patches of yellow developing between major veins of older leaves. These symptoms are not obvious and may be overlooked. If you cut an infected stem in a diagonal cross section, you will see discontinuous streaks of dark brown discoloration in the woody, water-conducting vessels. Discolored streaks also occur near the base of petioles. Early in disease development the dark streaks and leaf symptoms may be one-sided, as in Fusarium wilt. Discoloration is generally darker than that associated with Fusarium wilt. *Verticillium* does not kill infected cole crops plants, but it can limit yields.

The fungus can persist for several years in the soil in the small, dark resting bodies (microsclerotia) produced in the roots and lower stems of dead or dying plants. When a susceptible crop is planted in the field, the microsclerotia germinate, and the fungus enters through the roots and spreads through the plant in the xylem. Cool soil and air temperatures favor infection and disease symptom development. The disease is most commonly seen in coastal areas between August and fall harvest, but it may occasionally appear in spring.

There are no economically feasible controls available. Avoiding stress in the later part of the growing season may help limit damage. Rotation is of little value because of the pathogen's wide host range.

Fusarium Wilt or Yellows of Cabbage

Fusarium oxysporum f. *conglutinans*

Fusarium wilt or yellows can destroy susceptible cultivars of cabbage and may also cause losses in kohlrabi and kale. Cauliflower, broccoli, brussels sprouts, and collards are not known to be affected. Another race of the fungus, found recently in California, affects cabbage cultivars resistant to the established race. The disease is most serious during summer; susceptible cabbage varieties grown in winter and spring usually suffer only mild symptoms. A different form of the fungus, *Fusarium oxysporum f. raphani*, causes Fusarium wilt of radish and does not affect cole crops.

Symptoms and Damage

The first symptom usually is the yellowing of one or more lower leaves. As the disease progresses, more leaves become yellow, most often more intensely on one side of a leaf or plant. Eventually, the whole plant yellows, wilts, and dies. Soon after yellowing appears, the water conducting tissue (xylem) becomes reddish brown, usually first on one side of the stem. Occurrence of one-sided symptoms, most readily seen in the stem's xylem, is characteristic, but a lab test is required to distinguish it from Verticillium wilt.

Seasonal Development

The fungus can persist indefinitely in the soil as thick-walled resting spores called chlamydospores that can survive long periods of unfavorable temperature and drought. When a susceptible crop is present, the chlamydospores germinate, and the fungus penetrates the plant through young roots or wounds. The mycelium enters the xylem and progresses up the root and stem into the leaves.

Fusarium develops most rapidly at temperatures ranging from 75° to 85° F (24° to 29° C); little development occurs below 60° F (15° C). The fungus is spread with infected plants and in infested soil on farm machinery, drainage water, boots, or tools. Once in a field, the pathogen is dispersed through cultivation and other practices that move soil or plant debris.

Management Guidelines

Some cultivars of cabbage are available that resist Fusarium yellows. Choose resistant cultivars even for crops grown in winter when disease development is slow. Farm advisors or seed company representatives can suggest resistant cultivars best suited for your area.

Grow transplants in artificial greenhouse soil or soil that has been fumigated with a methyl bromide/chloropicrin mixture to eliminate the pathogen. Rotate infested fields to such nonhost crops as tomatoes, peppers, or lettuce to prevent buildup of the fungus in the soil.

Sclerotinia Rot or White Mold

Sclerotinia sclerotiorum and *S. minor*

White mold occurs on lettuce, tomato, bean, celery, and many ornamentals. A common problem in cole crops grown for seed, *Sclerotinia sclerotiorum* occasionally damages brussels sprouts in the coastal areas and winter cole crops in the southern end of the San Joaquin Valley. *Sclerotinia minor* sometimes affects cauliflower in the coastal areas. Cool, wet conditions favor disease development.

During wet weather, stalks, heads, leaves, or flowers of infected plants may be covered with a white cottony growth. The plant tissue beneath the white mycelium usually turns soft and watery. Hard, black resting bodies—sclerotia—are produced in or on diseased tissue. In the absence of a susceptible host, sclerotia enable the pathogen to survive in the soil for up to 2 or 3 years.

See the section on Sclerotinia drop of lettuce (page 67) for details on biology, identification, and control of these pathogens. Use deep plowing against both species and chemical controls against *S. sclerotiorum* in seed crops.

Black Rot

Xanthomonas campestris p v. *campestris*

Black rot is destructive under rainy, humid conditions. California's dry summers are not conducive to its spread or infection, and it was of minor importance until recently. Increasing use of sprinkler irrigation and repeated cropping of crucifers have caused it to become more prevalent. The most severe losses have occurred in cabbage and cauliflower. It also affects seed production crops.

Symptoms

Initially, yellow to light brown patches appear at the margins of leaves and later a network of black veins develops within the yellowed areas. Black rot derives its name from this black vein symptom, which makes it fairly easy to identify. Affected areas turn brown and dry out, often leaving a triangular-shaped lesion on the leaf margin with one point of the triangle directed toward the midrib. Sometimes most of the leaf's margin is affected. The pathogen spreads from the leaf margins to areas within the leaf blades that soon turn necrotic. Older leaves with lesions may drop from the plant. The bacteria continue to move into the main veins and vascular elements of the stem, turning the tissue brown. In severe cases, the disease may cause taste changes in the cauliflower curd that may inhibit market acceptance. Plants infected in the seedling stage may die in the plant bed or remain stunted if infected after emergence.

Seasonal Development

The bacteria may be carried over from year to year in or on the seeds of infected crucifer host plants, on overwintering cruciferous weeds, or in partially decayed, infected host plant material in the soil. Splashing water from sprinkler irrigation or rainstorms commonly disseminates the bacteria within a field. They enter the plant at the margins of the leaves through natural openings or through insect wounds. The pathogen invades the leaf veins and progresses down the vascular system to the main stem where it may invade the entire plant.

Management Guidelines

Because the pathogen may survive in infected plant debris, do not plant a crucifer crop more often than every 2 years in any infested field. Many crucifer weeds host bacteria and must be controlled to prevent continued contamination. Deep plowing can speed decomposition of infected plant debris, but care must be taken to bury all debris.

Avoid sprinkler irrigation wherever possible, and do not plant infested fields during winter and spring when heavy rainfall occurs. The bacterium can be carried on or in the seed. A hot water seed treatment, 122° F (50° C) for 30 minutes, can be used to reduce inoculum, but it may not be desirable because it often reduces germination of seed or vigor of seedlings. A hot water seed treatment is not 100% effective; new seed treatments are being developed. Transplants should only be grown from seed that has been independently tested for presence of the pathogen. Seed treatments are usually made by seed companies, but growers occasionally treat their own seed. Contact your farm advisor, plant pathologist, or seed company representative for the latest information.

In seed production fields, only use seed that has been tested and laboratory certified as free of the black rot pathogen. Do not plant seed crops in fields where a crucifer crop has been grown in the previous 4 to 5 years or near fields with commercial plantings of crucifers. Use only furrow irrigation in seed fields.

Plant breeders are developing cabbage cultivars tolerant to black rot; ask your farm advisor or seed company representative for more information.

Bacterial Leafspot of Cauliflower
Pseudomonas syringae p.v. *maculicola*

Bacterial leafspot occurs sporadically, mainly on cauliflower, in coastal valleys. The disease appears first as small, faint, water-soaked areas on the undersides of lower leaves. These water-soaked areas develop in a few days into brownish-to-purplish gray necrotic spots, somewhat irregular in outline. They may coalesce to form large irregularly shaped spots. When the lesions are numerous, the leaf becomes puckered, and the affected tissue tends to tear. The disease can cause superficial necrotic lesions on the curds, but this is rare.

The disease, caused by a bacterium capable of living in soil and in infected plant debris, is believed to be seedborne. Most severe during cool, moist weather, it spreads usually during cool, rainy periods in spring or under sprinkler irrigations. Its progress is checked when warm, sunny weather prevails.

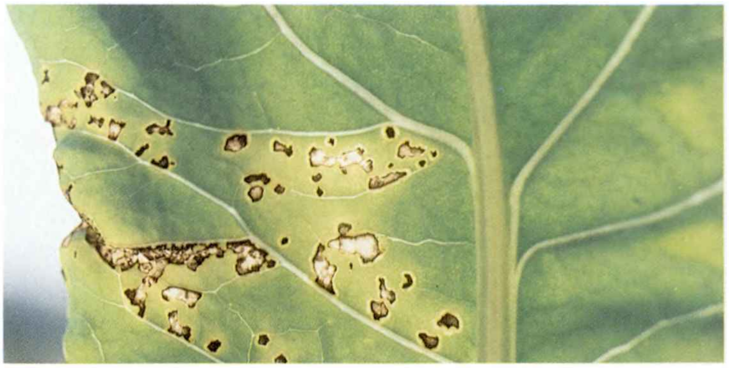
No control measures are practiced. Rotation away from fields where the disease has recently occurred may reduce inoculum levels in soil or infected debris. A change from sprinkler to furrow irrigation may limit its spread. Cultivars vary in susceptibility.

Black Leg
Phoma lingam

Black leg, a fungal disease, occurs sporadically in California, primarily on brussels sprouts, broccoli, and cauliflower in the central coastal areas. Cool, moist conditions favor its development.

In California, infections are usually limited to the basal part of the stem at or below ground level. Occasionally in California and commonly in other areas, the

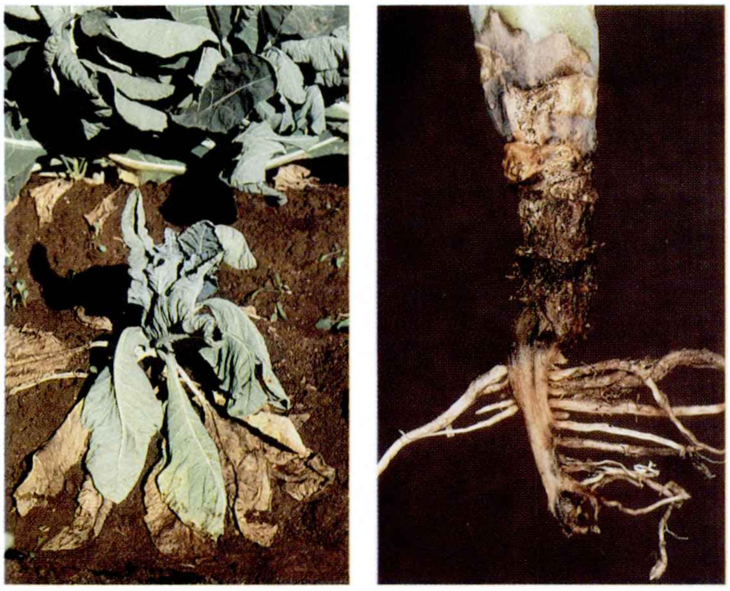
The black rot bacteria may move into the main veins of the leaf turning the tissue brown. This symptom can be seen by slicing open veins with a knife.



ROBERT CAMPBELL

Cauliflower plants infected with bacterial leafspot have small, irregular necrotic spots that may coalesce.

Plants infected with black rot have yellow to brown patches around the margins of leaves.



Black leg damages roots, so affected plants are often wilted and small (left). The most distinctive black leg symptoms occur on the basal part of the stem below the soil surface (right). The area has a semi-dry rot and often blackened areas; small black pycnidia often cover portions of the surface.

Black rot lesions are usually triangular in shape. As the disease progresses, veins within the infected areas turn black.

These black leg pycnidia are greatly magnified (left). If you cut open the stem, you can see the blackening of the xylem caused by black leg (right).

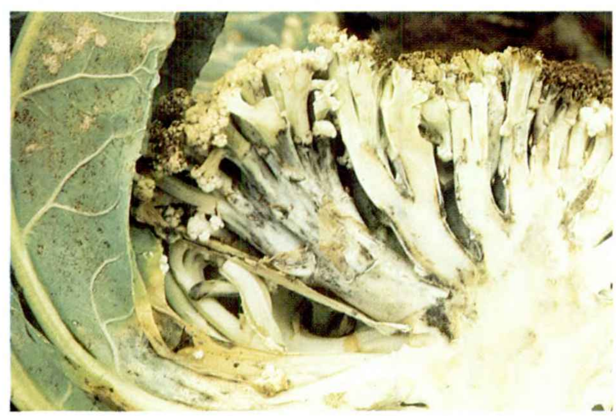
disease also produces leaf and stem lesions that contain small, distinctive black fruiting bodies called pycnidia.

In California infections start at ground level or below the soil suface. Inoculum apparently comes from infected plant debris in the soil and occasionally from infected seed. As the disease progresses, the whole basal part of the stem below the ground may become decayed with a semi-dry, tan colored rot; small black pycnidia cover all or part of the lesion. The disease damages the water-conducting tissue, and the blackened streaks of xylem can be seen by cutting open the stem. Water transport is affected, and plants may wilt and die.

Black leg can be managed by combining preventive procedures. Always use disease-indexed seed or treat infected seed with an appropriate fungicide. Seek your farm advisor's recommendations. Laboratory techniques are available for testing seed for the pathogen. Fumigate seedbeds under a polyethylene tarp with a mixture of methyl bromide and chloropicrin. Plow under debris in diseased fields to allow for more rapid and thorough decomposition. Rotate infested fields out of cruciferous crops for 1 to 2 years.

Downy mildew causes irregular yellow brown spots to develop on leaf surfaces (left). When conditions are cool and moist, gray growths of fruiting bodies develop on the undersides of leaves with downy mildew lesions (right).

These downy mildew sporangia are magnified 12 times.



ART GREATHEAD

Occasionally the downy mildew fungus can get into cauliflower heads, producing dark, purplish spots beneath the cortical tissue.

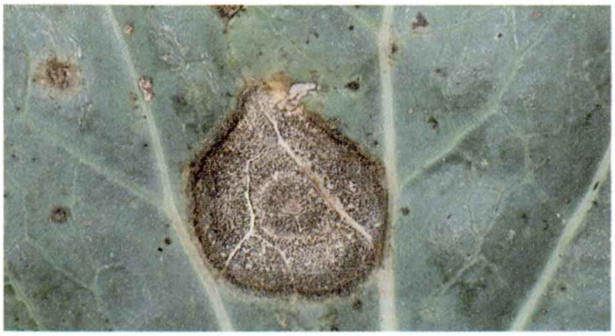
Downy Mildew of Cole Crops
Peronospora parasitica

Downy mildew, an important disease of broccoli, cauliflower, cabbage, and brussels sprouts, prevails during cool, moist weather. Economic damage most often occurs in seedlings, where infections may kill large numbers of plants. Severe leaf infections or stem or flower infections can stunt older plants, reducing yield and quality of a commercial crop. Downy mildew may seriously damage seed crops.

Symptoms and Damage

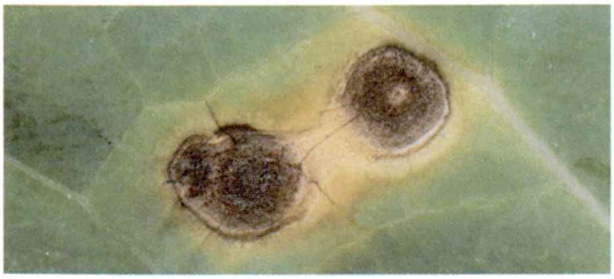
The most distinctive characteristic of downy mildew is the grayish white, fluffy growth that develops on the undersides of infected leaves during cool, moist weather. Irregular, yellow to brown spots develop on both leaf surfaces. The spots turn purplish and later light brown or yellow. When the disease is confined to leaves on a crop in which only flower parts are marketed, losses may not be great since many lesions are required to reduce yields.

The infection may spread to stems or flower parts. Dark brown areas will develop internally in curds or floral stems of cauliflower or broccoli. These areas will fail to produce flowers on cauliflower being grown for seed. In broccoli, some florets and infected stems may be darkened or contain black streaks. In the stems and heads of cabbage, the fungus may produce dark purplish spots visible beneath the cortical tissue. The internal darkening caused by downy mildew in these crops may not be apparent until affected parts are sliced open. Stem and flower part lesions may be invaded by soft rotting bacteria or other secondary organisms.



Ringspot lesions are made up of a series of concentric rings. Numerous tiny fruiting bodies develop within the lesion on older lesions.

These ring spot fruiting bodies have been magnified 15 times.



Alternaria leafspot lesions are often made up of concentric rings but never have the black fruiting bodies common to ring spot lesions.

ROBERT CAMPBELL

Broccoli leaves infected with white spot have white to light colored spots scattered over the surface. A black ring sometimes develops around the spot, and black veins may develop within.

Seasonal Development

The fungus survives from season to season on overlapping crucifer crops or as thick-walled resting spores, called oospores. These sexual spores can survive in the soil for extended periods and produce sporangia under favorable environmental conditions. During the growing season, the fungus produces sporangia on the underside of the leaf at night when conditions are moist. The sporangia are carried primarily by air currents and, to a lesser extent, by rain. Under favorable conditions the sporangia germinate, producing germ tubes that directly penetrate the leaves and flowers to cause new infections. About 10 days after initial infection, sporangia form on the new lesions.

Management Guidelines

A few broccoli varieties are now available that are tolerant to downy mildew. Fungicide treatment of susceptible varieties is needed when the disease occurs early in crop development; repeated applications may be required, depending on the weather. Treatment during early flowering is required on seed crops. Consult your farm advisor, pest control advisor, or seed company representative for the latest developments on tolerant cultivars and information on fungicides and application methods.

Ringspot
Mycosphaerella brassiciola

In California, brussels sprouts is the only cole crop commonly damaged by ringspot. Cool, moist weather favors disease development and dissemination.

The first symptoms are small, dark tan spots that rapidly enlarge and turn gray. Older spots are usually made up of a series of concentric rings. Numerous tiny, dark bodies develop within the aging lesion. The disease does not damage sprouts directly, but when it causes severe defoliation, yields may be reduced.

The fungus can survive in infected plant refuse in the soil, the most common source of infection at the beginning of the season. Plowing under infected debris will speed decay of plant tissues and reduce the inoculum level. Consider using protective fungicides in fields where the disease is spreading. Ask your farm advisor to recommend materials.

Alternaria Leafspot
Alternaria spp.

Alternaria leafspot may be a problem on Chinese cabbage and cabbage during cool, rainy months and can also be an economic problem on brussels sprouts if it infects sprouts. The pathogen occasionally infects broccoli and cauliflower. Leaf spots begin as small, dark areas and spread rapidly to form large circular lesions that sometimes develop a bull's-eye pattern. During wet periods the lesions appear dark brown. A brown, velvety, spore-bearing growth appears on the older lesions. There are, however, no tiny dark bodies as in ringspot lesions. A good hand lens or microscope is required to see the growth. Spores are spread from plant to plant by the wind under favorable conditions. During unfavorable periods, the fungus can survive in plant debris or on seed.

Certain fungicides applied as foliar sprays will control Alternaria leafspot. Ask your farm advisor for more information.

White Spot
Pseudocercosporella capsellae

White spot of crucifers is a common disease of such crucifers as turnip, Chinese cabbage, and wild mustard in high rainfall areas outside of California. It has been observed occasionally on broccoli, as well as Chinese cabbage and bok choy, in California'a coastal region during periods of above-normal rainfall, usually in late spring. It may also affect other cole crops.

The disease causes round to irregularly shaped white to light tan spots about 1/5 to 1/2 inch (5 to 10 mm) in diameter that are scattered over the leaf surface. Veins darken within the spots and black sclerotia form within the lesion; veins and sclerotia can be best seen by holding a leaf up to the light. When it is damp, a white "fuzz" of conidia grows on the underside of the leaf beneath lesions. A good hand lens or microscope is required to see the conidia.

No management practices are recommended.

Mosaic or Virus Diseases

Cauliflower and turnip mosaic viruses occasionally occur on cole crops, but they usually do not cause significant damage. However, on the related crops Chinese cabbage or bok choy, they can reduce yield and quality.

Leaves of infected plants are mottled in a mosaic of light green or yellow to dark green and may have varying amounts of necrosis, depending on the virus strain and other factors. Some plants show vein clearing. Plants may be stunted if infection occurs early.

The viruses cannot survive in the absence of a living host; they depend for survival on perennial and annual plants. They are spread from plant to plant by aphids. Avoid planting next to old virus-infected crucifer fields, and control such weed hosts as wild mustard.

DISEASES OF LETTUCE

Sclerotinia Drop
Sclerotinia minor and *S. sclerotiorum*

Sclerotinia drop or lettuce drop is a major disease of lettuce. Two species of *Sclerotinia* cause the disease in California. *Sclerotinia minor* predominates in the coastal valleys and occasionally occurs in the San Joaquin Valley and the lower desert. *Sclerotinia sclerotiorum* occurs in all areas but predominates in the San Joaquin Valley and the lower desert areas and is most prevalent during cool, wet periods in winter and spring. *Sclerotinia minor* may damage lettuce throughout the year. Both species are most common in or near fields repeatedly cropped to lettuce or other susceptible crops. Although symptoms and damage are similar, life cycles and management guidelines for the two fungi differ.

Symptoms and Damage

Lettuce drop is most often observed as plants approach maturity; at first, lower leaves wilt. With the collapse of the lower leaves, the entire head wilts and yellows.

The limpness of the entire plant resembles the symptoms of Botrytis rot; however, the hard, black sclerotia and white, cottony mycelium on the underside of the lower leaves and the basal part of the stem distinguish lettuce drop from Botrytis rot infections, which have a gray sporulation. Sclerotia of *S. minor* are small and about 1/16 to 1/8 inch (1.5 to 3 mm) or less in diameter, whereas *S. sclerotiorum* resting bodies are more irregularly shaped and usually larger—up to 1/2 inch (12.5 mm) or more in size. Sclerotia usually are concentrated first on the lower portion of the plant close to the soil. In later stages the stem and head often disintegrate into a soft, watery mass covered with sclerotia.

Seasonal Development

Cool, moist weather favors development of lettuce drop. *Sclerotia minor* is more functional under somewhat drier conditions than *S. sclerotiorum*, but severe losses are rare when high temperatures or wind rapidly dries out the surface soil. Sclerotia may remain viable in the soil for 2 to 3 years.

Germinating sclerotia of *S. sclerotiorum* do not infect the lettuce plant directly. Instead, sclerotia in or on the soil form small, tan, cupshaped or flattened fruiting structures called apothecia; they are 1/8 to 1/4 inch (3 to 6 mm) in diameter. Apothecia form just above the soil surface and forcibly eject ascospores into the air when a slight decrease in the humidity occurs. Ascospores landing on lettuce plants may survive up to 2 weeks and

The first sign of lettuce drop is a wilting of the lower leaves.

Sclerotia form on the lower stem of plants infected with *Sclerotinia*. These smaller sclerotia are typical of *S. minor*. A white mycelium grows over the infected and rotting area.

***Sclerotinia sclerotiorum* sclerotia are larger and more irregularly shaped than those of *S. minor*.**

germinate only in the presence of free water. For an infection to become established, the fungus must first invade dead or dying tissue. Most infections occur in the crown and lower senescing leaves of mature plants. Once the ascospore germinates and infects the plant, the mycelium grows into the crown, girdling and eventually killing the plant. As tissue invasion advances, many large sclerotia are produced.

Production of apothecia from sclerotia requires continuous moisture, cool temperatures, and overcast or shaded conditions that keep soil moisture near the soil surface at near saturation. Apothecia begin to appear in fall after the first substantial rainstorms or after an irrigation and increase in humidity. Neighboring weedy areas, alfalfa fields, orchards, or other shady crops are likely locations for apothecia development and sources of spores for lettuce fields. Apothecia usually do not occur in lettuce fields until the crop is large enough to provide shade. One or more apothecia may develop from a single sclerotium, and each produces thousands of ascospores, so the disease may increase and disperse much more rapidly than the form of the disease caused by *S. minor*, which is soilborne and rarely produces apothecia.

The sclerotia of *S. minor* infect lettuce plants directly by germinating eruptively. Plants as young as in the four- to five-leaf stage may be killed. The germinating scle-

Sclerotia of *Sclerotina sclerotiorum* form apothecia such as these when conditions are cool and moist. Spores are ejected when slight decreases in humidity occur.

rotium sends a plug of vegetative mycelium through its rind and infects the lettuce root and crown, decaying and killing the plant. White mycelium soon covers the plant's underside. New sclerotia start forming within a week to 10 days after the initial invasion. Airborne spores are not an important source of inoculum because *S. minor* does not commonly form apothecia in California.

Management Guidelines

Because of differences in disease cycles, the two *Sclerotinia* species must be managed differently.

Sclerotinia minor. Several cultural practices, particularly plowing, will help control lettuce drop when it is caused by *S. minor*. Plows should be pulled fast enough to roll the soil over as completely as possible with the objective of burying the sclerotia 10 or more inches below the surface. Sclerotia buried that deeply do not germinate, cannot infect the lettuce plant, and are rapidly destroyed by microorganisms. Ask your farm advisor about the availability of improved plows.

The disease is favored by a wet soil surface that can be avoided by keeping the bed surface as dry as possible with careful irrigation. This can be difficult as plants near maturity and shade the beds. Level your land to provide for even distribution of water. Assure good drainage with beds as high as possible.

Removing infected crop residues from the field is costly initially but significantly decreases sclerotia levels and subsequent disease. In the long run, it is an economical management practice especially when combined with deep plowing and careful irrigation management.

Application of fungicides as soon after thinning as possible will significantly reduce losses by *S. minor*. As much of the soil surface as possible must be covered. Applications at the rosette stage will not be effective.

Sclerotinia sclerotiorum. Most of the cultural practices recommended to control *S. minor* will not significantly reduce the incidence of *S. sclerotiorum* because ascospores rather than sclerotia are its main means of spread and infection. Keeping bed surfaces dry can help, but this is difficult during the rainy season when the disease prevails. Removing weedy areas around edges of fields and avoiding planting lettuce near weedy orchards may be helpful.

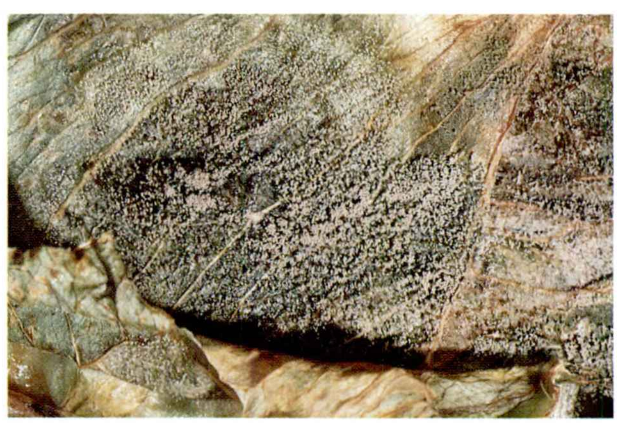
Several applications of fungicides made beginning at the rosette stage will reduce the disease. Applications at thinning will not control *S. sclerotiorum*. Thorough plant coverage is essential. Add a spreader-sticker to increase effectiveness. Ask your farm advisor for more information about fungicides.

Botrytis Rot
Botrytis cinerea

Botrytis rot, often called gray mold, commonly affects lettuce under cool, moist conditions. It may occur in combination with Sclerotinia drop but usually is much less prevalent. Frequently found in the coastal production areas, it is only occasionally found in the San Joaquin Valley and southern desert areas. The disease is usually not of economic importance. The fungus infects many other crops including cole crops.

Symptoms of Botrytis crown rot are similar to Sclerotinia rot: Lower leaves yellow, and eventually the whole head wilts and rots. A firm, watery, brown decay develops on the underside of the head at the crown. A dense gray or light brown sporulation appears over the damaged areas when moisture from dew, rain, or irrigation is abundant; this gray sporulation distinguishes Botrytis from lettuce drop. Occasionally, the fungus produces small, black, usually flattened sclerotia on the plant's underside.

The wilt caused by Botrytis rot is similar to that caused by Sclerotinia drop; however, the spores on the wrapper leaf distinguish this infection as *Botrytis*.



***Botrytis* spores are light brown and often cover much of the rotting leaf surface when moisture is abundant.**

The *Botrytis* fungus may also cause a head rot, a symptom most common in fields where harvest has been delayed, heads are at or past optimum maturity, and conditions are cool and moist. The fungus can enter the head only where an injury has occurred; once inside, it produces a brown, soft decay. Under cool, moist conditions, lesions are covered with a dense gray to light brown mass of spores.

Botrytis infects primarily through germination of its airborne spores. An injury or dead or dying tissue must be present for the fungus to invade. Senescing wrapper leaves often provide entry sites for crown rot. Head rot may develop on sites damaged by aphids, downy mildew or other diseases, or harvesters testing heads for maturity.

Fungicide applications for gray mold are not usually needed. Management practices recommended for *Sclerotinia*, including deep plowing, high beds, good drainage, and careful irrigation, will also limit *Botrytis*. Harvest fields at prime maturity to avoid senescence of wrapper and cap leaves.

Bottom Rot
Rhizoctonia solani

Bottom rot can cause serious losses in the southern desert growing areas and in the San Joaquin Valley; it is rarely seen damaging lettuce elsewhere in California. The disease is most prevalent on early season lettuce that matures between the end of November and mid-January. Initial symptoms of bottom rot appear after the head begins to form. Sunken, brown, necrotic spots develop on the bottom of midribs of the lower leaves that touch the ground. The spots may merge, forming larger but delimited brown areas. Small gray brown sclerotia develop in the lesions. A fine, webbed network of white-to-brown mycelium often grows over the lesions. The coarse mycelium can usually be seen without a hand lens and helps distinguish the disease from other disorders that may also produce sunken, necrotic spots. As the disease progresses, the fungus grows from leaf to leaf inside the head and near the stem, and the outer leaves wilt and become yellow. The head eventually becomes slimy as secondary organisms, usually soft rot bacteria, invade the damaged tissues.

Rhizoctonia has a broad host range, and its most serious outbreaks are associated with warm, moist weather. Once leaves form a canopy over the planting bed, the soil under the leaves may fail to dry between irrigations, inviting disease development. Mycelium from germinating sclerotia is believed to penetrate the healthy leaf blades or midribs in contact with the moist soil during warm weather.

At present there is no control for bottom rot.

Corky Root
An Unidentified Bacterium

Corky root, a recent serious newcomer in some coastal area fields repeatedly cropped to lettuce, is believed to be caused by a soilborne bacterium.

Symptoms and Damage

In mild cases, corky root may produce no noticeable aboveground symptoms, but in severe infections plants exhibit symptoms typical of root rotting or root-pruning diseases: stunted and uneven growth, yellowing of lower leaves, wilting at midday, and poor head formation.

The first symptoms, yellow lesions on roots at or shortly after thinning, increase and coalesce. The roots darken to dark mohagany and sometimes appear a faint green. The root's surface becomes rough and cracked or pitted. Roots are brittle, and the root tip breaks off readily when it is bent or the plant is pulled out of the ground. The feeder root system is much reduced, although there may be numerous lateral roots near the soil surface. Plants growing in fine-textured, poorly drained soils are most severely damaged. However, plants growing in light soil may also develop corky root, especially when overirrigated.

Seasonal Development

Little is known about the seasonal cycle of the corky root causal agent. The soilborne bacterium is known to persist for at least 3 years after a field has been rotated out of lettuce. Movement of infected soil with machinery, water, or other means may spread the disease. Research suggests that low oxygen and high moisture levels in the soil promote the disease. Dense or compact soils, too frequent or extended irrigation, and low planting beds intensify disease severity.

Management Guidelines

Growers who regularly rotate their fields out of lettuce usually do not have severe corky root. If lettuce is repeatedly grown in a field, promote root growth by planting a cereal rye cover crop in fall before the first rains and mowing and discing it in spring before planting to lettuce. Rye's dense, fibrous root system breaks up and aerates compact soil layers, making it easier to till and improving drainage and lettuce root penetration. Other measures that reduce soil compaction usually reduce corky root severity. These include making beds high and furrow irrigating as infrequently as possible, between thinning and rosette stage, to allow deep root growth but to avoid severe reduction of growth rate. Normal irrigation should be resumed after heads begin to form, but do not overirrigate.

Downy Mildew of Lettuce
Bremia lactucae

Downy mildew is a common lettuce fungus in most lettuce-growing regions, especially during the cool, moist weather often prevalent in early spring and late fall or in summer in the coastal regions. The disease is usually of minor importance in the southern desert.

Symptoms and Damage

The fungus attacks older leaves first, causing light green or yellow lesions on the upper surface of the leaves; these are later covered with white spores on the underside. Plants of any age may be affected. In severe epidemics, infections can extend into the cap leaves and the head. The angular lesions are delineated by leaf veins as they grow larger. Affected portions on the leaf eventually turn brown, and with numerous lesions the leaves may die.

The disease can reduce yields and quality, although the crop may be salvaged by removing damaged wrapper leaves at harvest. If cap leaves are heavily affected, the head generally cannot be salvaged. Mildew-damaged tissue also provides an entry site for rot-producing organisms that can compound crop losses in the field or cause severe rot problems in transit.

Seasonal Development

Damp, moist conditions and cool temperatures are ideal for development and spread of downy mildew. Spores, produced only under conditions of subdued light or darkness and a near-saturated atmosphere, are dispersed by wind, and under cool, moist conditions, they can survive several days. Free moisture on the lettuce leaf is necessary for spore gemination and infection, but moisture is not required for vegetative growth once the fungus is within the leaf. Although downy mildew may develop on wild lettuce, cultivated lettuce is the most common source of the disease, so areas with year-round lettuce culture and favorable climate often have the most serious outbreaks. The disease can be transported on transplants. Dry, desiccating winds and clear, warm days inhibit growth and spread of downy mildew. Orienting rows to take advantage of the drying effect of prevailing winds on soil and crop canopy may help reduce downy mildew.

Management Guidelines

Resistant lettuce varieties effectively controlled downy mildew for many years, but several new races of the fungus appeared in 1976 and overcame the resistance. Research is underway to develop lettuce varieties resistant to the races of the fungus now predominant in California. Check with your seed company representative or

FRANKLIN LAEMMLEN

Bottom rot causes sunken necrotic spots at the bottom of midribs. A fine network of mycelium grows over the spots.

The feeder root system of roots affected by corky root is reduced, and the tip of the root often breaks off.

Corky root causes the root surface to become pitted. Affected roots turn dark and often take on a faint green appearance.

farm advisor for more information about available resistant or tolerant varieties.

Systemic and nonsystemic fungicides are available to control downy mildew. Effectiveness of nonsystemic fungicides depends on thorough coverage of both sides of leaves, timely first applications, and repeated applications. While copper compounds are effective, they should be used with caution; repeated applications may cause yellowing and necrosis of the leaves and midrib. Check with your farm advisor or pest control advisor for current information regarding registered materials and application procedures.

Powdery Mildew of Lettuce
Erysiphe cichoracearum

Powdery mildew of lettuce occurs sporadically in fall, primarily in the interior of the coastal valleys and in the southern San Joaquin Valley. Unlike downy mildews, which are favored by cool, moist conditions, powdery mildew is favored by warm, dry conditions. Although the disease may occasionally reduce yield and quality, it is rarely of economic importance.

Both downy mildew and powdery mildew produce whitish collections of spores on the leaf surface, but similarities end there. The white sporulation of powdery mildew covers much of both the lower and upper sides of the leaf. If you examine the spores under the microscope or with a high-powered hand lens, you will see that downy mildew spores are produced on branched stalks that look like little trees, whereas powdery mildew spores occur in chains on a single stalk. Occasionally small, black, fruiting bodies (cleistothecia) will also develop in the powdery mildew mycelium; cleistothecia provide a means for the fungus to survive on debris for short periods between crops. Areas affected with powdery mildew enlarge in a circular pattern, spreading a white, dusty growth over the whole leaf; there is no clear veinal delineation as in downy mildew infections. Leaves become brown and dried.

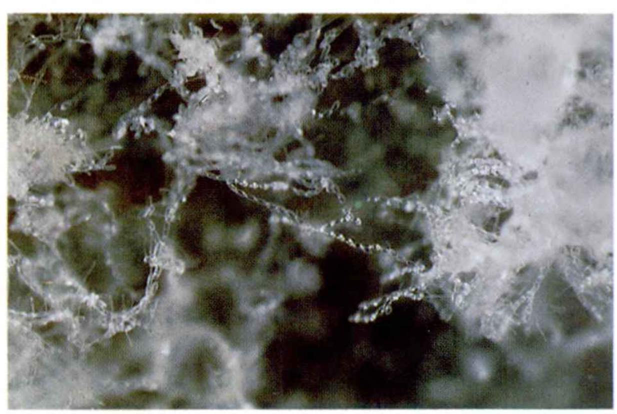
Powdery mildew rarely becomes serious enough to require treatment.

Lesions caused by downy mildew are light yellow to brown on the upper side of the leaf.

Downy mildew lesions are angular and delineated by leaf veins as they grow larger.

When moisture is abundant, downy mildew spores form in a fluffy white growth on the underside of leaves.

The white sporulation of powdery mildew may be found on both the upper and undersides of lettuce leaves.



Powdery mildew spores are produced in chains, unlike the branched fruiting bodies of downy mildew.

Big Vein
An Unidentified Viruslike Agent

Big vein is the most important disease of lettuce in the southern desert and also frequently causes losses in California's other lettuce-growing areas. Disease expression is favored by cool weather and is most prevalent in spring in the coastal areas and in late December and January in the Imperial Valley. The pathogen that causes big vein has not been characterized, but it is transmitted by the root-inhabiting fungus, *Olpidium brassicae.*

Symptoms and Damage

The most distinctive symptom, a clearing of the tissue next to leaf veins, makes the veins appear enlarged. Vein clearing becomes more intense over time, and leaves pucker and appear ruffled. Plants with big vein often have outer leaves that grow more upright than normally, may fail to form a tight head, or may be delayed in maturity. Symptom expression varies among cultivars; susceptible cultivars often fail to make a head. More tolerant ones may be delayed in development, but eventually they will make a marketable head.

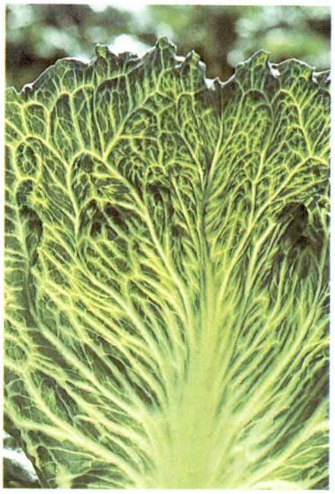
Seasonal Development

Big vein is more likely to be found in fine-textured, poorly drained soils. Its causal agent can persist in the soil within the resting spores of the fungus vector, *Olpidium brassicae,* for 10 years or more. Resting spores of the fungus germinate to form zoospores that infect and colonize the epidermal cells of roots of the lettuce plant and release the big vein agent. Symptoms do not appear until at least 35 days after planting. Intensity of disease symptoms varies, being most pronounced at air temperatures between 42° and 60° F (5 to 15° C). Infected plants may show no symptoms if air temperatures are well above 60° F (15° C).

Management Guidelines

Rotation does not control big vein because of the fungus' persistence. Keep records of fields where it has occurred and, if possible, avoid planting lettuce in those fields during the coolest part of the season, especially in fine-textured soil. Plant lettuce crops that are likely to mature during cool weather in the lightest, best drained soils available. In coastal areas and the Central Valley, spring planting of fields prone to big vein should be delayed to avoid infection. In the southern deserts, such fields should be planted with early maturing varieties.

Choose soils that drain well. Level and laser plane fields so that water is distributed uniformly through the field. Sprinkler irrigate in the early stages of plant development where possible—do not overirrigate. Avoid prolonged saturation of the soil when temperatures are cool.



A clearing of the tissue next to leaf veins is the most distinctive symptom of lettuce big vein.

Plants with big vein, such as the one at left in this photo, often have outer leaves that grow more upright than normal and are puckered.

Some cultivars are tolerant to big vein. Check with your seed company representative for those suitable to your area.

Anthracnose
Marssoninia panattoniana

Anthracnose, also called shothole, is an increasingly important problem in the coastal areas; it also occurs sporadically in the San Joaquin Valley. Anthracnose is favored by cool, wet periods in spring. Symptoms begin to appear in February on wild and field lettuce. Few new outbreaks appear after April.

The first symptoms are small, yellow, water-soaked spots on lower leaves. The spots darken, enlarge slightly, and dry up. After a few days to a week the centers fall out, producing a shothole appearance that might be confused with insect damage. Affected leaves wither and die rapidly. Small, water-soaked spots may also appear on the midrib's underside; these darken, elongate, and sink slightly, giving the midrib a rough, indented surface.

The pathogen spreads when rain or sprinkler droplets splash spores from infected plants in random hot spots onto adjacent uninfected plants. Cool temperatures are required for high spore production, and free moisture is needed for germination and infection. Thus, the disease is primarily a problem early in spring, during and following rain.

Little is known about the life cycle of the fungus or how it survives, but it is known to be soilborne. The pathogen also infects prickly lettuce, *Lactuca serriola*, so this weed species, when growing near lettuce fields, may be a source of inoculum for early infections.

Anthracnose may cause watersoaked lesions on the underside of the midrib.

BRYAN DELP

Lettuce plants infected with anthracnose have small lesions and shot holes on their lower leaves.

Several practices can limit incidence of the disease. Before planting, eliminate wild lettuce or infected lettuce plants or debris in or near the new field. Don't cultivate infested fields while the plants are wet because wet equipment can spread the disease. Rotating out of lettuce and removing wild lettuce in surrounding ditches may reduce the anthracnose inoculum. Fungicides are also available for its control and must be applied weekly from the time the disease is first seen until harvest or until the weather dries and the pathogen ceases activity. Ask your pest control or farm advisor for the latest information on materials and rates.

Varnish Spot
Pseudomonas cichorii

Varnish spot, a soilborne bacterial disease, occurs sporadically on lettuce in the Salinas Valley and Kern County. Heads are most susceptible when they are exposed to rain or sprinkler irrigation after the rosette stage.

Shiny, dark brown, firm, necrotic spots appear on the head leaves but not on the outermost cap leaf. Usually the disease can only be detected when outside leaves are pulled off. Infected tissue remains firm and does not break down until it is invaded in the later stages by soft-rotting bacteria. Symptoms do not usually appear until just before harvest.

The bacterium requires specific moisture and maturity conditions to infect. It is believed to survive in weed or crop hosts or roots or plant debris in the soil or in reservoir water used to sprinkle irrigate. Plants are probably infected in the late rosette stage during rain or sprinkler irrigation, Little else is known about development of the disease or pathogen.

Varnish spot can usually be prevented by avoiding sprinkler irrigation after thinning. No other management guidelines are available at this time.

BRYAN DELP

Firm, shiny, dark brown spots on the head leaves are typical of varnish spot. The outermost leaves have been peeled back to reveal the spots on this head.

Lettuce Infectious Yellows
Lettuce Infectious Yellows Virus

The lettuce infectious yellows virus is transmitted by the sweet potato whitefly, *Bemisia tabaci*. In California the disease has been limited to the southern desert areas during fall when the whitefly is abundant. It was first detected in California in 1980.

Symptoms and Damage

The first symptom is a yellowing around the margin of the oldest leaves; sometimes the outermost edge will turn brown. Soon the whole plant takes on a yellowish cast that remains most intense around the outer edges of leaves. Symptoms resemble those caused by beet western yellows. Infectious yellows stunts plant growth and subsequently head development. Plants infected in the seedling stage are the most seriously damaged. Yields may be reduced up to 50%.

Seasonal Development

The disease is most prevalent in fields planted early in fall when whitefly populations are high. Normally lettuce fields planted after November first are not as seriously affected because whitefly populations decline by then. The timing of symptom development distinguishes infectious yellows from beet western yellows, which normally occurs in the desert in January or February on later planted crops. Fields close to cotton, melons, or squash often appear to be most severely affected, but the disease has occurred in fields distant from these crops. Cotton hosts the whitefly, but it is not a source of the virus. Melons and squash host both the whitefly and the virus. It has a wide host range including sugarbeets, cucumbers, and carrots. Many weeds and ornamentals also serve as a reservoir for the virus.

The whitefly transmits the virus during feeding as it moves from infected to noninfected plants. The virus can be transmitted in as little as 10 minutes of feeding. See page 44 for photographs and discussion of whitefly biology.

Management Guidelines

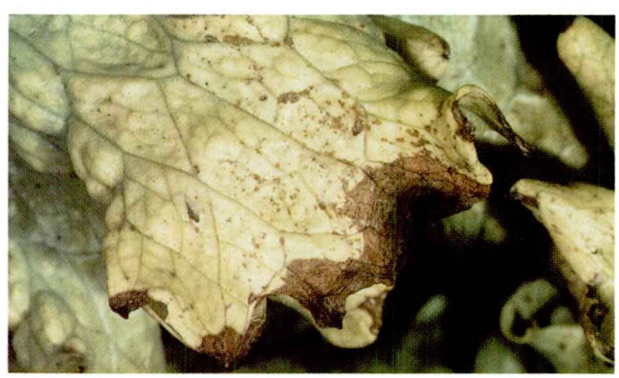
Insecticides applied to control whitefly on lettuce or other crops will not prevent spread of the disease, but certain cultural practices may reduce invasion of fields by whiteflies or spread of infectious yellows virus. For instance, it has been suggested that disease incidence may be reduced by destroying weeds or crop residues from cotton, melons, and other crops that might harbor whiteflies or the virus; no data are available on the effectiveness of these practices, however. Whitefly populations in the desert usually decline dramatically in mid-October and November, so crops planted after this time usually escape the disease.

Beet Western Yellows
Beet Western Yellows Virus

Beet western yellows occasionally causes economic damage to lettuce, although increased use of tolerant cultivars has reduced the disease substantially. The virus is

Infectious yellows causes the most damage when seedling plants are infected. The first symptom is yellowing of the margin of the oldest leaves.

Older plants infected with lettuce yellows take on a yellowish cast that is most intense around the edges of the outermost leaves. Plants infected with beet western yellows show similar symptoms.



Infectious yellows sometimes causes the outer margin of leaves to turn brown.

transmitted only by aphids, primarily the green peach aphid, *Myzus persicae*. An aphid can acquire the virus after 5 minutes of feeding on an infected plant and transmit it to another plant after a 12- to 24-hour latent period has passed. Once infected, the aphid can continue to transmit the virus for at least a month. The virus is not seedborne. A wide range of other crops or weeds can harbor it.

Infected plants in the field display typical yellows symptoms and cannot be readily distinguished from plants suffering from infectious yellows. Magnesium deficiency symptoms are also similar. Symptoms usually first become apparent just after the plant forms a rosette. Older leaves thicken and become brittle, and interveinal areas turn yellow around the outer edges, progressing inward. As chlorotic areas expand, the wrapper leaves also begin to show symptoms. In very susceptible cultivars, most of the leaf surface may turn yellow with only the principal leaf veins of the older leaves remaining green. Such unfavorable conditions as poor nutrition, excessive salinity, or poor root development can enhance symptoms.

The disease is most prevalent after green peach aphid populations have reached peak activity—in January and February in the desert areas, March through May in the San Joaquin Valley, and in the late spring and late summer in the coastal areas. When aphid populations are high, the disease can spread rapidly.

Insecticides applied to control the green peach aphid will not control the disease because even a few aphids can effectively spread it through a field. Destroying overwintering weed hosts of the virus and crop debris can reduce virus reservoirs somewhat. Several lettuce cultivars are tolerant to beet western yellows.

Lettuce Mosaic
Lettuce Mosaic Virus

At one time lettuce mosaic was one of the most destructive lettuce diseases in California, but use of virus-indexed seed and sanitation has almost eliminated it. Now rarely seen, it still has the potential to threaten production seriously.

Leaves of young, infected plants are slightly rolled along the long axis. The first true leaves of plants developing from infected seed are often irregular or slightly lobed. These symptoms are followed or accompanied by light green to yellow mottling on the leaves. Infected plants in the young rosette stage may show vein clearing and bronzing. The mottle symptom disappears or becomes indistinct on older plants. However, half-grown to mature plants may be severely stunted and discolored. Margins of older leaves roll downward.

Lettuce mosaic virus is seedborne and is usually introduced into a field with seed. Aphids, especially green peach aphid, can transmit the disease from plant to plant and from field to field once the disease is in the area.

Lettuce mosaic has been reduced to an insignificant level in California through programs requiring planting of mosaic-free seed, a lettuce-free period, and use of sanitary practices, including prompt discing of old lettuce fields and elimination of weed hosts.

Aster Yellows
A mycoplasmalike organism

Aster yellows disease, caused by a mycoplasmalike organism, is spread primarily by the aster leafhopper, *Macrosteles fascifrons*. Relatively rare, the disease may appear anywhere lettuce is grown and may also affect carrot, onion, spinach, potato, tomato, celery, barley, and a wide range of other crop and ornamental hosts.

The first symptoms are blanching and chlorosis of the young heart leaves. Center leaves fail to develop normally, often remaining as short, thickened stubs in the plant's center. Pink-to-tan latex deposits collect on the underside of midribs of affected leaves. Development of latex deposits is a diagnostic feature. If young plants are infected, outer leaves may yellow and overall growth may be severely stunted. Older plants often show no external symptoms, but internal symptoms and latex deposits make them unsuitable for marketing. The disease causes sterile or aborted flowers in seed crops.

The disease is spread primarily by the aster leafhopper, as it feeds in the phloem of plants. When susceptible crops are not in the field, the pathogen may overwinter in perennial or biennial ornamental plants or weeds.

DENNIS HALL

The plant in the center of this picture is suffering from lettuce mosaic. The tops of the leaves roll down and there is a slight mosaic pattern on some of the older leaves.

Abiotic Disorders

Environmental conditions, agricultural chemicals, and nutrient deficiencies can cause lettuce and cole crop plants to develop symptoms similar to those caused by pathogens, insects, or other pests. These abiotic disorders can reduce yields and sometimes kill plants or prevent them from reaching maturity. The most common abiotic disorder in lettuce and cabbage is tipburn. However, many others are occasionally seen in the field. The most common are described and pictured here.

Tipburn

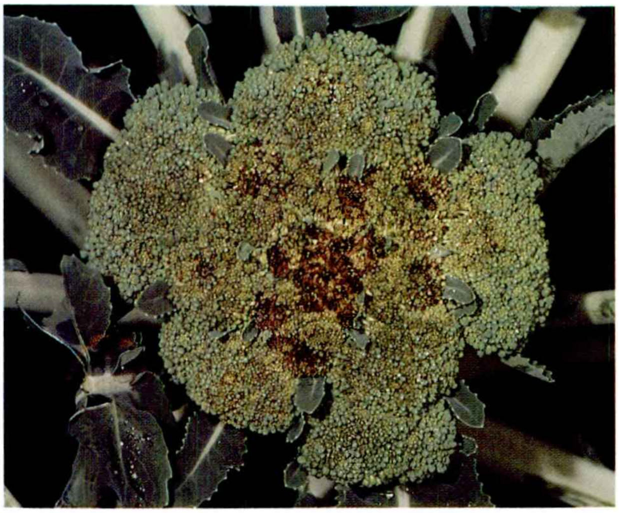
Tipburn occurs on cabbage, brussels sprouts, and lettuce. Symptoms are not usually visible from the outside, but break open an affected head, and you will see that edges of the internal leaves are brown. The necrosis may involve a few spots along the margin, or the whole edge of the leaf may be affected. The lesions are frequently invaded by soft-rotting bacteria that can cause severe decay.

The disease is related to a calcium deficiency aggravated by high soil fertility and high temperatures. It often occurs when a sudden water stress is followed by excessive growth and low humidity. Once heads are cooled after harvest, further development of tipburn symptoms ceases.

To avoid tipburn, hold nitrogen levels as low as possible for adequate yields. Apply nitrogen in nitrate forms, rather than as ammonia forms, and do not apply excessive potash or other fertilizers that might compete with calcium uptake. Take soil samples to be sure the soil has an adequate base saturation and adequate calcium. Follow good irrigation practices and avoid water stress. Harvest when heads are at optimum maturity and avoid excessively firm heads. Cultivars vary in their susceptibility to tipburn.

Riceyness of Cauliflower

Riceyness of cauliflower occurs when temperatures remain warm during curd development. The curd appears uneven and fuzzy, and floral parts start to grow up through the head prematurely. There are no practices for prevention, other than planting to avoid curd exposure to warm weather. Some cultivars are less likely to develop riceyness than others.



Flower buds of broccoli plants affected with the brown bud disorder turn brown as heads mature.

Brown Bud of Broccoli

Brown bud of broccoli is frequently seen in all growing regions, usually when temperatures are warm. Its cause is not known. Flowerbuds (beads) of broccoli turn brown as they approach maturity. The disease may be associated with calcium nutrition and rapid growth. Certain cultivars are apparently less likely than others to develop the condition.

Hollow Stem of Cole Crops

Hollow stem, a condition of cabbage, cauliflower, and broccoli, may occur during very rapid growth. On affected plants the interior pith tissue of the stem or head is collapsed or cracked and often hollow. Usually the head or stem must be cut open to see the damage. High temperatures, in combination with high levels of nitrogen and large stem diameters, are associated with the disorder. Wide spacing of plants may also contribute to the problem. Plants deficient in boron may exhibit symp-

The pith tissue of cole crop plants with hollow stem syndrome is cracked open.

Freezing causes the epidermal layers of the lettuce leaf to separate and take on a silvery appearance.

DENNIS HALL

Lettuce plants injured by high levels of free ammonia show discoloration of the central xylem core of the root.

toms, but when boron deficiency is involved, the interior of the cracked stem cavity is darkened. Keeping nutrients at recommended levels and avoiding excessive rates of growth help prevent hollow stem.

Wind Injury

Strong winds carrying abrasive sand may injure plants of all ages, especially in the lower deserts. The

CLYDE ELMORE

The yellow margin on the left leaf of this red leaf lettuce plant is due to injury by the herbicide pronamide.

CLYDE ELMORE

These lettuce plants were planted in soil treated with alachlor herbicide 60 days previously. The curling and stunting are typical symptoms.

CLYDE ELMORE

Contact with the herbicide glyphosate can cause stunted growth.

abrasives damage outer leaves and provide entry for secondary rot organisms. Wounded areas will often heal over on cole crops, leaving thickened, wartlike, discolored spots that would be mistaken for pathogen injury. Some injury can be prevented if the field is sprinkled as soon as the sand storm begins.

Wind injury to seedlings after thinning (sometimes called "windwhip") can occur in cole crops and lettuce in all areas. Affected plants are pinched at ground level, bent over, and often spindly.

Cold Injury

Lettuce is fairly tolerant to temperatures below freezing. With gradual drops in temperature, plants may escape injury even at 20° F (−7° C). However, a sudden temperature drop will freeze and injure leaves and, less commonly, the growing point. Symptoms appear within a few days. Injured leaves appear silvery, and the epidermis usually ruptures and separates from the underlying tissue.

Cole crops are more tolerant to cold temperatures than lettuce, and frost damage is not common in most California growing areas. Damage is usually limited to nonmarketed leaves. Curds of cauliflower and heads of broccoli may occasionally be damaged, leaving wounds vulnerable to secondary infection. Wrapper and outer leaves of cabbage can be damaged, but these can be removed with little economic loss. Brussels sprouts are quite tolerant to cold and can withstand temperatures of 14° F (−10° C) with little damage if temperatures drop slowly.

Salt Injury

Salt-injured plants are stunted and have thick, dark green foliage with marginal yellowing or burning. With high salt concentrations, roots may be injured and take on an orange-colored, roughened appearance that can be confused with corky root in lettuce. Salt injury symptoms become more pronounced after water stress or in seedling fields when salt that has accumulated on the soil surface is carried by light rain or sprinkler irrigation to the seedling roots. Also, salt can prevent seed germination, resulting in poor, uneven stands. In fields with bicarbonate salts, crowns become corroded, and plants may be broken and blown away by high winds, but this condition is not common.

Ammonia Injury

Ammonia injury occurs when ammonium or ammonia-forming nitrogen fertilizers break down to form free ammonia in amounts toxic to lettuce. Aqua ammonia and urea fertilizers are much more likely to induce symptoms than are ammonium nitrate, sulfate, or calcium nitrate. Manures, especially chicken manure, may also produce injury during decomposition. Ammonia injury is sometimes associated with cool, waterlogged, and compacted soil. High ammonia concentrations near the plant roots will dehydrate the roots. Warm, aerobic conditions are necessary for the nitrification of ammonium into the usable nontoxic form of nitrogen.

Free ammonia damages roots, killing small root hairs and lateral roots. Larger roots are usually not killed completely, but they exhibit degrees of yellowing or browning, rifting, or corking that may be confused with corky root disease. These symptoms may occur in isolated portions of the root near the zone of fertilizer application or they may involve most of the root system. Yellow, red, or brown discoloration of the central xylem core of the root often occurs. In severe cases, xylem tissue may collapse. Aboveground symptoms are those typically associated with root injury: temporary wilting of leaves and dull, dark green or gray green leaves. Yellowed V-shaped sectors may develop on leaf margins and later turn brown.

To prevent ammonia injury, carefully place ammonium forms of nitrogen fertilizers keeping them out of the seed row or where roots may touch them. Also, make regular leaf analysis tests for nitrogen and avoid overfertilizing.

Herbicide Injury

Cole crops or lettuce can be damaged by herbicides that are applied to the crop, remain in the soil as residues from a previous crop, or drift in from neighboring fields or borders. Affected plants may occur in a discernible pattern: at the field edges from herbicides drifting in from neighboring crops or field borders; in distinct lines or rows where residues from a previous crop or application have failed to decompose; or in rows that were treated twice by mistake; or they may occur generally throughout the field if too high a rate or an inappropriate material is applied.

When using an herbicide for the first time or trying a new crop cultivar, leave part of a row untreated to detect phytotoxic effects in the rest of the field. This will also demonstrate weed control effectiveness.

Many herbicides can cause spotting or yellowing of leaves or distortion of growth that can be confused with symptoms caused by pathogens or nutrient deficiencies. To identify an herbicide injury, you may require a laboratory to analyze soil, water, or plant tissue for residues; this is easier if you can tell them what material was applied. One limitation of laboratory analysis is that the presence of an herbicide residue does not necessarily prove that it caused the injury. Farm advisors and professional consultants can help in identifying these problems.

Avoid herbicide injury by following directions on labels and by making sure before planting that the soil and water do not contain harmful residues.

Insecticide Injury

Organophosphate insecticides can produce a distinctive injury on lettuce. Young plants up to and just beyond the thinning stage are most susceptible. Plant growth is distorted; leaves are twisted and thickened, and the shoot apex may be deformed or distorted. Unless severely damaged, young plants usually continue to grow and produce normal appearing heads. Yield loss may occur, even when visible symptoms are not apparent, so limit insecticide treatments to times when monitoring and management guidelines indicate a need for treatments. No information is available on insecticide injury to cole crops.

Nutrient Deficiencies

Nutrient deficiencies may be caused either by low amounts of nutrients in the soil or by conditions that reduce the plant's ability to absorb them. Root damage, excessive water, water stress, too high or too low temperatures or soil pH, or other nutrient imbalances may contribute to a plant's inability to obtain adequate amounts of one nutrient. Symptoms often include slow growth, chlorosis, change in leaf color, or spotting of leaves. A few more common deficiencies are described here. Tipburn of lettuce and cabbage, described previously, is also related to a deficiency of the nutrient calcium within the plant tissue.

Often it is not possible to correct nutrient imbalances in the soil once plants are established, although nitrogen may be added if the deficiency is identified early. To avoid deficiencies, regularly sample soil and plant tissue for deficiencies (see page 20).

Nitrogen. Most growers add enough nitrogen each time they plant a crop so that nitrogen deficiencies are not common. Deficiency symptoms are not very distinctive. Plants yellow, starting with the older leaves, and overall growth is reduced. Nitrogen deficiencies are sometimes seen when cool and waterlogged conditions reduce the plant's ability to take up adequate amounts of nitrogen and other nutrients.

Phosphorus. Plants deficient in phosphorus are stunted and often have a purple cast, especially in the lower leaves. Curds of flowering stalks of cole crops may be spindly. Deficiency symptoms most frequently occur during cold periods when temperatures are below 50° F (10° C) because plants have greater difficulty taking up phosphorus in cold weather. However, cold temperatures alone can also cause purpling.

Molybdenum. Molybdenum deficiency symptoms are occasionally seen in cauliflower growing in acid soils. Foliage of affected plants is straplike consisting of a midrib with a very thin blade; it is brittle and usually curled up. Symptoms in cauliflower are sometime called "whiptail."

Nematodes

Nematodes are important soil-inhabiting pests in California. Of the many plant parasitic nematodes found in soils in vegetable-producing areas, only two—the cyst nematodes (genus *Heterodera*) and the root-knot nematodes (*Meloidogyne*)—warrant careful consideration in cole crop pest management.

In lettuce, root-knot nematodes are the only species known to cause economic damage in most areas. However, the needle nematode, *Longidorus africanus*, causes damage in the Imperial Valley. Stunt nematode (*Merlineus*) and spiral nematode (*Rotylenchus*) have been associated with reduced growth of lettuce in the central coastal districts, but direct proof of pathogenicity has not been made. Other commonly found nematodes, such as pin (*Paratylenchus*), lesion (*Pratylenchus*), stubby root (*Trichodorus* and *Paratrichodorus*), ring (*Criconemoides*), and dagger (*Xiphinema*), have not been generally associated with reduced growth of these crops. However, seek professional advice if high populations of any one species of plant parasitic nematodes appear.

Root-knot nematodes are widespread in California, but they tend to be associated with crop injury mostly on coarse-textured soils, where they can usually be effectively managed with soil fumigants. Because root-knot nematodes have a wide host range, rotations that are effective against them are usually difficult to select from desired cropping sequences.

Cyst nematodes are widespread throughout California's cole crop and sugarbeet growing regions. They present a greater management problem to cole crop production than do root-knot nematodes because they can severely damage the crop on any soil type. Cyst nematodes' limited host range allows management through crop rotation, but they are less amenable to chemical control, particularly on fine-textured soils. Under optimum conditions, however, chemical control costs can be justified with improved yields.

Cyst Nematodes
Heterodera spp.

Two species of cyst-forming nematodes are pests of California's cole crops. The sugarbeet cyst nematode, *Heterodera schachtii*, is widely distributed, but it mostly troubles production areas where sugarbeets are also grown—especially when beet crops are rotated with cole crops. Other crops commonly attacked by the nematode and listed in Table 10 include spinach, beets, and turnips. The cabbage cyst nematode, *Heterodera cruciferae*, also called the Brassica cyst nematode, has a limited, but unsurveyed, distribution centered in San Mateo County's Half Moon Bay region. The crop host range of this pest is limited to cole crops; it sometimes occurs in the same

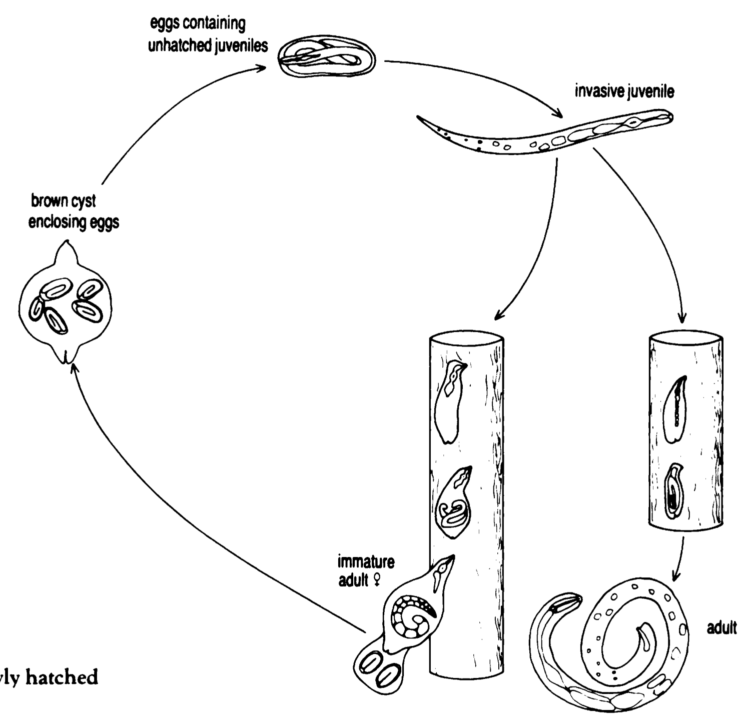


Figure 18. Life cycle of the cyst nematodes. All stages except eggs, newly hatched juveniles, and adult males occur within the roots of the crop.

field in mixed populations with the sugarbeet cyst nematode. Life histories, damage, and basic biology of the two species are similar; only their host ranges differ. A professional laboratory should identify the casual nematode because rotation options differ. Management of the sugarbeet cyst nematode in sugarbeets is discussed in detail in University of California Agriculture and Natural Resources publication 3272, *Sugarbeet Pest Management: Nematodes* (see References).

Table 10. Hosts of Sugarbeet Cyst and Cabbage Cyst Nematodes.

HOSTS
broccoli
brussels sprouts
cabbage
cauliflower
kale
mustard
rape
Chinese cabbage
sugarbeet[a]
fodder beet[a]
red beet[a]
rutabagas
spinach
turnip

[a] Beet crops are attacked only by sugarbeet cyst nematode; they do not host the cabbage cyst nematode.

Description and Biology

The cyst nematode life cycle (Figure 18) begins with hatching of the invasive second-stage juvenile from the egg. Water is required for hatching, and host root exudates diffusing into the root zone increase the percentage of eggs hatching. The juvenile migrates through the moist soil to penetrate plant roots, mainly behind root tips and at lateral root junctions. The young nematode begins to feed, secreting substances that cause enlargement of root cells and breakdown of cell walls. A large "transfer cell," from which the developing nematode withdraws nutrients, forms next to the root's conducting tissue. The juvenile continues to draw nutrients from the transfer cell, swells, and molts through the third and fourth juvenile stages to become an adult male or female. The adult female enlarges and ruptures the root cortex; females are visible as white, pinhead-sized bodies on the root surface. After maturing, the worm-shaped adult male leaves the root to copulate with females on the root surface.

After fertilization, the female secretes a gelatinous egg sac at her posterior, but she retains most eggs within her body. The female dies and her body wall forms a tough brown protective cyst containing up to 600 eggs. The cyst may detach from the roots or remain attached to root fragments after crop destruction. The enclosed eggs can remain viable in the soil for several years. Approximately 40% to 60% of the eggs hatch each year during suitable temperature and moisture conditions. Newly hatched juveniles die if host plant roots are not available, especially during warmer months.

The sugarbeet cyst nematode is adapted to a wide soil temperature range and can survive in freezing soil as well as surface soil that may reach 120° F (49° C) and above in the Imperial Valley. These nematodes reproduce best at 70° F (21° C) to 81° F (27° C), but reproduction can occur at any temperature between 50 to 90° F (10 to 32°C). Temperature requirements of the cabbage cyst nematode have not been studied in detail, but it may have a more limited range since it is found mostly in California's cooler coastal areas. Temperature, time of planting, and length of season determine the number of generations completed in one season. One generation can be completed during the long, cool winter growing season, and probably one to two generations occur on the short season cole crops in spring and summer. Up to three generations of the sugarbeet cyst nematode may occur on a sugarbeet crop in coastal and Central Valley regions.

Population levels of cyst nematodes are highest following summer host crops and decrease during winter if susceptible crops are not grown. Sugarbeet cyst nematode population levels decline by 50% to 60% annually in the absence of a host crop.

Cyst nematodes occur in a wide range of soil types, including sands, sandy loams, loams, silty clay loams, clay loams and clays, muck and peat soils. Nematodes will damage crops in any of these soils. In the Salinas Valley and coastal Oxnard plain, heavy infestations are especially prevalent on clay loam soils.

Injury and Field Symptoms

All cole crops and cruciferous plants in general are susceptible to cyst nematodes. Brussels sprouts are the least tolerant to infection, followed by cabbage and broccoli. Cauliflower appears slightly more tolerant than do the other cole crops. However, heavy cyst nematode infections can greatly reduce yields of all crops. Little information is available on differences in cultivar susceptibility.

The nematodes impair the root system, preventing the plant from obtaining the amounts of water, nutrients, and minerals needed for normal top growth. Seedlings are most vulnerable to damage because they lack a strong root system. However, heavy infestation of established plants can also reduce yields.

Aboveground symptoms consist of patches of stunted or dying plants. In newly infested fields, affected areas are often small and go undetected. As the infestation increases and spreads in subsequent years, affected patches enlarge and coalesce so that large areas within a field may show severe symptoms. The infested areas resemble those damaged by waterlogging, poor soil conditions, or mineral and nutrient deficiencies. Foliage may become pale and then yellow, and weeds often smother the stunted plants. Infected plants wilt when stressed, especially on hot, dry days or under conditions of low soil moisture. Heads and curds of affected plants are reduced in size, and cabbage heads may be less firm than normally.

To confirm that damage is caused by cyst nematodes, dig up the affected root system. The nematode may stimulate production of more lateral or feeder roots than normally, but this symptom is not reliable. A diagnostic symptom is the presence of the cyst nematodes themselves. Check the root surface, preferably with a hand lens, for the white, lemon-shaped females and the brown cysts. Females or cysts may occur singly on a root or close together, aligned side by side, usually on the lateral roots. Cyst nematode does not cause formation of visible galls on the roots.

Root-Knot Nematodes

Meloidogyne spp.

Of the several root-knot nematode species that occur in California, the four most commonly found in cole crop and lettuce growing areas are *Meloidogyne incognita*, *M. javanica*, *M. arenaria*, and *M. hapla*. Life histories, damage symptoms, and basic biology of all species are similar, although *M. hapla* is generally adapted to cooler temperatures than are the other species and is more common in the cooler coastal and northern areas. Species identification is currently only of practical value when choosing nonhost crops or resistant varieties to use in rotation. For instance, some tomato varieties are resistant to all root-knot species except *M. hapla*. However, because of their wide host range, root-knot nematodes cannot normally be economically controlled with rotation in vegetable growing areas.

Description and Biology

The root-knot nematode's life cycle (Figure 19) is similar to that of the cyst nematode. The major difference is the lack of the egg-containing cysts. Root-knot eggs are deposited mostly in a gelatinous egg mass extruded by the female, usually on or just below the root surface. After the female dies, the eggs remain in the soil or in root fragments. When environmental conditions are favorable, second stage juveniles hatch from eggs and enter roots near the root tips or at lateral root junctions. Substances secreted by root-knot nematodes during

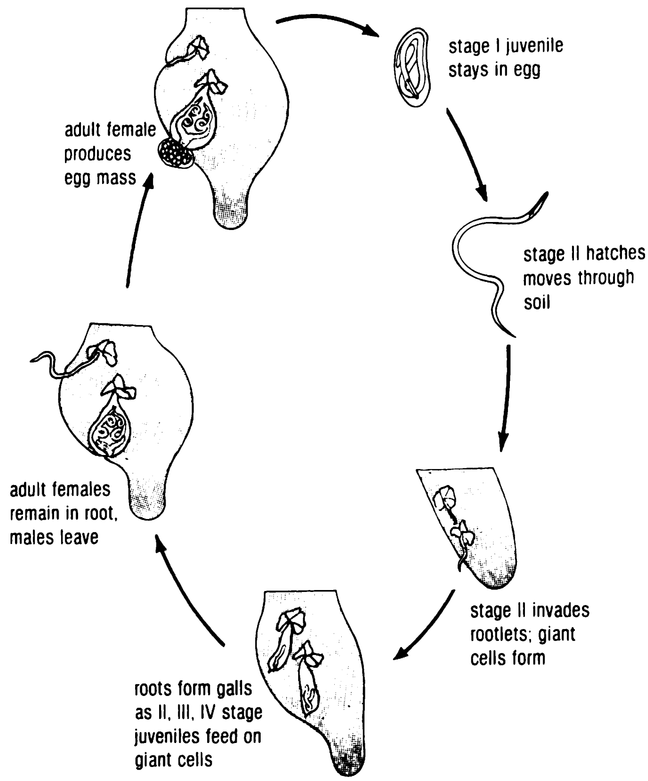


Figure 19. Root-knot nematodes spend most of their life cycles in galls on roots. Second stage juveniles invade new sites, usually near root tips, causing some root cells to grow into giant cells where the nematodes feed. As feeding continues, the plant produces a gall around the infected area.

feeding stimulate growth of plant cells and formation of galls. In contrast to most cyst nematode species, adult root-knot females do not break through the root surface, and their bodies, with the exception of the egg mass, are contained within the gall. Like cyst nematode males, root-knot males do not feed and do not affect plant health. However, they are a positive indicator of root-knot presence in soil samples.

The nematode may have several generations during summer, when juveniles take only 2 to 3 weeks to develop into egg-laying adults. In winter, one generation may require several months. Populations of each root-knot species may adapt to different temperature regimes in different localities. In southern coastal California, invasive, second-stage juveniles of *M. incognita* do not penetrate roots and are inactive at soil temperatures below 64° F (18° C). However, they can survive in the soil longer in the cooler winter temperatures than in summer. Juveniles that penetrate roots in autumn before temperatures drop below the activity threshold can develop in roots providing temperatures exceed 50° F (10° C). *Meloidogyne hapla* is adapted to slightly lower temperatures than other root-knot species.

Females of cyst nematodes are visible as white bodies on the root surface.

The white body at left is a sugar beet cyst nematode female, and the brown cysts to the right contain eggs of the nematode.

The galls on these roots indicate that this lettuce plant is heavily infested with root knot nematodes.

JOHN RADEWALD

Needle nematodes prune lettuce root tips, often causing lateral roots to become swollen at the tips or to branch.

Egg and juvenile numbers in the soil are generally highest in the autumn and early winter following summer reproduction. Numbers may decline by 90% between autumn and spring if no host plants are in the field. Populations are usually lowest in spring and early summer under most annual cropping situations. However, a significant portion of eggs can survive for 2 years or more if conditions do not favor development.

Root-knot nematodes occur in a wide range of soil types, but they are most common in coarse-textured sandy, loamy sand, and sandy loam soils. Plant damage is often accentuated in sandy fields or sand patches or streaks because water and nutrients are often more difficult for the damaged roots to obtain in these soils.

Injury and Field Symptoms

Root-knot nematodes cause distinctive galls to form on roots. Checking roots of damaged plants for galls is the best way to detect nematodes in the field. Galls formed by M. *hapla* are spherical, beadlike, and discrete, whereas other species may produce galls more irregular in shape and often contiguous. If you cut open galls, you may see the mature females as tiny—no more than 1/16 inch (1.5 mm) long—white "pearls" within the gall tissue.

Gall formation damages the root xylem tissue, interfering with the flow of water and nutrients to the plant and causing aboveground symptoms similar to various disorders, including infection by cyst nematodes. Plants infected as seedlings are stunted, and patches of stunted plants are commonly evident by midseason. Infected plants may wilt under temperature and moisture stress. Heavily galled roots are open to secondary infections, especially by root-rotting fungi, which can compound damage.

Lettuce, brussels sprouts, cabbage, broccoli, and cauliflower are all susceptible to root-knot nematode attack and can sustain significant yield reductions when heavily infested. Cauliflower curd maturity may be delayed by a few days. Although small increases in growth of cabbage and cauliflower may be stimulated by light M. *hapla* infections, growth reduction occurs at increasing population levels. Cabbage is more tolerant than cauliflower to M. *hapla* attack, but there is little data comparing the four main cole crops or other *Meloidogyne* species, and all crops should be regarded as equally susceptible.

Needle Nematode
Longidorus africanus

The needle nematode, a pest on lettuce in the Imperial Valley, is an ectoparasitic species that feeds only on root tips, never entering the root. Many field and vegetable crops host it, allowing reproduction and population increase. Hosts include corn, sorghum and small grains, bermudagrass, cotton, sugarbeets, beans, cucurbit crops, okra, tomato, eggplant, spinach, and carrot. Damage to carrots and lettuce and sugarbeet seedlings has been observed, but its pathogenicity to most other crops is unknown. Needle nematodes do not show a soil texture preference and are found in soils ranging from clay loams to sandy loams.

Female nematodes lay eggs in the soil near plant roots. Second stage larvae hatch from eggs and go through three more molts before becoming adults. All juvenile stages and adults feed in the same manner, although no feeding occurs during molting.

Needle nematode feeding inhibits main root growth and elongation. Lateral roots often proliferate to compensate for loss of some main root growth. In large numbers the nematodes will cause the root system to branch and become shortened. Root tips often die with the region just behind the tips swollen and distorted and the number of functional feeder roots reduced.

At seedling emergence, most seedlings may show symptoms or affected seedlings may be scattered throughout an area. Cotyledons cup downwards, as though they were wilting, even when there is ample moisture. Leaves may be grayish green with the outer margins chlorotic. Damage to early and late fall plantings can delay maturity and reduce head size. An extra harvest may be required to compensate for lack of uniform growth.

Management and Sampling Guidelines for Nematodes

Qualitative Sampling

A qualitative sample is taken to determine the presence of nematodes and their distribution in the field. The simplest qualitative sampling procedure is to pull up plants in different areas of the field and examine their roots for galls, cysts, or swollen root tips. Choose particularly those plants showing signs of comparatively poor or erratic growth and stress. Sandy soils should be regularly monitored for root-knot infestations in this way. Sampling is best carried out between mid- to late season when nematode populations would have built up and galls or cysts are obvious on roots. However, the root stunting and root tip swelling caused by needle nematode on lettuce is usually detected in seedlings.

Other host crops grown in rotation with cole crops or lettuce can indicate nematode presence. For example, check sugarbeet roots to determine whether a more detailed quantitative sampling is necessary before deciding on a cole crop, lettuce, or some other crop for the next planting. Sugarbeets can host root-knot nematodes and sugarbeet cyst nematode, but they are not a host for the less widely distributed cabbage cyst nematode. Most of California's summer grown annual crops are hosts to one or more root-knot nematode species and can be used as indicators. Host crops for both cyst nematodes on cole crops include broccoli, brussels sprouts, cabbage, cauliflower, kale, mustard, rape, Chinese cabbage, rutabagas, spinach, and turnip.

Some sugarbeet processors perform a dump sample survey for sugarbeet cyst nematode on sugarbeets arriving at the factory. Results can provide information on cyst nematode infestations to growers who produce cole crops on sugarbeet land. (For more details on dump sampling and other sampling techniques, see University of California Agriculture and Natural Resources publication 3272, *Sugarbeet Pest Management Series: Nematodes.*)

Quantitative Sampling

The purpose of quantitative sampling is to determine whether the number of nematodes is sufficiently high to cause yield loss or what management procedures, if any, are needed. Take a quantitative sample if you detect an infestation with qualitative sampling or if the field or adjacent areas have a history of nematode infestation.

Sample well in advance of planting to allow for sample analysis before a decision must be made on chemical treatment or rotation. Sample in autumn for winter and spring planted crops so that fields can be fumigated in autumn if necessary.

Divide the field into identifiable subareas or blocks of up to 5 to 10 acres (Figure 20). Delimit blocks according to such factors as soil texture differences, previous areas of poor growth, or cropping history. Background information is important in interpreting sample results, so provide it to the laboratory accepting your samples. If the field or parts of the field are uniform, apply a grid pattern to subdivide into blocks no smaller than 10 acres.

Take one composite sample from each block. The composite sample should consist of a mixture of 15 to 20 individual cores or subsamples taken uniformly throughout the block. To sample for root-knot nematodes or invasive second stage juveniles of the cyst nematode, use a soil core tube and take the required subsamples in moist soil to a depth of 18 inches. Cyst nematode cysts and eggs can be sampled in surface soil after cultivation. Use a spoon or scoop on a long handle to sample at 15 to 20 sites throughout the block. Collect the cores or scooped soil in a bucket as you walk through the block. After collecting all the samples, mix them thoroughly, and remove a 10- to 35-ounce (300- to 1000-gram) composite sample to send to the laboratory for nematode extraction.

Keep samples at 40° to 60° F (5° to 15° C). Never store them below 35° F (2° C) or above 90° F (35° C) or allow them to sit in the sun or in a hot car. Place them in a strong plastic bag to keep them moist. Tie a label to the outside of the bag and list (in pencil) the date, grower's name, field name, and block location. A field map showing the blocks is a useful reference. Transport samples from field to laboratory in an ice chest, or send them via a dependable delivery service in a sturdy, insulated, cardboard box.

A number of private commercial laboratories provide nematode diagnostic services, and some also provide field sampling services. Laboratories vary in the service they offer and in the techniques and methods used for sampling or extracting nematodes. Most laboratories process potential nematode samples using extraction methods that detect only the worm-shaped, invasive juveniles and males of cyst nematodes and the worm-shaped stages of root-knot nematode, needle nematode, and other nematode species. Few laboratories use the very efficient flotation can procedure required to assay cysts and eggs of cyst nematodes; current treatment thresholds require egg counts for cyst nematodes. Be sure the laboratory notes the extraction method when it returns its analysis. Some laboratories interpret the analysis; if yours does not, ask your farm advisor to help you interpret the results. (A directory of commercial laboratories is listed in References at the end of this manual.)

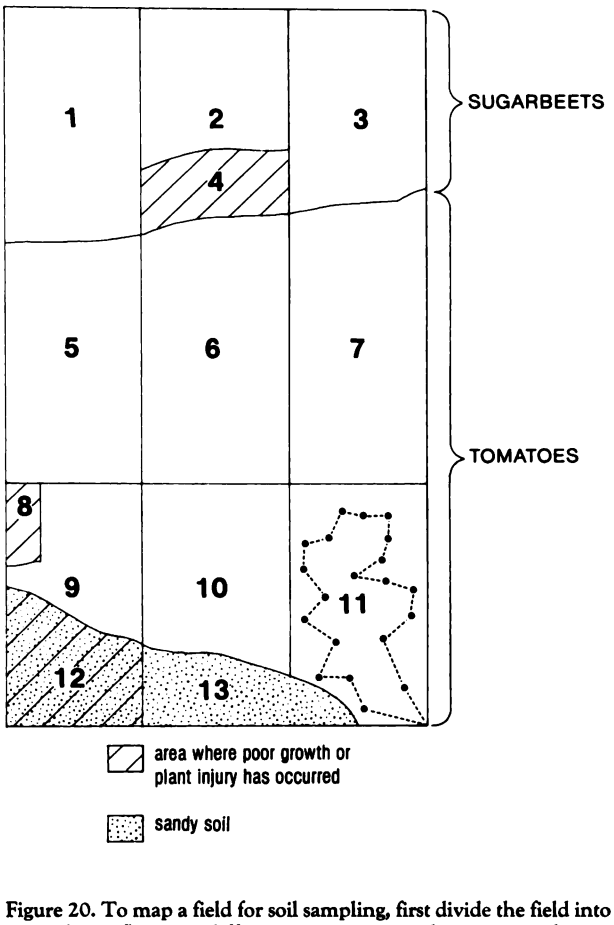


Figure 20. To map a field for soil sampling, first divide the field into areas that reflect any differences in cropping history or soil type. Subdivide these areas into blocks not larger than 10 acres. If there are any areas where there has been poor growth, treat them as separate blocks, even if these blocks are much smaller than the others. Assign each block a number, and take a series of soil samples from each one, following a random pattern that covers the entire block, as shown in block number 11.

Treatment Guidelines

Although information is not available to correlate nematode population levels with expected yield loss in cole crops and lettuce, some general guidelines can help you make management decisions based on soil analysis results.

Cyst Nematodes. For cyst nematodes, two to four eggs per gram of soil can be used as a rough guideline for a cyst nematode damage threshold on cole crops in coastal and central valleys and one egg per gram in the Imperial Valley. Nematode numbers above these levels, when samples are taken in autumn, would indicate that an extended rotation or nematicide treatment is required before planting susceptible crops. Numbers below these levels indicate that no controls are needed before planting. Use these treatment thresholds for general guidance only. They are the same treatment thresholds recommended for cyst nematodes in sugarbeets in the same areas. No damage data are available in California to develop definitive thresholds for cole crops. Research in Ontario, Canada, and New York state indicates that the threshold for cyst nematode in these cooler areas is six eggs and juveniles per gram of soil in both direct-seeded and transplanted cabbage.

Winter cole crop plantings along the coast will be more tolerant to cyst nematode attack. Spring and summer plantings will suffer more damage with the same nematode population levels.

Root-knot Nematodes. Damage threshold estimates for *Meloidogyne* species are unavailable. In general, where root-knot nematodes are detected on sandy, loamy sand, and sandy loam soils, or where high numbers are found on any soil type, a nematicide treatment is advisable, especially in spring and summer plantings. If soil sampling indicates that only certain areas of a field are infested, where practical, fumigate these areas without treating the whole field; spot fumigation minimizes overall treatment cost per acre.

Needle Nematodes. No treatment guidelines are available for needle nematodes, but observations suggest that a treatment should be considered whenever this nematode is present in soil samples before lettuce is planted in the Imperial Valley. Treatment is especially critical for fall plantings when soil temperatures are high and favorable to nematode activity.

Management Methods

Sanitation

Nematodes do not disperse rapidly on their own, and undisturbed populations spread slowly. However, the egg stages of both cyst nematodes and root-knot nematodes are readily transported by agricultural equipment, soil movement, and water. Infested soil adhering to machinery can introduce infestations into different parts of the same field, into different fields, and even into different regions. Thoroughly cleaning all equipment used in an infested field with high pressure water or other suitable methods is essential to prevent spreading the pests.

Because dry cysts float in water, cyst nematodes can spread during furrow and flood irrigations. Don't allow tailwater from an infested field to recirculate in irrigation water without impounding; cysts transported in this manner can be redistributed throughout an irrigation district. Don't allow livestock to graze on infested fields after harvest because cysts can be spread on animal hooves and can survive passage through the alimentary tract of cattle.

Cultural Tactics

Infected plants can sometimes be brought to harvest with careful fertilizer and water management. Sprinkler irrigation is better than furrow for supplying water to the small, stunted root systems of damaged plants. However, if severe damage symptoms are evident over extensive areas early in the season, the crop may have to be disced under and the field either replanted after fumigation or planted to a nonhost crop. Always plough or disc under infected harvested plants as soon as possible to prevent more nematode reproduction.

Resistant Cultivars

No cultivars resistant to any of the pest nematodes are available for cole crops or lettuce. Future research may change this situation, so stay abreast of cultivar breeding developments.

Crop Rotation

Crop rotations effectively manage cyst nematodes, which have limited host ranges; any crop that is not a host (Table 10) can be used. Cyst nematode populations decline by about 50% per year in fields planted with nonhost crops. If you know the field population at the beginning of a rotation, you can determine the approximate number of years required to reduce the nematode to an economically acceptable level. Usually 3 to 5 years between host crops are necessary. Resample at the end of the rotation to assure adequate population reduction. Good weed control is essential because many weeds are nematode hosts and will maintain population levels during the nonhost rotation.

Root-knot nematodes have wide host ranges among both annual and perennial crops, making them difficult to control. Only such grain crops as wheat, barley, corn, oats, and rice are not susceptible; use of these crops may be difficult to work into a feasible rotation in most lettuce and cole crop growing areas. However, strawberries, a crop that is fumigated annually, may be suitable for growing before cole crops or lettuce. Rotation cannot be used to manage needle nematodes because their host range includes most crops grown in the Imperial Valley.

Chemical Control

Fumigation of Seedbeds for Transplants. Nematode-free seedbeds for transplant production can be prepared by fumigating with methyl bromide and chloropicrin under a plastic tarpaulin. Methyl bromide is most effective at soil temperatures between 40° and 75° F (5° and 25° C). Autumn treatments, where possible, are suggested.

Preplant Fumigation. Preplant treatment of fields will control root-knot, cyst, and needle nematodes. However, recent regulatory actions have limited fumigation choices. Check with your local Cooperative Extension office for currently available materials and best application procedures. In addition to dosage rate, several factors determine the effectiveness of fumigation: timing, mode of application, soil type, soil moisture, soil temperature, soil compaction, and nematode population level. Control is easier on coarse-textured, sandy soils with low water-holding capacity than on fine-textured, clay loam and clay soils. Dispersal of the fumigant in fine soils is often limited because pore spaces remain filled with water for a longer time after rain or irrigation. Cold, wet soils are especially difficult to treat for this reason. Compacted soil layers can also limit fumigant movement and the amount of fumigant reaching a substantial portion of the nematodes.

Root-knot nematode problems are mostly associated with coarser textured soils, so they can usually be controlled by fumigation. However, cyst nematodes occur in a wide range of soils, and about five times more fumigant is required to kill eggs in cysts than second stage juveniles or root-knot nematodes. For this reason, fumigants for cyst nematode control should be used at the highest recommended rate for the soil type.

A fumigation or rotation may only adequately reduce nematode populations for one season. Neither measure controls the population entirely, and the population may resurge to damage levels rapidly, especially when low numbers are evenly dispersed throughout a field after fumigation or rotation. For example, population levels of cyst nematode on successfully fumigated land can be as high by harvest time as they would be on nontreated land. Always check population levels in infested fields before planting a susceptible crop.

Vertebrates

Mammals are not commonly major pests in cole crops and lettuce, but birds often affect them. Of the major bird species horned larks, house finches, and crowned sparrows are the most troublesome, reducing stands of direct-seeded crops by feeding on seeds and newly emerged seedlings and injuring transplant seedlings grown in unprotected seedbeds. White-crowned sparrows will also damage maturing lettuce or cole crops plants during winter. Meadow mice occasionally damage cauliflower, brussels sprouts, and other cole crops. Ground squirrels, jackrabbits, rabbits, gophers, and deer are sporadic pests.

Managing vertebrate pests requires anticipating problems and establishing a strategy well in advance. The first step: Survey the land surrounding the field. Few vertebrate pests live year-round in plowed fields, so most infestations begin in nearby crops, pastures, natural habitats, or in weedy fencerows and ditchbanks.

Some vertebrates that damage crops are protected by law; you may need special permits to control them (Table 12). It is important to identify vertebrates correctly to choose suitable control measures and avoid killing protected species. Ask local agricultural commissioners, farm advisors, or experienced pest control advisors for help in identifying pest species.

Poison baits are often used to manage vertebrates. Bird baits are usually single dose toxicants, but rodent baits may be either single or multiple dose. A single dose or acute poison kills an animal after a single feeding; a multiple dose poison usually kills an animal only after several feedings over a period of days. Single dose baits can be cheaper to use, but they are more acutely poisonous, so more care is needed to avoid killing domestic animals and other nontarget species. Some single dose poisons produce bait shyness in rodents that learn to associate the bait with sickness; prebaiting with untreated grain may be necessary to avoid this problem. Most multiple dose baits are anticoagulants that kill animals by causing internal bleeding; they are not as likely to produce bait shyness. A disadvantage of multiple dose poisons is that they often require more than one application and take longer to control the pest.

House finches have stubby bills and dark streaks on their bellies. Males have orange coloring on the breast, head, and at the base of the tail.

Crowned sparrows can be distinguished by the prominent white stripes on their heads.

Other methods available for managing vertebrate pests include habitat modification, trapping, exclusion, shooting, fumigation, and using visual or sound repellents against birds. Most of these methods, including baiting, are most effective if used in combination with other methods and in conjunction with a monitoring program directed at early detection of invading vertebrates. Contact your county agricultural commissioner well before planting to find out what methods are available for controlling vertebrate pests in your area and what permits may be necessary; getting the permits before the pests appear will save valuable time later. Predators, such as hawks, owls, coyotes, weasels, badgers, and snakes, feed on vertebrate pests, but they rarely prevent populations of pest species from causing economic damage.

Table 12. Legal Status of Vertebrate Pests.

Species	Legal Status and Restrictions
Meadow mice	No legal protection.
Ground squirrels	No legal protection.
Pocket gophers	No legal protection.
Brush and cottontail rabbits	Classified as game mammals by California Fish and Game Code; there are seasons and bag limits for sport hunting. May be killed at any time if injuring crops, but *poison bait may not be used* and traps must comply with Fish and Game regulations.
Jackrabbits	Classified as game mammals by California Fish and Game Code; hunting season is all year with no bag limit. When injuring crops, jackrabbits may be killed in any manner.
Deer	Classified as game mammals; a depredation permit is required for shooting. Poisoning of deer is illegal.
Blackbirds	Classified as migratory birds under federal law. May be controlled when damaging or likely to damage crops.
Horned larks, house finches, and crowned sparrows	Classified as migratory birds under federal law. May be controlled when necessary to protect crops from depredations. In California, control must be supervised by the county agricultural commissioner.

Birds

Birds can reduce stands in direct-seeded lettuce and cole crop fields by feeding on seeds and young seedlings. Seedlings may be nipped off, or small holes may remain in the soil where the seedling was pulled. They may also damage plants being grown in seedbeds for transplanting if they are not adequately protected. Most damage occurs before seedlings have two or three true leaves, although crowned sparrows may occasionally damage mature plants nearing harvest.

The most important bird pest in lettuce and cole crops is the horned lark, *Eremophila alpestris*. Two other important species are the house finch or linnet, *Carpodacus mexicanus*, and crowned sparrows, *Zonotrichia* spp. Blackbirds and some other bird species also occasionally cause damage. Watch for birds while seedlings are growing and be ready to act as soon as you see them causing damage.

Horned larks are about 6 to 7 inches (15 to 18 cm) long—smaller than robins but slightly larger than sparrows. They are brown to gray with a distinctive pattern of yellow, black, and white bands on the face and throat. Their black tail feathers are visible in flight. Their name comes from the small tufts (or horns) of erect, dark colored feathers behind the eyes of mature males. Horned larks, hard to see in the field because their colors blend with the soil, usually fly low. Some experience is needed to recognize them from a distance. Horned larks tend to walk rather than to hop as do house finches and sparrows.

Horned larks occur throughout California; living mainly in open grasslands where they feed on seeds of wild plants and on insects. They may move into lettuce or cole crops when natural forage is scarce or when these crops are planted close to a favorable habitat. Horned larks feed in flocks of about a dozen and can create bare spots in a few hours. They tend to feed well out into the field and do not concentrate along fence rows or wooded areas. In contrast, house finches, crowned sparrows, and blackbirds work the edges of the field.

House finches are small, gray brown birds with stubby bills and narrow dark streaks on the belly and flanks. They are about the size of a house sparrow. Mature males have red or orange coloring on the breast and head and at the base of the tail. Females and immature birds lack the red color. House finches will nest in a great variety of habitats. Although they feed primarily along field edges, they are often seen in open areas and tend to scatter to high open perches when alarmed. Unlike many bird species, house finches usually stay in a relatively local area, often traveling no distance greater than a few miles during the year.

Crowned sparrows are migratory birds and reside in the lettuce and cole crop growing regions of California primarily in fall, winter, and early spring. They spend their summers and breed further north. Crowned sparrows not only damage seedlings, but they feed on maturing plants as well. Damage to lettuce heads will make produce unmarketable. In cole crops, feeding is restricted to leaves, but bird feces often contaminate the heads. Crowned sparrows prefer sheltered areas of deep brush or dense weeds; most of their damage occurs along field edges close to such cover. Crowned sparrows can be distinguished by their gray breasts and prominent white stripes on their heads.

Management Guidelines

Monitoring. Watch the field closely from emergence until plants are beyond the three-leaf stage. Check the field every day at dawn and at dusk, when birds are most likely to be feeding. Use binoculars to identify birds from a distance. Also look for crowned sparrows and house finches in neighboring weedy or brushy areas. After some experience, you may learn to recognize horned larks by their high pitched, distinctive songs; they often sing while flying. Male house finches also may sing during breeding season. The most serious time for damage in most areas is during winter and early spring, when few sources of other food are available. However, damage may occur at any time of the year. For instance, horned larks often heavily damage seedling lettuce in late summer in Kern County.

Habitat Removal. Eliminating their cover can be the most important factor in controlling crowned sparrows. Remove all weedy borders along fields and fencerows. Where possible, remove shrubs and brushy areas adjacent to fields. Because crowned sparrows will not feed more than a few yards from safe cover, elimination of these bird harbors may be all that is needed to manage the problem.

Removal of large brush piles, stacks of boxes, windbreaks, or other sheltered areas will limit nesting and resting areas for house finches. When these sites are removed, the birds are likely to spend less time in the area, although they are not as timid as crowned sparrows and will feed in areas some distance from shelter.

Horned larks do not require sheltered areas for nesting or resting, so habitat modifiction is not effective.

Scaring Birds from Fields. It may be possible to protect seedlings in small fields by stationing someone to scare birds away. Shell crackers or shotgun noise often helps. Shotgun patrol is not usually practical in larger fields because birds get used to this activity and move only a short distance when frightened, instead of leaving the field.

Such mechanical noisemakers as gas cannons are not very effective in scaring horned larks or house finches, but they may be useful for blackbirds. For best results, frequently change the timing of the noises and the position of the devices to make the sound as random as possible. Noisemakers are more effective when combined with an occasional shotgun blast in the direction of the birds. Like other kinds of repellents, noise works best when it is used before damage occurs. Once birds have established a feeding pattern, it is hard to force them to change it.

Some growers have used helium-filled balloons with hawk-shaped kites suspended from them to scare birds away from their fields. Balloons and kites should be moved to a new part of the field each day. Little experimental information is available on their effectiveness. In many cases they have not been effective. If used, they should be used in combination with other bird deterrents.

Use of Transplants. Because cauliflower and brussels sprouts are commonly transplanted, they are not usually damaged by birds; transplanted broccoli and other cole crops are similarly unaffected. Growers could consider plug-planting lettuce seedlings to limit bird damage as well. Protect seedbeds for transplants with wire mesh, bird netting, or other covering to keep birds away.

Baiting. Baits are the most effective control available for birds. Contact your county agricultural commissioner for help in finding a source of bait; commissioners in most vegetable-growing counties provide baits for certain uses. Legal baits and local regulations concerning bird control vary from county to county. Baits for horned larks, house finches, crowned sparrows, and other legally protected birds can be used only when the birds are actually damaging crops and must be used under the supervision of the county agricultural commissioner. Although permits can be completed in advance, the commissioner must verify that the birds are causing damage before he can allow you to control them.

Put out baits in early morning. Place bait in furrows in central portions of the field for horned larks and in

Horned larks get their name from the small tufts (or horns) of erect, dark colored feathers behind the eyes of mature males.

troughs at the field edges for other species. Always prebait furrows or troughs with untreated bait to encourage acceptance before putting out treated bait. Five to ten days of prebaiting are recommended to be sure the whole flock will actively feed, so the procedure should begin as soon as you know that bird depredations will occur. In some cases, such as a field surrounded by other fields where damage is occurring, prebaiting may even begin before crop emergence. Although plants are only vulnerable for 2 to 3 weeks after emergence, three to four treatments may be required during this time if bird populations persist.

Seeds can be treated with pesticides by seed companies or properly licensed PCOs. Seed treaments are only effective for 3 to 4 days, but they often provide control until the field dries out enough to bait.

Meadow Mice
Microtus spp.

Meadow mice, also called voles and field mice, occur throughout California and sometimes invade cole crops, mostly cauliflower and brussels sprouts, from uncultivated areas or other crops. Besides feeding on leaves and heads or curds, meadow mice may urinate on cauliflower heads, causing them to turn yellow. Meadow mice are rarely a problem in lettuce. Mice should be controlled before they move into the field. Once in the field, they are difficult to control. Poison baits are the most effective control in most situations. However, eliminating favorable habitat near the field can reduce sources of an infestation and is often important to successful management.

Description and Biology

Full grown meadow mice are 4 to 6 inches (10 to 15 cm) long, not including the tail; they are larger than house mice or deer mice but smaller than rats. Meadow mice are chunky in overall appearance, with a blunt nose, short legs, small eyes, and short, furry ears. Body fur is coarse and dark brown to grayish brown. The tail is less than half as long as the body and has only sparse hair.

Meadow mice live in colonies where there is grass or other vegetation for cover, often in meadows, irrigated pastures, or weedy ditchbanks, streambeds, roadsides, and fencerows. Fields of alfalfa, grain, sugarbeets, and potatoes may also support large populations. Infestations can usually be recognized by the network of 1- to 2-inch-wide runways connecting numerous shallow burrows that contain nesting and storage chambers. Active runways are littered with small pieces of forage and small piles of brown feces. Burrow openings are round and are not plugged with soil. Runways usually are not obvious in cole crops, but burrows, feces, and signs of feeding can be found under and around plants.

Meadow mice are active day and night all year. They feed on leaves, succulent stems, and curds or heads. In late fall and winter, when forage is scarce, they may also eat roots, tubers, and bark of perennial plants.

Female meadow mice bear five to ten litters each year; the average litter size is four to five. Although some individuals may breed at any time of the year, especially in vegetable-growing areas, the main period for reproduction is in spring. Populations fluctuate dramatically, peaking every 4 to 7 years and then declining sharply. At peak abundance there may be 1,000 to 3,000 meadow mice per acre in favorable habitats such as alfalfa fields. There may be several populations in a given area, and one or more of them may peak in any particular year. It is difficult to predict population peaks, but it is usually possible to recognize increasing populations with the following monitoring techniques.

Meadow mice normally remain within a few yards of their nests; the young leave the nest area and move to the edges of the colony or form new colonies nearby. When populations are high, however, the young can move 1,000 feet (300 meters) or more to reach new cover and food, and entire populations may migrate when alfalfa or other infested crops are harvested. Irrigation or other flooding may also cause migration.

Management Guidelines

Meadow mice do not move into fields until crop plants are big enough to provide cover. By the time this happens, the population in surrounding fields may already be large and control may be difficult. To prevent infestation, control nearby populations during winter before the peak breeding season and before the mice move into cole crops.

Monitoring. Visit the field and the surrounding land before planting and look for signs of meadow mouse activity. Check grassy areas along fencerows, ditchbanks, and roadsides and survey neighboring fields for runways and burrows. In tall grass of alfalfa, you may have to part the vegetation to see runways on the ground. There is no practical way to estimate populations accurately, but you can get a good idea of how many mice are present by the number of runways and burrows and the amount of feces and freshly cut forage in the runways.

Trapping with snap traps can help in preplant monitoring of habitat near prospective fields. Traps are most effective when baited with a mixure of peanut butter and oats. Use at least five to ten traps along each edge of the field that may harbor meadow mice. Put the traps in a level position under vegetation cover, preferably in or near mouse runways, and leave a marker so that you can find them later. Check the traps within 24 hours, if possible. There are no numerical guidelines for evaluating the results of trapping, but trapping helps generally to identify areas that need attention.

Baiting. If you find significant numbers of meadow mice in areas adjacent to the field, treat these areas with a bait before planting. Treating infested areas in late winter, before spring breeding season begins, is especially important. A single treatment then may be more effective than several applications later. Once a population of meadow mice begins rapid growth in spring, numbers may increase so fast that baiting may not prevent mice from infesting adjacent fields. In late winter baits are usually more readily accepted because forage is less abundant. If you do not have access to adjacent infested areas or cannot get permission to apply bait there, you may have to limit baiting to the edges of the field. This is less effective, especially when medow mouse populations are high.

Use broadcast baiting where large areas are infested; this can be done by hand but usually is more efficient mechanically. Use spot baiting for small infestations or where broadcast baiting is impractical; place small amounts of bait by hand in runways and burrows. Regardless of the method, bait must be in or near runways to be effective. Always follow bait label directions for rates, application methods, and precautions. Check with your county agricultural commissioner regarding legal use of baits in your area.

Habitat Management. In some cases it is useful to destroy habitat around the field where meadow mice can overwinter and breed. Habitat destruction is not practical if the field is surrounded by large areas of suitable habitat, such as alfalfa or pastures, but it may be worthwhile to destroy grassy areas along roads, fences, and canals. It is important, however, to destroy the habitat before planting your crop; otherwise, you may force the mice into your fields.

Meadow mice have a blunt nose, small eyes and ears, and a short tail.

These brussels sprouts have been damaged by meadow mice.

Ground Squirrels
Spermophilus spp.

Ground squirrels occasionally feed on mature, partly grown, or seedling cole crops or lettuce, usually at field edges. Check for ground squirrels and their large, open burrows in ditchbanks, roadsides, and other areas around the field well in advance of planting. Adult ground squirrels hibernate in winter, so a few burrows may indicate a substantial infestation even when they are not apparent. Ground squirrels are not easy to keep under control; constant effort may be required over a long period, especially when populations have gone uncontrolled for several years. The benefits of one season's control measures are often not realized until the following year.

Shooting or trapping may control small numbers, but baiting or fumigating must be used for large infestations. Fumigating burrows is not effective when squirrels are hibernating because they plug their tunnels. Fumigation is most effective in late winter or early spring after adult squirrels have emerged from hibernation and before the annual litter of young is born in midspring. Fumigation is generally not as effective in summer since fumigants readily escape through dry soil, but in some cole crop growing areas soils may be moist enough. Because ground squirrels often refuse to eat grain bait early in spring, baiting is often not effective until late spring or early summer after the young are born and are old enough to feed on seeds. When using baits, first prebait with untreated bait to encourage acceptance; check with your county agricultural commissioner about local regulations and available baits.

Jackrabbits
Lepus spp.

Jackrabbits are occasional pests of lettuce and cole crops, mainly in fields surrounded by open land. Baiting is the most practical control, but it is best done well before planting to reduce the population before plants are exposed to damage. Both single dose and multiple dose baits are available. Rabbit fences can be effective in some situations. The *Vertebrate Pest Control Handbook*, available from the California Department of Food and Agriculture or through local agricultural commissioners, includes instructions on applying baits and using other controls for jackrabbits. (See References.)

Pocket Gophers
Thomomys spp.

Pocket gophers occasionally damage cole crops seedlings near alfalfa fields or uncultivated areas. They stay underground most of the time and are rarely seen, but their characteristic plugged mounds indicate their presence. The gophers dig tunnels 4 to 12 inches (10 to 30 cm) below the surface, push the soil out lateral exits, and plug these openings. On irrigated land, gophers breed most of the year, and the female may bear three litters averaging five to six young. In cole crops the gophers will feed on roots and pull entire plants underground into their tunnels.

Gophers can be controlled with traps or bait. Fumigants are not effective because the burrow systems are extensive, and the gophers quickly seal their tunnels when they detect the gas. Ask your agricultural commissioner for information about traps and baits available in your area.

Rabbits
Sylvilagus spp.

Cottontail and brush rabbits sometimes feed on young transplants, especially in coastal southern California, where crops are planted near brushy creek bottoms or chaparral. Temporary fences of wire mesh or plastic sheeting usually provide adequate protection during the relatively short time that plants are most vulnerable to damage. Ask your local game warden about regulations that apply to other means of controlling rabbits.

Deer

Deer may occasionally damage cole crop or lettuce fields in areas where nearby habitat, especially wooded or brushy areas, provides cover. Because deer are night feeders and may not be observed in fields, tracks, scat, and damage are often the first evidence of their activities.

Using traps, poisons, and toxic baits to control deer is illegal. Deerproof fences are expensive but provide the only effective control in many situations. The fences should be 7 to 8 feet (2.1 to 2.4 m) high, made of woven mesh wire (4" × 4" mesh), and enclose the entire field. A few strands of barbed wire not more than 4 inches (10 cm) apart can extend the height of shorter fences. Noisemaking devices and lights sometimes discourage deer, but results are erratic and long-term effectiveness is unlikely. Perimeter repellents are of limited effectiveness. Deer are classified as game mammals, but depredation permits to shoot deer out of season may be issued by the local game warden. A variety of regulations must be followed to comply with permit requirements. Deer numbers may also be reduced during the regular deer sport hunting season.

Weeds

Weeds compete with cole crops and lettuce for sunlight, nutrients, and water. Weeds in and around the field before planting sometimes harbor pathogens, nematodes, insects, or vertebrates that can invade or spread to the crop soon after planting. Weed control is especially important in precision planted crops where loss of seedlings to competition can substantially reduce the vigor and uniformity of the overall stand.

An integrated weed control program relies on several management methods, both cultural and chemical, to keep weed populations at tolerable levels. Management of insects, diseases, and nematodes can affect your program's success because damage by pests may limit the crop's ability to outgrow competing weeds. The first 30 days after planting are the most important for weed control in cole crops and lettuce. As they grow older, most cole crops, especially cauliflower and brussels sprouts, shade and compete well with weeds. Lettuce and cabbage, on the other hand, produce little shade.

Accurate identification of weeds is essential for choosing effective control. Follow the monitoring guidelines outlined in this section.

Field Selection, Planting Date, and Rotation

Weed control is easier and cheaper in fields that are not infested with weeds difficult to control in the planted crop. Problem weeds include such perennial weeds as nutsedges as well as such annual weeds as sowthistle and common groundsel that cannot be effectively controlled with available selective herbicides in lettuce. Weeds in the mustard family are difficult to control, especially in cole crops.

Planting date can have an impact on weed problems in a given region. For instance, fields planted between October 1 and October 15 in the southern desert are often fairly weed free. At this time summer weeds are not vigorous and winter weeds have not started germinating. If competitive crops, such as broccoli and cauliflower, are planted at this time, weeds often require little management.

If problem weeds are present in significant numbers, the best strategy is to rotate to a crop where they can be successfully controlled. Differences in planting time, cultural practices, and available herbicides may all contribute to better weed control in an alternate crop. Rotation options may be limited by the high cost of land in some vegetable-growing areas and other production management considerations, but crops to consider include tomatoes, dry beans, celery, carrots, sugarbeets, sweet corn, and other grain crops in coastal areas plus alfalfa and cotton in the central and southern desert valleys. Unfortunately, available herbicides and cultural practices are too similar to allow cole crops and lettuce to be used effectively in rotation with each other for weed control purposes in most cases. Find out what herbicides and cultural practices are available in rotation crops suited to your area, then choose the rotation crop that will best control the weeds present. Check herbicide labels to make sure residues will not damage subsequent crops.

Cultivation

Repeated cultivation is integral to good weed management. Preplant plowing, followed by irrigation and one or two discings before bed formation, will destroy many weeds. Deep plowing and inverting soil to a depth of 16 inches, as recommended for control of Sclerotinia drop of lettuce, has significantly reduced sowthistle or groundsel infestations within 6 months in the central coast region. Plowing must be followed by rain or irrigation and discing of any emerging weeds before they flower. Deep cultivation is not as effective against such weeds as cheeseweed whose very persistent seeds can germinate from depths several inches below the soil surface.

Proper bed preparation is important to successful weed cultivation after the crop is planted. Plant on beds even in fields that are 100% sprinkler irrigated. Effective cultivation of bed tops requires precise row spacing and careful alignment of cultivating tools. When plants have two to three leaves, sweeps or knives can be set as close as 2 inches on each side of the seed rows as long as they cultivate shallowly; closer cultivation will cut feeder roots. When cole crop seedlings are so large that they won't be buried—usually when they have three to four leaves—

HERBICIDES AVAILABLE FOR COLE CROPS

	DCPA (DACTHAL®)	BENSULIDE (PREFAR®)	TRIFLURALIN (TREFLAN®)	NAPROPAMIDE (DEVRINOL®)
ANNUAL GRASSES				
Annual bluegrass	C	C	C	C
Barnyardgrass	C	C	C	C
Canarygrass	C	C	C	C
Foxtail barley	C	C	C	C
Rabbitsfootgrass	C	C	C	C
Wild oats	P	P	N	C
Volunteer grains	N	N	N	C
GOOSEFOOT FAMILY				
Lambsquarters	C	P	C	C
Nettleleaf goosefoot	C	P	C	C
MUSTARD FAMILY				
Brassica species (mustards)	N	N	N	P
London rocket	N	N	N	P
Shepherdspurse	N	N	N	P
Wild radish	N	N	N	P
NIGHTSHADE FAMILY				
Black nightshade	C	N	N	N
Hairy nightshade	C	N	N	N
Ground cherry	C	N	N	N
SUNFLOWER FAMILY				
Common groundsel	N	N	N	C
Pineappleweed	P	N	C	C
Prickly lettuce	C	N	N	C
Sowthistle	C	N	N	C
OTHER BROADLEAF ANNUALS				
Burning nettle	C	P	P	P
Cheeseweed	N	N	N	C
Chickweed	C	N	C	C
Knotweed	C	P	C	C
Pigweeds	C	P	C	C
Purslane	C	C	C	C
PERENNIAL WEEDS				
Nutsedge	N	N	N	N
Field bindweed (seedlings only)	N	N	N	N

C - Controlled P - Partially controlled N - Not controlled

Figure 21. Susceptibility of major weeds to herbicides available in cole crops.

arrange tools so they will move a 1-inch layer of soil toward and into the seed row. This mulch of dry soil will prevent many weed seeds from germinating. This technique is useful for cole crops, but it cannot be used in lettuce. Soil thrown into the row will dirty lettuce wrapper leaves, distort growth, and may also allow moisture to accumulate, providing conditions favorable to development of Sclerotinia drop and other diseases.

Fields may be cultivated up to four or more times between planting and harvesting. Cauliflower and lettuce are usually hand hoed during thinning and once again a few weeks or a month later. Broccoli is sometimes planted to a stand and not thinned, but it is usually hand hoed or cultivated at least once if economically feasible. Weed control in brussels sprouts relies largely on cultivation. Mechanical cultivation in this crop is fairly easy since plants are transplanted from seedbeds and grow tall rapidly in the field. Fall planted cole crops or lettuce in the coastal valleys may require more cultivation than summer planted crops because cooler temperatures slow their growth rate. It may take 30 to 60 days for them to grow large enough to shade out weeds and eliminate need for further weed control activity. On the other hand, when it is warm in the San Joaquin Valley, one or two cultivations in combination with selective herbicides may be enough.

Mulch Planting. Some Salinas Valley growers of cole crops have successfully used a program that requires no herbicides and relies entirely on cultivation for weed control. A simple program provides adequate weed control in broccoli and cauliflower when weather conditions are ideal. The procedure must be preceded by thorough plowing and discing. Once plant beds are formed, fields are preirrigated and weed seeds allowed to germinate. Bed tops are then lightly tilled to remove weeds and soil crust. At the same time, cole crop seeds are planted about 1/2 to 3/4 inch (1 to 2 cm) deep. Coastal valley conditions in summer favor rapid germination. Under this program, seeds germinate in the moisture below the 1/2-inch soil layer in about 7 days. The dry upper surface forms a shallow, dry mulch that prevents germination of shallow germinating weeds, such as groundsel and sowthistle. Certain weeds, such as pigweeds, cheeseweed, and nightshades, are still able to germinate, but the strategy is to get the crop plant big enough to cultivate before these more deeply seeded weeds become established. The first cultivation occurs when the crop seedlings have three leaves. The first irrigation follows this cultivation. Further cultivation is carried out as necessary. Later, a hoeing crew may be brought in to pull weeds out of the seed line.

The program's drawback is that weather conditions must be ideal. If drying winds or warm weather occur while crop seeds are germinating or before the three-leaf stage, sprinkler irrigation may be needed to keep the crop growing. The irrigation will stimulate germination of fast-growing, shallow-seeded weeds and will also prevent entering the field with cultivation equipment, making weed control impossible without postplant herbicides. Because these conditions often prevail in the San Joaquin Valley and in the southern desert, this program cannot be recommended there.

Water Management

Careful water management is important in weed control. Poorly leveled land or poorly maintained furrows will cause water to collect in certain parts of the field, favoring growth of water-loving weeds, as well as many crop pathogens. When furrow irrigating, avoid wetting the tops of beds; shallow-seeded weeds will germinate in wet bed tops. Sprinkler irrigation is a mixed blessing. Sprinkling after herbicide application eliminates the need for mechanically incorporating many materials, reduces wheel traffic over wet soil and resulting soil compaction, and also leaches salts below the root zone of young crop seedlings. However, sprinklers stimulate germination of weed seedlings on the bed surface. Common practice is to sprinkle at the seedling stage and to switch to furrow irrigation after herbicides have been incorporated or after thinning.

Sanitation

Weeds can produce many seeds in just one season; for example, a single sherpherdspurse plant can produce more than 30,000 seeds. To reduce seed production, disc harvested fields before weeds flower and produce seeds, and cultivate or treat field edges, fence lines, roadsides, and irrigation ditches frequently to prevent weed seed production in these areas. Use hoeing or spot applications of foliar-applied herbicides for weeds that are difficult to control. Keep cultivation equipment and irrigation water as free of weed seed or vegetative propagules as possible to prevent spreading populations. You can also rogue out small infestations of hard to manage perennials or weeds. If they already have fruit or seeds, remove them from the field, if possible.

Herbicides

A limited selection of herbicides is available for use in cole crops and lettuce (Figures 21 and 22). Several important weeds are not controlled by registered materials in one or both crops. Good weed management must complement herbicide use with careful field selection, regular cultivation, rotation, and other cultural practices.

Choice of Materials. Choosing an herbicide depends largely on the weed species to be controlled, but it is also influenced by soil type, irrigation method, crop rotation, and such conditions as temperature and rainfall at the

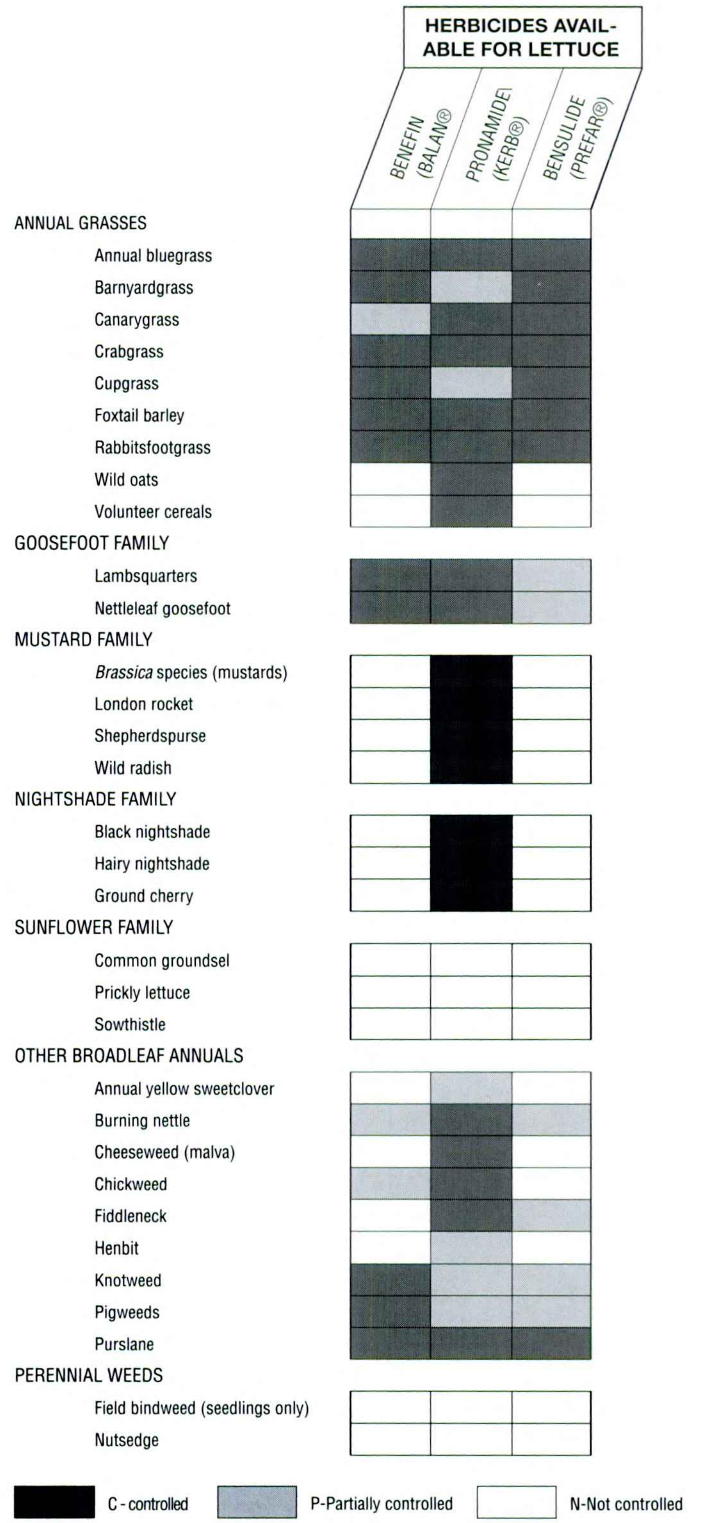


Figure 22. Susceptibility of major weeds to herbicides available for lettuce.

time of application. For example, sandy soils prevent safe use of certain herbicides. Materials also vary in their selectivity or potential for damaging the crop at certain stages of development. New crop cultivars may be sensitive to herbicides at rates that do not adversely affect older varieties. Formulations and wetting agents may also alter the selectivity of herbicides. When trying out a new material or if you suspect an herbicide may be causing crop damage, leave part of a row untreated to check for effectiveness on weeds or crop sensitivity. No herbicide registered for cole crops or lettuce provides satisfactory control of all the weeds likely to be found in the crop. Sometimes combinations of herbicides or sequential applications will be required. Check with your farm advisor, agricultural commissioner, or chemical supplier to make sure you have the latest information on available materials, their compatibility and recommended rates. Registrations change frequently. Always read the label before using any herbicide and follow label instructions completely.

Application. Proper application is just as important as the right choice of herbicide for controlling weeds without injuring the crop. Most herbicide labels provide detailed directions for applying herbicides, including precautions for protecting crops; always follow these directions carefully. Usually, lower rates are recommended in sandy soils. Timing of applications relative to rain or irrigation is important, as some herbicides may lose effectiveness when leached from the soil surface by excess water. In other cases, water can serve to move the herbicide into the soil after surface application, although care must be taken not to apply too much; 1/2 to 1 inch is often enough. Most herbicides used in cole crops and lettuce do not kill emerged weeds, so cultivation is often needed before application to remove emerged weeds. If there is a chance that residues will damage subsequent crops, use a band application to reduce the total amount of herbicide in the soil. Then dilute the herbicide residue after harvest with deep plowing and discing. Use application equipment suited to field conditions, and calibrate sprayers before each use. Consult the leaflet, *Calibration of Herbicide Sprayers*, listed in References.

Herbicides may be applied before planting (preplant) or after planting (postplant, usually as a preemergence treatment before the crop emerges). In some districts, fall planted cole crops may receive a layby treatment before winter rains. However, most crops receive only one herbicide application, partly because of the short growing period and partly because of the lack of satisfactory postemergence herbicides. The choice of timing depends on your schedule and the proper method for materials you choose. Many materials are incorporated with a sprinkler irrigation, so the timing of the first irrigation may be the most important determinant of when materials are best applied.

Cole Crop Herbicides. Three preplant and preemergence herbicides commonly used in cole crops in California are DCPA (Dacthal), bensulide (Prefar), and trifluralin (Treflan). Napropamide (Devrinol), registered in 1984, should effectively control weeds not controlled by the three older materials. Several other materials have been removed from the market, and several new ones may be registered in the future. Check with your county agricultural commissioner or pest control advisor about the availability of materials and recommended rates.

DCPA (Dacthal) can be used preplant incorporated as a preemergence application at seeding, or as a posttransplant application. When applied to the soil surface, it must be sprinkler incorporated. DCPA controls most annual grasses, with the exception of volunteer cereals and several broadleaf annuals. However, the material poorly controls most mustard family weeds under most conditions. DCPA's activity lasts about 6 to 10 weeks, depending on soil and environmental conditions.

Bensulide (Prefar) can be used preplant with mechanical incorporation or postplant with sprinkler incorporation. Relatively insoluble, it is readily adsorbed onto organic materials, and it leaches very little in the soil. Degradation by soil microorganisms is slow. Soil surface applications of bensulide do not volatilize significantly, although there is minor photodecomposition. Bensulide is a good grass herbicide, effective against crabgrass, barnyardgrass, purslane, and to a lesser extent, lambsquarters and pigweeds. It is ineffective on volunteer grain crops and many broadleaf weeds.

Trifluralin (Treflan) is a preplant herbicide that must be mechanically incorporated. Usually it is incorporated 2 to 3 inches (5 to 7.5 cm) deep; once incorporated, it remains stable until activated by irrigation. Trifluralin is most effective in transplanted fields against germinating seeds of summer weeds. Barnyardgrass, yellow foxtail, lambsquarters, pigweed, and knotweed are all controlled, but the material poorly controls mustards, chickweed, stinging nettles, and weeds in the sunflower and nightshade families. In addition to the limited spectrum of susceptible weeds, trifluralin's major drawback is soil persistance. Residues harmful to acutely sensitive crops—spinach, sugarbeets, milo, and corn—may persist up to 12 months.

Napropamide (Devrinol) can be applied preplant and incorporated with power-driven rotary tillers or applied after seeding, but before crop emergence, and sprinkler incorporated. It provides excellent control of all annual grasses, including volunteer cereals and a large number of broadleaf weeds. It does not control nightshade family weeds or certain sunflower or mustard family weeds.

Napropamide has long residual properties, and certain crops, especially lettuce, sugarbeets, and cereals, should not be planted following its use in cole crops.

Surface Banding of Fertilizer. In addition to application of herbicides, a new technique—surface banding nitrogen fertilizer compounds—can also control weeds after emergence. A spray directed at the weeds on the bed and in the seed row will burn them back. The waxy cuticle of cole crops prevents damage once crop plants have at least three true leaves, unless they are very wet. Table 11 shows the susceptibility of various weed species to the surface banding of ammonium nitrate.

Table 11. Effect of Surface Banding of Ammonium Nitrate Fertilizer (20-0-0) on Weed Species in Cole Crops.

WEEDS IN COLE CROPS		
Controlled	Partially Controlled	Not Controlled
black nightshade	purslane	annual grasses
Brassica species		field bindweed
burning nettle		lambsquarters
cheeseweed		nettleleaf goosefoot
chickweed		nutsedge
common groundsel		sowthistle
hairy nightshade		
London rocket		
pigweeds		
pineappleweed		
shepherdspurse		
wild radish		

Lettuce Herbicides. Three herbicides are commonly used in California lettuce, but as is the case with cole crops, some of these may become unavailable, and new herbicides may be registered eventually. Also, some are not recommended for use in certain soils or areas of the state. Ask your farm advisor for the latest information on herbicides and application rates suitable for your area.

Benefin (Balan) is applied before planting and controls many broadleaf weeds and grasses. However, nightshades, mustards, and weeds in the sunflower or lettuce family are not satisfactorily controlled. Benefin must be incorporated immediately 2 to 3 inches (5 to 7.5 cm) into the soil. Treated soil must remain in place in the bed. If treated soil is moved into the furrows or concentrated in the wrong area of the bed, good control will not be achieved. Large clods will also reduce benefin's effectiveness. Some rotation crops are sensitive to benefin residues; do not plant them following use of benefin in lettuce.

Pronamide (Kerb) controls a broad spectrum of weeds, including mustard family weeds, but it does not control sunflower family weeds. Postplant treatments onto moist soil with sprinkler irrigation for incorporation are most effective; sprinkler irrigation should follow application within 72 hours. When furrow irrigation is used for crop germination, mechanically incorporated preplant treatments can be used. Do not plant small grains or other sensitive crops following treatment. Persistance of pronamide can be limited by placing it only along a 5-inch (12.5 cm) band on either side of the seed line and then deep plowing after harvest, but immediate rotation with crops such as wheat is still not recommended.

Bensulide (Prefar) provides excellent control of purslane and barnyardgrass but poorly controls many other broadleaf weeds. Bensulide works best postplant with sprinkler incorporation, but shallow mechanical preplant incorporation has been successful. For good postplant control, sprinkler water must reach a depth of 2 to 4 inches (5 to 10 cm).

Fallow Bed Treatments. Several foliar-active herbicides are available that can be used on fallow beds before planting lettuce or cole crops to control troublesome weeds. Paraquat will control most emerged annual weeds and grasses and burn back perennials. Glyphosate (Roundup) will control most annuals and many perennial weeds. Neither, however, will completely control field bindweed, nutsedges, or cheeseweed. Make fallow bed treatments after weeds have germinated following rains or irrigation. A common practice in the desert is to sprinkler irrigate to germinate weeds and to apply aerially a fallow treatment a few weeks later.

Monitoring

To plan a weed management program, you must know what kinds of weeds are present, which are the most abundant, and whether the abundance of the various species is changing. Most herbicides used in cole crops and lettuce are effective only on germinating weeds, so it is essential to know what the target weeds are before they grow. Normally this information comes from routine weed surveys carried out during the previous crop. In some cases, it may be necessary to take soil samples for seed germination tests to determine the weed spectrum before planting.

Survey each field for weeds once before planting and once during crop development. If possible, conduct the first survey while the previous crop is still in the ground. Repeat the survey midway thorugh the growing season to check on the effectiveness of weed control measures. Accurate identification of species is essential.

To conduct a weed survey, walk through the field in a random pattern and rate the degree of infestation for each weed species. Use a numerical scale such as 1 (a few weeds present) to 5 (very heavy infestation) or just rate infestations as light, medium, or heavy. Check fencerows and ditchbanks as well as the field itself. Pay special attention to perennials. Sketch a map of the field and mark where they occur.

Farm advisors sometimes provide special weed survey cards, or you can make your own. A sample form is shown here (Figure 23). Whether you use a printed form or not, be sure to take written notes in the field and keep them as part of the permanent field history. Weed survey information collected over several years is extremely valuable in identifying changes in weed populations and in planning herbicide and rotation programs.

Weed Species and Identification

The weed species that cause the most serious problems in lettuce and cole crops in a given region are mostly the same, largely because time of planting, growing conditions, herbicides, and cultural practices used in the two crops are similar. Regional differences in weed problems can be marked, however. The winter-spring weeds, which are favored by cool, moist germinating and growing conditions, predominate most of the year along coastal areas. On the other hand, the most serious weeds in the southern desert crops germinate under the warm to hot conditions of early fall in the desert. In the San Joaquin Valley, grass weeds and the late winter and early fall weed spectrum are most common.

Among the most serious weed problems in both crops are weeds in the sunflower family (same family as lettuce), such as sowthistle and common groundsel, and weeds in the mustard family (same family as cole crops). Cheeseweed and other very persistant, deep-germinating weeds can also create major problems. Among the annual

Weed Infestation Record

Field________ Current Crop________ Date Planted________

Herbicide________ Rate________ Date Applied________

Previous Crop________ Date of this survey________

ANNUAL GRASSES					
Annual bluegrass	1	2	3	4	5
Barnyardgrass	1	2	3	4	5
Volunteer grains	1	2	3	4	5
________	1	2	3	4	5
________	1	2	3	4	5
GOOSEFOOT FAMILY					
Lambsquarters	1	2	3	4	5
Nettleleaf goosefoot	1	2	3	4	5
________	1	2	3	4	5
MUSTARD FAMILY					
Brassica species (mustards)	1	2	3	4	5
London rocket	1	2	3	4	5
Shepherdspurse	1	2	3	4	5
Wild radish	1	2	3	4	5
________	1	2	3	4	5
________	1	2	3	4	5
NIGHTSHADE FAMILY					
Black nightshade	1	2	3	4	5
Hairy nightshade	1	2	3	4	5
Ground cherry	1	2	3	4	5
________	1	2	3	4	5

SUNFLOWER FAMILY					
Common groundsel	1	2	3	4	5
Pineapple weed	1	2	3	4	5
Prickly lettuce	1	2	3	4	5
Sowthistle	1	2	3	4	5
________	1	2	3	4	5
________	1	2	3	4	5
OTHER BROADLEAF ANNUALS					
Burning nettle	1	2	3	4	5
Cheeseweed	1	2	3	4	5
Chickweed	1	2	3	4	5
Knotweed	1	2	3	4	5
Pigweeds	1	2	3	4	5
Purslane	1	2	3	4	5
________	1	2	3	4	5
________	1	2	3	4	5
________	1	2	3	4	5
PERENNIAL WEEDS					
Nutsedge	1	2	3	4	5
Field bindweed	1	2	3	4	5
________	1	2	3	4	5
________	1	2	3	4	5

Figure 23. Example of a weed survey sheet. Circle the appropriate number to indicate the degree of infestation: 1 = very few; 2 = light; 3 = moderate; 4 = heavy; 5 = very heavy.

broadleaf weeds, burning nettle is unique because the hairs on its stem and leaves irritate field workers' skin. Annual grasses, such as barnyardgrass, are most serious in the San Joaquin Valley and the lower deserts, although volunteer grains may be a problem wherever lettuce or cole crops are rotated with wheat or barley. Fields infested with such perennial weeds as nutsedges may require special management because it is so difficult to destroy their vegetative propagules. Because lettuce and cole crops are cultivated frequently, some perennial weeds, such as field bindweed, are often not as serious as they are in other crops.

Some of the most common and troublesome weeds in California lettuce and cole crops are illustrated here. Many others are included in University of California Agriculture and Natural Resources publication 4030, *The Growers' Weed Identification Handbook*. Figure 24 illustrates the most important terms used in weed descriptions.

When using photographs or descriptions to identify weeds, remember that most weeds vary considerably in size and appearance, depending on environmental conditions. Also, it is not possible for this manual or the *Handbook* to include every species that might grow as a weed in some part of California. Farm advisors can usually identify common local weeds or they can refer samples to specialists for help in identification.

Weeds in the Sunflower Family

Because weeds in the sunflower family are so closely related to lettuce, they are particularly difficult to control with herbicides registered in that crop. Several of these weeds, notably common groundsel, are also hard to control in cole crops. In addition to common groundsel, prickly lettuce and sowthistle are common sunflower family weeds that occur in both crops. Another common weed in the sunflower family that is not covered here is pineappleweed, *Matricaria matricarioides*.

Common Groundsel *Senecio vulgaris*

Common groundsel, a winter annual weed found throughout California, may cause problems all year in the cooler coastal areas. It cannot be controlled with any herbicide available in lettuce and is difficult to control in cole crops and most other broadleaf crops as well. Groundsel seeds cannot successfully germinate and grow unless they are in the top 1/2 inch (1 cm) of soil, so certain cultural practices can be helpful in weed management. Preplant irrigation to germinate seeds and a shallow cultivation just before planting will limit populations somewhat. This program can be augmented in cole crops by throwing a dry, dust mulch along the seed row

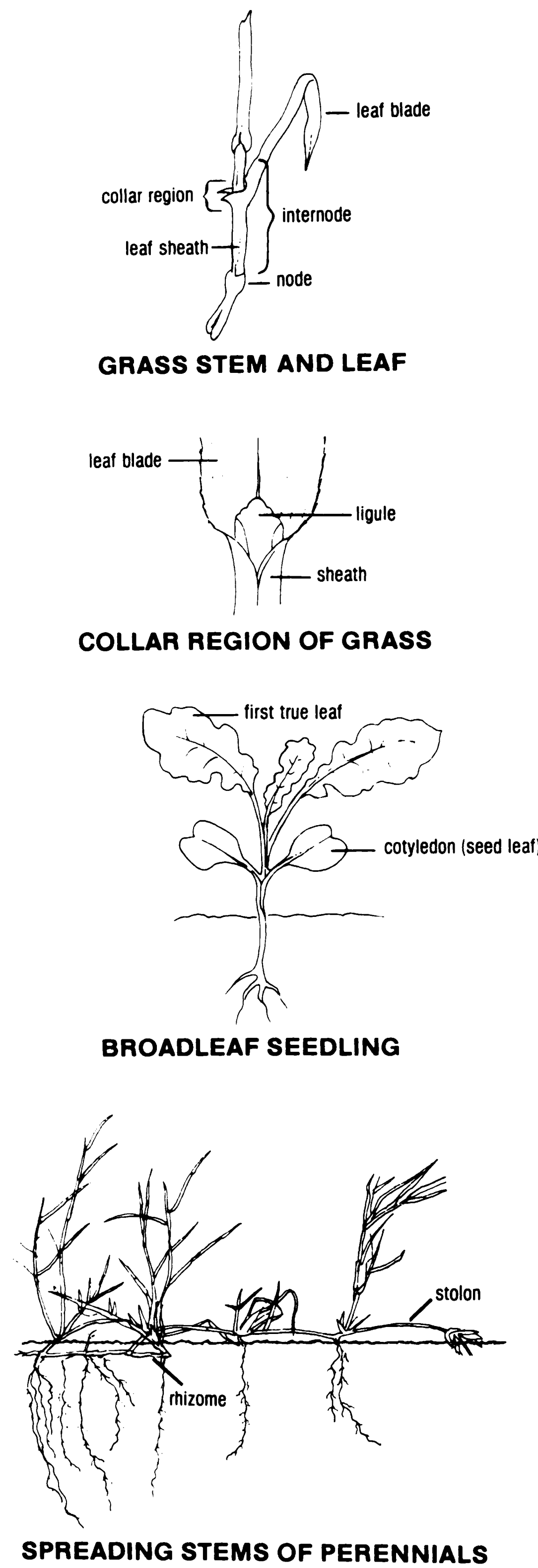


Figure 24. Vegetative parts commonly used in identification of weeds.

while carrying out the first cultivation. Deep plowing and inverting soil to 16 inches (40 cm) deep, as recommended for control of Sclerotinia drop of lettuce, can reduce the number of viable groundsel seeds in 6 months if followed by rain or irrigation and discing of emerging weeds before they flower.

A

B

A. Groundsel seed leaves are elongated and oval with a blunt, rounded tip. The first true leaves have shallow teeth, but the third and fourth true leaves are more deeply lobed.

B. The mature groundsel plant may grow 20 to 24 inches (50 to 60 cm) tall with single or branching stems. Leaves are deeply indented, red veined, and alternate on the stem. The upper leaves are attached directly to the stem; the lower leaves may have short stalks. Mature plants have many flower heads with yellow disk flowers. The green bracts surrounding the flower cluster have conspicuous black tips that distinguish groundsel from most other weeds in the thistle family.

Prickly Lettuce *Lactuca serriola*

Prickly lettuce, a common winter weed in the Central Valley, germinates after fall irrigations or with the onset of winter rains. Management practices recommended for sowthistle will also help control prickly lettuce. In cole crops, DPCA or napropamide will control prickly lettuce; in lettuce, no herbicides are available for its control.

C. Prickly lettuce seedlings have cotyledons that are about twice as long as they are wide. The first true leaves have rounded margins; leafstalks are not winged.

D. Prickly lettuce grows as an erect annual or biennial. The stem may be prickly near the base. If the stem is broken, it exudes a white, milky sap. The mature plant bears numerous creamy yellow flowers on branches off the main stems.

E. Prickly lettuce leaves are alternate, clasp the stem, and may be lobed or entire with prickly margins. Prickly lettuce can be distinguished from sowthistle by checking the midrib on the underside of the leaf (see leaves at right). Prickly lettuce has rough prickles; sowthistle is smooth.

C

D

E

Annual Sowthistle *Sonchus oleraceus*

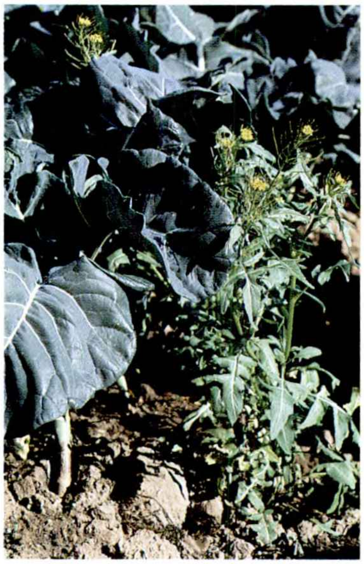
Annual sowthistle, a widely distributed weed commonly germinating from late fall to early spring, cannot be controlled with herbicides registered for use in lettuce, but DCPA and napropamide will control it in cole crops. As is the case with common groundsel, preplant cultivations, a dry soil mulch thrown over the seed row in cole crops, and deep plowing and inverting soil to a depth of 16 inches (40 cm) will provide some control.

F. The sowthistle seedling has markedly stalked, almost spoon-shaped cotyledons, rounded at the tip. The cotyledons often have a grayish powdery bloom, but later leaves have only a few hairs. True leaves have prickles or teeth along the margin with a winged stalk on the third or fourth and later true leaves.

G. Sowthistle plants can grow several feet high. Like common groundsel, flowers are yellow and mature into fluffy white seed heads. Flower buds of sowthistle are more pointed, however, and bracts are not black tipped. Stems are hollow and exude a milky juice when cut open. Leaves are pointed with toothed margins; leaves usually clasp the stems with a pair of clawlike lobes. The smooth midrib on the underside of the leaf distinguishes sowthistle from prickly lettuce, which has a rough, prickly midrib.

F

G



I

H

Weeds in the Mustard Family

Weeds in the mustard or crucifer family are most abundant when cole crops and lettuce grow best—in late fall, winter, or early spring or year-round along the milder coastal region. Because they are in the same family as cole crops, cruciferous weeds are very difficult to control with herbicides in cabbage, cauliflower, broccoli, and brussels sprouts. Many of the herbicides also available for use in lettuce do not control these weeds; however, pronamide (Kerb) provides good control. London rocket, shepherdspurse, wild radish, and weeds of the *Brassica* genus—the common "mustards"—are the most frequently seen crucifer species in these vegetable crops. All crucifer flowers have four petals and are borne on a terminal branching inflorescence, subtended by seedpods.

London Rocket *Sisymbrium irio*

London rocket is a serious problem in southern California and the San Joaquin Valley and an increasing problem along the coast. It is common in many fall, winter, and spring crops and on roadsides.

H. Seed leaves of London rocket are oval on long stalks, and its first true leaves are often somewhat indented; shepherdspurse's first true leaves are usually entire. Otherwise, seedlings of London rocket and shepherdspurse are difficult to distinguish, with one more exception: London rocket does not have stellate hairs on its leaves as does shepherdspurse.

I. London rocket grows as an erect annual from 1 1/2 to 4 feet (45 to 120 cm) tall, usually with well-branched stems and deeply divided leaves. Stems and leaves have few or no hairs. Small, yellow, four-petalled flowers are borne in small clusters on stalks at the tip of stems. Seedpods begin forming at the base of the inflorescence. Pods are slender and 1 1/2 to 2 1/2 inches (3.75 to 6.25 cm) long and held loosely, divergent from the stem.

Shepherdspurse *Capsella bursa-pastoris*

Shepherdspurse grows abundantly throughout California in spring and fall and all year along the coast. Pronamide controls shepherdspurse in lettuce; no herbicides fully control it in cole crops, so cultivation must be used.

If populations are high, rotate to a crop where crucifers are easily controlled with herbicides. Shepherdspurse seedlings closely resemble those of London rocket except the first true leaves are usually not indented. The fourth and later leaves may be indented.

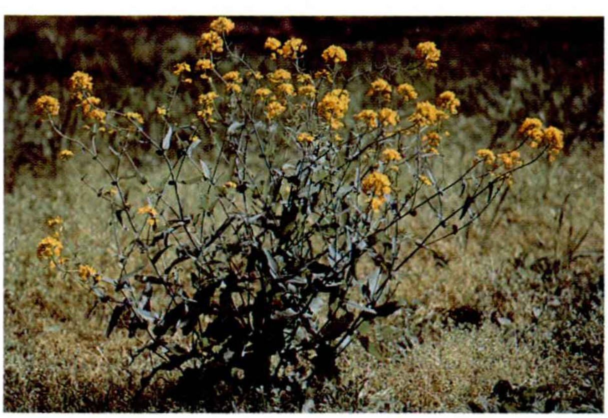
J. A character that distinguishes shepherdspurse from other seedlings is the short, fine, starlike hairs on the surface of the true leaves. A good hand lens is needed to see this feature.

K. The mature plant varies in size from 6 to 20 inches (15 to 50 cm) tall, but it is usually shorter than most other common crucifer weeds. The weed produces simple or branching stems that grow out of a rosette of mostly indented leaves. Leaves on the stem are arrow shaped, often without a stalk and clasping the stem. The flowering stalks are distinctive with small white to pinkish flowers and heart-shaped seedpods.

J

L

K



M

Mustards *Brassica* spp.

Crucifers in the *Brassica* genus are commonly called mustards. All mustards have large, lobed lower leaves and yellow flowers. Mustard seed pods narrow into a beak at the tip, distinguishing them from most other crucifers. Some of the most common species in vegetable growing areas include wild turnip, *Brassica campestris;* shortpod mustard, *B. incana;* wild mustard, *B. kaber;* and black mustard, *B. nigra.* The same management practices recommended for shepherdspurse will control mustards as well.

Mustard flowers, produced on the stalk with seed pods, are bright yellow with four petals. The flowers of most species are similar, but the seed pods are distinctive, although they all have beaked tips. In black mustard the pods are close to the stem, often overlapping, and the beaks are short; in wild turnip, the pods stand away at a sharp angle from the flower stem; pods of shortpod mustard are about 1/2 inch (1cm) long, bumpy or constricted, and held appressed to the stem, but beaks are about half as long as the pod.

L. All mustard seedlings have seed leaves that are broad with a deep notch at the tip. The first true leaves are bright green on the upper surface and paler on the undersides.

M. Mature mustard plants are 2 to 6 feet (60 to 180 cm) tall, erect, and freely branching. The leaves are toothed and alternate on the stem with the lower ones large and irregularly lobed. The plant pictured here is wild turnip.

Wild Radish *Raphanus raphanistrum*

Wild radish occurs throughout California but it seriously affects cole crops and lettuce mainly in Riverside, Ventura, and Orange counties. Management recommendations are the same as those for shepherdspurse.

Seed leaves are broad with a deep notch at the tip. The first true leaves are irregularly lobed and may have separate lobes at the base of the leaf blade. Seedlings resemble mustards in the genus *Brassica* but are duller green and rougher textured. *Brassica* species do not have completely separate lobes at the base of the true leaves.

N. Mature wild radish is an erect annual, usually 2 or more feet (60 cm) high, and branched in the upper portion. Leaves vary in size and shape. Lower leaves are deeply divided with leaflets arranged on both sides of the leafstalk and a large rounded terminal segment. Upper leaves are smaller and undivided or have a few small lobes. Flowers range in color from white to purple to pink or light yellow brown with streaks of different colors. Seedpods are elongated and pithy or spongy.

Other Broadleaf Annual Weeds

Cheeseweed *Malva parviflora*

Cheeseweed or little mallow, the most common mallow family weed occurring in cole crop and lettuce fields, thrives under the conditions of high nutrient levels and moist soils prevalent in vegetable crops. Cheeseweed seeds can germinate from deep in the soil and remain viable for many years, so they cannot be inhibited by deep plowing. The weed rapidly grows a deep, tough tap root, so cultivate seedlings while they are small.

O. Cheeseweed plants may grow up to 50 inches (125 cm) tall. Flowers are purple and white, and the distinctive fruit resembles a tiny wheel of cheese—hence, the name cheeseweed.

P. Seed leaves of cheeseweed are heart shaped. True leaves are rounded and scalloped, with shallow teeth along the margins.

Nightshades *Solanum* spp.

Black and hairy nightshades are common in cole crops that have been rotated directly out of tomatoes or potatoes, where they cannot be easily controlled with herbicides. In lettuce they are fairly easy to control with herbicides but in cole crops herbicides only give partial control. If you have a heavy infestation, rotate to lettuce or some other crop in which control is easier. Nightshades are more common during warmer weather in spring, summer, and early fall. Two species are common—hairy nightshade, *Solanum sarachoides*, and black nightshade, *S. nigrum*. Hairy nightshade plants are usually, but not always, much more densely covered with fine hairs than are black nightshades. Both species have berry-like fruits.

Q. Seed leaves of black nightshade are elongate-oval and pointed. The first true leaves are spade shaped with smooth edges. Lower surfaces are often purple.

R. First true leaves of hairy nightshade have wavy edges and prominent veins. The leaves usually have numerous fine, short hairs, especially along the underside of the main vein.

S. Hairy nightshade berries (shown) are green or yellowish brown when mature; they are never black. The calyx covers the fruit's entire upper surface. The pedicles, like the stems and leaves, are usually conspicuously hairy. Black nightshade berries (not pictured) turn from green to black when mature and the calyx covers only a small part of the fruit surface. Petioles, stems, and leaves have some hairs, but they are not densely hairy or sticky. In vegetable fields mature plants of both species reach about 2 feet (50 cm) in height.

N

O

P

Q

R

S

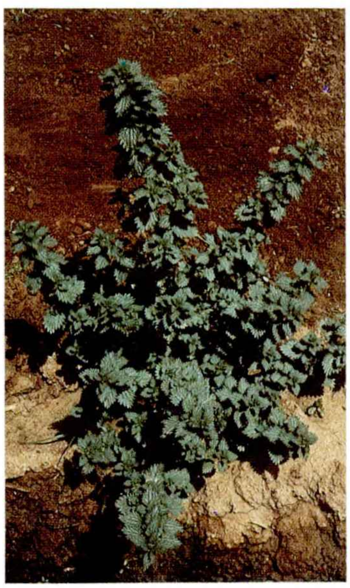
Burning Nettle *Urtica urens*

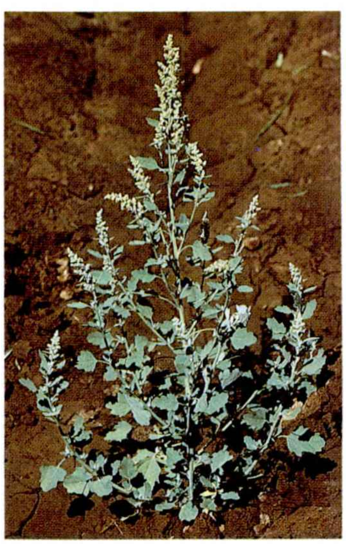
The stinging hairs on the leaves of burning nettle make it a nuisance to field workers. The weed, a winter annual, is especially troublesome in coastal counties where it grows all year. Several herbicides control it satisfactorily in both cole crops and lettuce.

T. Seed leaves are oval and slightly notched at the tips and smooth around the edges. The first true leaves are opposite on stalks and have margins with pointed teeth. Stinging hairs are interspersed with regular hairs on the leaf surface.

U. The mature plant is 5 to 24 inches (12.5 to 60 cm) high, erect, and sparsely branched from the base. The stems are four-angled and covered with stinging hairs. Leaves are opposite with toothlike margins, stinging hairs and leaflike structures (stipules) at the base of stalks. Flowers, small and greenish white, are located in clusters in the leaf axils.


T


U


V


W

Lambsquarters *Chenopodium album*

Lambsquarters, a common summer annual weed in the goosefoot family, may germinate anytime from early spring through fall. It is a more frequent problem in the Central Valley and desert areas than along the coast. Herbicides are available for control in both cole crops and lettuce.

V. Lambsquarters may grow several feet tall if enough water and nutrients are available. The plant has one main stem but is often heavily branched. Tiny green flowers are packed in dense clusters at the tips of the main stem and branches.

W. Lambsquarters seed leaves are narrow with nearly parallel sides. The seed leaves and early true leaves are dull blue green above and often purple below. Seed leaves and true leaves of lambsquarters are coated with tiny white scales that look like dust or flour to the naked eye but can easily be seen with a hand lens. The scaly leaf texture distinguishes lambsquarters from most other seedlings. For example, nettleleaf goosefoot seed leaves are shiny on the upper surface.

Nettleleaf Goosefoot *Chenopodium murale*

Nettleleaf goosefoot, another common weed in the goosefoot family, often invades lettuce and cole crop fields. It is more common than lambsquarters in the Salinas Valley. Like lambsquarters, nettleleaf goosefoot can be easily controlled with herbicides available in lettuce and cole crops.

X. Seed leaves of nettleleaf goosefoot are similar in shape to those of lambsquarters but are shiny green on the upper surface and fairly thick. Young leaves have a moist, dewy coating, especially on the lower surfaces, and have a strong odor when crushed.

Y. Mature nettleleaf goosefoot plants are up to 3 feet (90 cm) tall, with branches arising mostly from the base of the main stem. Most flower clusters are at the tips of the main stem and branches, but some also arise from lower leaf axils.

Pigweeds *Amaranthus* spp.

Pigweeds are common in late spring, summer, and early fall, and in California vegetable fields they include redroot pigweed, *Amaranthus retroflexus*; tumble pigweed, *A. albus*; and prostrate pigweed, *A. blitoides*. All are coarse annuals with alternate leaves and small inconspicuous flowers. Pigweed leaves do not have the mealy texture common to lambsquarters and other *Chenopodium* species. Herbicides are available for pigweed control in both crops. Pictured here is redroot pigweed, probably the most important pigweed in cole crops and lettuce.

X

Z

B

Y

A

C

D

Z. Seed leaves of redroot pigweed are long and narrow and bright magenta on the under surface. First true leaves have a shallow notch at the tip.

A. Redroot pigweed may grow extremely tall in some situations. Branches arise mainly from the base. Stems are furrowed. Leaves may be several inches long with long petioles and prominent veins on the lower surface. Flowers are arranged in dense spikes at the tops of the main stem and branches and in small clusters in the leaf axils.

Common Purslane *Portulaca oleracea*

Purslane thrives under dry conditions, but it also competes well with many irrigated crops. Cultural practices, including high fertilizer rates, good moisture, and shallow seeding, favor purslane growth in lettuce and cole crops. The weed prefers loose, nutrient-rich, sandy soils and grows rapidly in spring and summer. Several herbicides control purslane in both cole crops and lettuce.

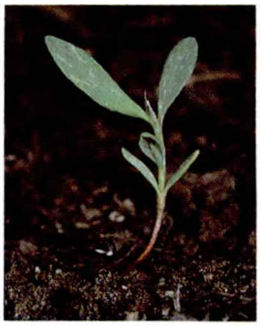
B. The mature purslane plant is prostrate or ascending, 6 to 12 inches (15 to 30 cm) tall. The plant branches at the base and along the stems. Leaves are succulent and often tinged red. Small yellow flowers are borne singly or in clusters of two or three in stem axils or at the tip of stems. They usually open only on sunny mornings.

Chickweed *Stellaria media*

Chickweed, a winter annual, is a low-growing, succulent weed that often spreads out in extensive mats. It may survive summer in shady, cool areas that offer sufficient moisture and occurs year-round along the coast. Chickweed rapidly dries up with the onset of hot, dry days. Several herbicides are available for control.

C. Chickweed seed leaves have prominent midveins and are about four times as long as broad, tapering to a point at the tip. True leaves are broader, opposite, and bright green.

D. Chickweed mats may cover a large area. Stems are trailing, weak, and slender, with a line of hairs down the side. Stems may root at nodes that are in contact with



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the soil. Mature leaves are ovate and opposite on the stem. Chickweed flowers are small but showy with five deeply cut white petals. They are borne singly on long slender stalks arising at the base of the leafstalk.

Prostrate Knotweed *Polygonum aviculare*

Prostrate knotweed, normally a low-growing weed, forms a mat over cleared land. It thrives even on poor, compacted soil and often in poorly drained areas. Several herbicides control it both in cole crops and in lettuce.

E. Knotweed seed leaves are narrow, six to eight times as long as they are broad, and are fused into a sheath from which the first true leaf emerges. The first true leaves are much broader, but they are also united at the base in a tubular, membranelike sheath. The next emerging leaf tears this membrane, giving it a ragged appearance. Branches may appear very early in the growth of knotweed.

F. The mature plant usually forms a prostrate or semiprostrate mat. Its stems are branched extensively and are swollen at the joints. Each leafstalk bears tiny pink or white flowers at its base.

Annual Grasses

Annual grasses, including volunteer cereals, commonly grow in vegetable fields. Most can be easily controlled with available herbicides, although volunteer cereals are harder to control. Two of the most common grasses are annual bluegrass, *Poa annua*, and barnyardgrass, *Echinochloa crus-galli*. Annual bluegrass is entirely a winter weed and doesn't persist in summer even in the cooler coastal areas. A summer annual, barnyardgrass is especially troublesome in the Imperial and San Joaquin valleys, but in recent years it has become more common along the coast.

G. Mature bluegrass plants range in height from 3 to 12 inches (8 to 30 cm) with leaf blades 2 to 3 inches (5 to 8 cm) long. The foliage is hairless, and the leaf blades are often crinkled at the midsection. The stems are somewhat flattened and bent at the base,

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sometimes rooting at the lower nodes when touching the soil. The flower head is roughly pyramid shaped and branched with flattened clusters of three to six flowers at the tip of each branch.

Especially in the seedling stage, annual blue grass can be identified by its broad, blunt leaf blades, which have turned-up tips resembling the bow of a boat. Held up to light, the leaf reveals transparent white lines on both sides of the midnerve. Some mature leaves show a crinkled section midway down the leaf.

H. The mature barnyardgrass plant grows upright, varying in height from 6 inches to 6 feet (up to 2 m). It may root at the lower nodes to form large clumps. Flower heads may be erect or drooping, depending on the variety.

I. A good way to distinguish barnyardgrass from other grasses is to strip off a leaf and look at the collar region. Barnyardgrass is the only major summer weedy grass without a ligule.

Perennial Weeds

The perennials most important in cole crops and lettuce have persistant rhizomes or tubers that survive when aboveground parts of plants are killed. Perennial weeds must be controlled before planting. The basic strategy is to destroy as many plants as possible and then prevent green parts of the weeds from regrowing. Important management practices include repeated deep cultivation of dry soil, planting alternate crops that shade out weeds, use of effective herbicides in rotation crops, postharvest and noncrop use of foliar-applied herbicides, and fumigation. It may be necessary to continue these measures for several seasons, but if growth of green vegetative parts can be prevented, the energy stored in underground parts will eventually be exhausted and the infestation will die out. Because the rhizomes and tubers of perennial weeds are readily moved with soil and water, sanitation is essential to keep infestations from spreading.

Nutsedges *Cyperus* spp.

The nutsedges—yellow nutsedge, *Cyperus esculentus*, and purple nutsedge, *Cyperus rotundus*—are among the most serious agricultural weeds in California and the most important perennial weeds in lettuce and cole crops. Summer weeds, they are favored by moist soil and warm, sunny conditions. Yellow nutsedge is the predominant species along the coast. Both species cause problems in the San Joaquin Valley and in the Imperial Valley. The nutsedge tubers or nutlets are easily carried in soil on farm equipment, and the weed has rapidly spread to new areas. No herbicides are available to control nutsedge in cole crops or lettuce. The best strategy is to plant these crops in infested fields during cool weather when nutsedge is not a problem, and plant other crops, such as tomatoes, beans, and potatoes, in which some control of nutsedge can be achieved with herbicides during summer.

Although nutsedges produce seed, most plants apparently originate from tubers. Plants produce tubers on rhizomes as deep as 8 inches (20 cm) in the soil. The tubers can remain viable for several years, even in dry soil, especially those of yellow nutsedge. Long-term control requires preventing the plants from growing beyond the five- to six-leaf stage when they start producing new tubers. Cultivation is the only method available for removing nutsedge during lettuce or cole crop growth.

J. Flowers of yellow nutsedge (shown here) are yellow green, and the basal leaves are as long or longer than the flowering stem. In purple nutsedge, flowers are tinged purple and basal leaves are shorter than the flowering stem. Young nutsedge plants are grasslike, but leaves are thicker and stiffer than most grasses. Leaves are triangular in cross section and arranged in a spiral at the base.

K. Tubers of yellow nutsedge (shown here) are spherical, and up to 3/4 inch (2 cm) in diameter with a smooth surface. Young tubers have loose outer scales that fall off. Purple nutsedge tubers are oblong, reddish, scaly, and coarse.

Field Bindweed *Convolvulus arvensis*

Field bindweed, also called perennial morningglory, is one of the most troublesome weeds in California agriculture. The mature plant is prostrate with slender stems, although it will climb upright structures when stems twist around plant stalks. Flowers are white to pink and funnel shaped. Mature plants have extensive rhizome systems that may be up to 10 feet deep. When chopped, parts of the rhizomes can grow into new plants. Seeds remain viable in the soil a long time. Fortunately, it is not as severe a problem in most cole crops and lettuce fields as in many other crops because the extensive cultivating required to grow these crops is unfavorable to bindweed. In fact, some growers may rotate to cole crops and lettuce to limit bindweed. Heavy bindweed infestations can create problems even in these crops.

Deep tillage, repeated cultivations, and foliar applied herbicides should all be part of field bindweed control. However, no herbicides registered for use in cole crops and lettuce satisfactorily control bindweed.

Field bindweed seedlings have nearly square seed leaves notched at the tip. Plants sprouting from rhizomes have no seed leaves. The first true leaves are heart shaped and deeply lobed at the base; later leaves are arrowhead shaped. Petioles are flattened and grooved on the upper surface.

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*These publications are available from the University of California, Agriculture and Natural Resources Publications; see p. 2 for address. A free catalog list many other titles on agricultural topics.

**Publications available through the offices of county agricultural commissioners.

Glossary

abiotic disorder. a disease caused by factors other than pathogens.

allowable depletion. the proportion of available water that can be used before irrigation is needed (Figure 7).

annual. a plant that normally completes its life cycle of seed germination, growth, reproduction, and death in a single year.

anticoagulant. a substance that slows blood clotting; some are used as rodenticides.

available water. the amount of water held in the soil that can be extracted by plants (Figure 7).

Bacillus thuringiensis. a bacterium that causes disease in many insects, especially caterpillars; formulations of the bacteria are used as insecticides.

biotic disease. a disease caused by a pathogen.

bolt. to initiate growth of flower structures.

bract. a modified leaf subtending a flower or flower cluster.

broad-spectrum pesticide. a pesticide that kills a large number of unrelated species.

calyx. the whorl of leaflike flower parts at the stem end of a flower or fruit.

canker. a dead, discolored, and often sunken area (lesion) on a root, stem, or branch.

chlorosis. a diseased condition in which normally green plant tissue is yellowed or bleached.

cocoon. a sheath, usually mostly of silk, formed by an insect larva as a chamber for pupation.

cole crops. any of the group of crucifer family crops that are varieties of the species *Brassica oleracea*, including cabbage, broccoli, cauliflower, and brussels sprouts.

conidia (plural). a type of asexual fungal spore.

control action guidelines. guidelines that can be used to determine whether pest control actions are needed.

cornicle. one of a pair of tubular processes on the posterior part of the abdomen of aphids.

cotyledons. leaves formed within the seed and present on seedlings immediately after germination; seed leaves.

crucifer. a plant in the family *Brassicaceae*, also called the mustard family, which includes cole crops.

cultivar. a specially developed agricultural variety.

diapause. a period of physiologically controlled dormancy in insects.

dormancy. a state of inactivity or prolonged rest.

evapotranspiration. the loss of water from soil by the combination of surface evaporation and withdrawal by plants.

field capacity. the moisture level in soil after saturation and runoff (Figure 7).

frass. a mixture of feces and food fragments produced by an insect in feeding.

girdle. to form a ring of dead or damaged tissue around a stem or root.

honeydew. an excretion of such insects as aphids, consisting of modified plant sap.

infection. the entry of a pathogen into a host and establishment of the pathogen as a parasite in the host.

inoculum. any part or stage of a pathogen, such as spores or virus particles, that can infect a new host.

instar. the stage of an insect between successive molts.

larva. the immature form of an insect, such as a caterpillar or maggot, that hatches from an egg and passes through a pupal stage before becoming an adult.

layby application. an application made after thinning or transplanting.

lepidopterous. belonging to the order of insects that includes butterflies and moths.

lesion. a well-defined area of diseased tissue, such as a canker or leaf spot.

ligule. in grasses, a short projection on the inner side of the leaf sheath where the sheath meets the leaf blade (Figure 24).

mycelium. the vegetative body of a fungus, consisting of a mass of slender filaments or hypae.

necrosis. death, usually of a well-defined part of a plant such as a leaf or the areas inside a canker.

necrotic. dead, or containing dead tissue.

nontarget organism. an organism other than the one (s) that a control action is intended to destroy.

nymph. the immature stage of insects such as grasshoppers and aphids that hatch from eggs and gradually acquire adult form through a series of molts without passing through a pupal stage.

parasite. an organism that derives its food from the body of another organism, the host, without killing the host directly; also an insect that spends its immature stages in the body of a host that dies just before the parasite pupates.

pathogen. an organism able to cause disease in a certain host.

pedicel. the stem of an individual flower or fruit.

perennial. a plant that may live three or more seasons and flower at least twice.

pesticide resistance. see p. 22.

pheromone. a substance secreted by an organism to affect the behavior or development of other members of the same species; sex pheromones that attract the opposite sex for mating are used in monitoring certain insects.

phloem. tissue that conducts food, including the products of photosynthesis, through a plant.

phytotoxicity. injury to plants, caused by toxic substances.

proleg. a fleshy, unsegmented leg of caterpillars.

pupa. a nonfeeding, inactive stage in which the tissues of an insect larva are reorganized into those of the adult.

pupate. to molt from the larval stage to the pupa.

reservoir. a site where an inoculum or a population of organisms can survive and from which it may invade a field or come into contact with host plants.

resistant. able to tolerate conditions harmful to other strains of the same species.

rhizome. a horizontal, underground shoot, especially one that forms roots at the nodes to produce new plants (Figure 24).

rosette stage. early stage of vegetative growth in cole crops and lettuce, when leaves begin to radiate out from the main stem on short, overlapping stalks.

sclerotium (plural sclerotia). a compact mass of hardened mycelium that serves as a dormant stage in some fungi.

secondary infection. infection by pathogens that enter the host through and injury caused previously by another organism.

secondary pest outbreak. see p. 23.

secondary spread (of diseases). the spread of a pathogen from one infected plant to another in the same field, as by an insect vector or splashing water.

seed leaf. cotyledon (Figure 6).

senescence. the stage of growth in a plant or plant part from maturity to death, characterized by an accumulation of metabolic products, an increased respiratory rate, and a loss in dry weight.

side-dressing. fertilizer added to the soil around a growing crop.

skeletonize. to remove leaf tissue between the veins, leaving the veins intact.

spiracle. an external opening of the system of ducts, or tracheae, that serves as a respiratory system in insects.

sporangium (plural sporangia). the structure in which asexual spores are produced.

spore. a one-celled, reproductive body produced by certain fungi and other organisms, capable of growing into a new individual under proper conditions.

stoma (plural, stomata). a tiny opening in the surface of leaves or stems for the exchange of gases.

tail-water. irrigation water that has drained from a field.

target pest. a pest that a control action is intended to destroy.

tensiometer. a device for measuring soil moisture, consisting of a closed, buried tube of water that develops a partial vacuum as surrounding soil dries out.

thorax. the second of three major divisions in the body of an insect, and the one bearing the legs and wings.

transpiration. the loss of water vapor by plant parts, mostly through stomata.

true leaf. any leaf produced after the cotyledons.

variety. an identifiable strain within a species, usually referring to a strain which arises in nature as opposed to a cultivar which is specifically bred for particular properties; sometimes used synonymously with cultivar.

vascular system. the system of plant tissues that conducts water, mineral nutrients, and products of photosynthesis through the plant, consisting of the phloem and xylem.

vector. an organism able to transport and transmit a pathogen to a host.

vegetative growth. growth of stems, roots, and leaves, not of flowers and fruits.

virus-indexed. tested for the presence of virus.

xylem. plant tissue that conducts water and nutrients from the roots up through the plant.