PUBLICATION 8208

Small Grain Production Manual

The *Small Grain Production Manual* presents essential information on producing wheat, barley, oat, triticale, and rye, from growth and development through seedbed preparation, fertilization, and irrigation, to pest management, crop rotation, cover cropping, and harvesting and storage. It also includes an overview of small grain production in California as well as a troubleshooting guide.

The *Manual* is available for free download from http://anrcatalog.ucdavis.edu in either of two forms: as individually downloadable parts 1 through 14 or as this single downloadable document that contains all 14 parts plus this cover sheet.

To read an individual section of the *Small Grain Production Manual,* click on a title in the table of contents below or in the Bookmarks strip at left. Once you have jumped to one of the *Manual's* sections, you can return to this page at any time by clicking "Contents" at the top of the Bookmarks strip.

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PUBLICATION 8164

SMALL GRAIN PRODUCTION MANUAL
PART 1

Importance of Small Grain Crops in California Agriculture

LEE JACKSON, Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis; **BONNIE FERNANDEZ,** Executive Director, California Wheat Commission; **HERMAN MEISTER,** University of California Cooperative Extension Farm Advisor, Imperial County; and **MONICA SPILLER,** Whole Grain Connection, Los Altos, CA

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This publication, *Importance of Small Grain Crops in California Agriculture*, is the first in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grains Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 2: Growth and Development*, Publication 8165
- *Part 3: Seedbed Preparation, Sowing, and Residue Management*, Publication 8166
- *Part 4: Fertilization*, Publication 8167
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- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

SMALL GRAIN ACREAGE AND REGIONS OF PRODUCTION

Production of small grain crops—wheat, barley, oat, triticale, and rye—has been a mainstay of California agriculture. From its meager beginning at Mission San Diego in 1769, wheat grew to a million-acre-plus crop by 1980. Overall, small grain acreage has declined since 1980, but it has fluctuated in recent years (USDA-NASS-CA 2005). From 1990 to 2003, planted wheat acres ranged from a low of 483,000 (195,000 ha) in 1991 to a high of 805,000 (326,000 ha) in 2003. Planted barley acres ranged from a low of 100,000 (41,000 ha) in 2003 to a high of 300,000 (122,000 ha) in 1990. Planted oat acres ranged from a low of 220,000 (89,000 ha) in 2000 to a high of 380,000 (154,000 ha) in 1990. Acreage of triticale is not reported officially, but over 50,000 acres (20,000 ha) are grown in the state, primarily as a forage that is green-chopped or ensiled for dairies in the San Joaquin Valley. Triticale is also grown for grazing and haying in the Intermountain Region of north-central and northeastern California.

Small grains are grown throughout California. The state can be divided into five main production regions: the Intermountain Region of north-central and northeastern California; the Sacramento Valley (which includes the Sacramento–San Joaquin

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Figure 1. Primary production regions for small grains in California.
Source: Strand 1990, p. 7.

Delta); the San Joaquin Valley; coastal areas (the North, Central, and South Coasts); and the Southern Desert (including irrigated southern desert areas) (fig. 1).

The Intermountain Region includes the Tulelake Basin, where small grains are grown primarily as spring-sown crops, usually in rotation with alfalfa, onion, and potato. Oat may be rotated with barley as a control for root-knot nematode. In the remainder of the Intermountain Region, small grains are primarily rotation crops for alfalfa. Spring-sown barley and fall-sown winter wheat (primarily soft white wheat) are most common. Oat, barley, and wheat are grown for grain or forage; triticale is grown for grazing and hay production. Some rye is planted for seed production, forage, or as a winter cover crop.

The Sacramento Valley produces a large share of California's fall-sown hard red wheat, along with fall-sown hard white wheat, barley, oat, and triticale. Conditions range from shallow soils along the western, eastern, and northern margins of the valley (rainfed grain production areas) to the deep, highly organic soils of the Sacramento–San Joaquin Delta. On the valley floor irrigated small grains are grown in rotation with alfalfa, cotton, corn, rice, safflower, sugarbeet, sunflower, melons, and a wide range of vegetable crops.

The San Joaquin Valley, like the Sacramento Valley, produces a large share of California's fall-sown hard red wheat as well as hard white and durum wheat, barley, oat, and triticale. Most of the production is irrigated and grown in rotation with other field and vegetable crops including tomato, cotton, alfalfa, and others. Rainfed grain production occurs primarily in foothill areas along the east side of the valley.

Coastal growing regions consist primarily of rainfed production systems. Conservation tillage is common in the central coastal region, where fall-sown spring barley is produced for feed. In areas of the central coast that produce high-value vegetable crops, rye grown as a green manure cover crop is an important rotation. In other locations, dry beans or alfalfa are rotated with small grains grown for grain or forage.

Valleys in the Southern Desert Region are major producers of durum wheat for the pasta market. All durum acreage is irrigated; some feed barley and forage oat are grown. Some rainfed small grain is produced under conservation tillage (reduced-tillage) in the northern portion of the area. Irrigated small grain crops are rotated with lettuce, melons, alfalfa, sugarbeet, cotton, and other crops.

SMALL GRAIN PRODUCTION AND USE

Wheat

Although most of California's wheat production is classified as fall-sown hard red spring wheat, other wheat classes (hard red winter, soft white winter, soft white spring, hard red spring, hard white, and durum) are also produced in California. Wheat is

grown in more than 35 counties of the state. Among the characteristics of wheat cultivars that are important for California production are

- short stature
- lodging resistance
- tolerance to soil saturation
- disease resistance or tolerance
- shatter resistance
- responsiveness to nitrogen fertilizer

For most of the state, with the exception of some production in the Intermountain Region, cultivars currently available have a spring growth habit (do not require vernalization) and are day-length insensitive.

California wheat growers annually produce an average of about 1.1 million tons (998,000 t) of common wheat (mostly fall-sown hard spring wheat but also lesser amounts of other wheat classes) and 250,000 tons (227,000 t) of Desert Durum wheat. A large proportion of California's hard red wheat is used for milling into bread flour or general purpose flour. Varying amounts are sold for feed, depending on price, supply, demand, and grain quality. California wheat is sold both in domestic and foreign markets.

Durum wheat is grown specifically for its semolina, a high-protein-content flour that is used to make macaroni, spaghetti, and other noodle products. Semolina produces a firm, translucent product that imparts a rich yellow color to noodles. The high-quality grain has protein content near or above 13 percent and is free of black point, a fungal disease that discolors the kernel and semolina. The incidence of this disease is influenced by the choice of durum cultivar and by cultural practices such as irrigation frequency and the amount and timing of nitrogen fertilization.

California annually exports up to 330,000 tons (300,000 t) of wheat. Destinations for California wheat have included Bangladesh, Bolivia, Ecuador, Indonesia, Italy, and Peru. China was the major importer of California wheat in the early 1980s, but due to quality and quarantine issues exports to China stopped and were only recently resumed on a limited scale. Hard red wheat is exported through California ports. Much of the exported wheat is produced and shipped by truck from within a 200-mile (320-km) radius of the Port of Sacramento or the Port of Stockton. Desert Durum wheat is exported "identity preserved" (i.e., not mixed with other durum wheat that does not have the Desert Durum trademark and quality traits associated with that designation) through U.S. Gulf ports, with California ports an option, depending on rail rates. The name "Desert Durum" is registered with the U.S. Patent Office and is owned by the California Wheat Commission and the Arizona Grains Research and Promotion Council.

California's domestic wheat flour milling capacity is the second-largest in the United States at 121,100 cwt (6,150 t) per day. Because California does not produce the quantities and diversity of quality characteristics needed within the state, wheat is brought in by rail from other states. Annually, California poultry and cattle producers buy 70 percent of their feed grain needs—7.3 million tons (6.6 million metric tons)—from outside California. Wheat partially fills this need, depending on the price of competitive grains.

Barley

Barley production in California consists primarily of fall-sown 6-row spring barley grown as a feed grain for livestock. Most of the acreage is concentrated in the Central Valley (Sacramento and San Joaquin Valleys) and surrounding foothills and in the south-central coastal area. Barley is grown as an irrigated rotation crop in the Central

Valley and as a rainfed crop in the Central Valley foothills and south-central coastal foothills. A substantial acreage of 6-row or 2-row spring-sown barley is grown under irrigation in the Tulelake Basin in the northeastern portion of California, where it serves as a rotation crop for potato, onion, and alfalfa. Malting barley is occasionally grown in the Tulelake Basin and in the Central Valley. Hooded cultivars of barley are also grown for forage and are often a component of forage mixes.

About 50 percent of the barley crop produced in the United States and consumed domestically is used for animal feed, 45 percent is used for malt production, 3 percent as seed, and 2 percent in food products. California has about 240 brewers, who consume barley indirectly as malt.

Key characteristics for barley cultivars are disease resistance (to scald, stripe rust, leaf rust, net blotch, powdery mildew, and barley yellow dwarf virus), good tillering, short stature, and lodging resistance. Malt-quality cultivars must have high levels of bushel weight, kernel weight, malt extract, diastatic power, and alpha-amylase activity.

Oat

Oat is grown almost exclusively as a forage crop in California and is fed as hay, green-chop forage, or silage to cattle, sheep, and horses. Dairies use oat alone, in mixtures with other small grains, or in mixtures with vetch, winter peas, or other legumes to increase forage protein content. The pleasure horse market uses high-quality pure oat hay as a feed. Fine stems and leafiness are important for this market.

Oat is sometimes planted as a companion crop, or nurse crop, for alfalfa and can be seeded into old stands of alfalfa to increase forage yields in the last year of alfalfa production. Oat also is used as a cover crop.

A limited acreage of 25,000 to 30,000 acres (10,000 to 12,000 ha) of oat is grown for seed or as a feed grain for livestock. The grain can be fed to dairy cattle, horses, mules, replacement layers, and turkeys, as well as to hogs, beef cattle, and sheep. Oat grain is useful in dairy cattle and horse rations because of its high fiber and 12 to 15 percent whole grain protein, compared to 8 percent protein for corn and 10 percent for barley.

White-grained oat is processed into food products by the oat milling industry, but little, if any, California production is used for this purpose. Food products include oatmeal, oat flour, natural cereals, meat product extenders, cookies and breads, granolas, and baby food. Oat-based foods have unique value in human nutrition. Oat groats (the caryopsis, consisting of embryo, endosperm, and outer layers contained within the floral bracts, the lemma and palea) contain 16 percent or more protein. The lipid content of oat, a desirable source of energy, is about 1.8 times that of corn. Daily intake of oat and oat bran can aid in the lowering of blood cholesterol and in the control of diabetes. High-fiber diets including grains such as oat have been linked to decreased incidence of high blood pressure, heart attacks, and colon cancer.

Triticale

Triticale is grown throughout the wheat-growing areas of California. Its main use is forage for dairies in the Central Valley. In that capacity it is green-chopped at the boot or soft dough stage. Triticale also is grown in the Intermountain Region of northeastern California to complement perennial pastures by extending the grazing period (permitting grazing to continue later in fall and then to resume earlier in spring), and it is also grown for hay.

A limited triticale acreage produces grain for livestock feed or as a specialty food grain. Key characteristics for triticale include high grain and total biomass production, rapid spring growth for forage, lodging resistance, and disease resistance.

CHARACTERISTICS OF CALIFORNIA CULTIVARS

Characteristics of cultivars of small grains grown in California can be found in the publication *UC IPM Pest Management Guidelines: Small Grains*, available at the UC Statewide Integrated Pest Management Program Web site, http://www.ipm.ucdavis.edu/PMG/selectnewpest.small-grains.html.

SMALL GRAIN BY-PRODUCTS

Straw is a by-product of production of all the small grain crops. The harvested acreage of small grains in California annually generates approximately 1.5 million tons (1.36 million t) of straw, based on harvest indices (ratio of grain to total biomass) of 40 to 50 percent. Some growers bale the straw and incorporate the remaining stubble into the soil. Other growers spread the straw at harvest and incorporate the entire accumulation of crop residue. Incorporating stubble and straw helps reduce soil loss from wind erosion, increases rainfall infiltration, and reduces the rate of evaporation. Straw accumulation and incorporation over the long term can increase organic matter and soil biological activity. The disadvantages of incorporation are the time, effort, and expense involved and the length of time straw takes to decompose. Depending on location and weather, some growers burn the straw and stubble, provided it is permitted by state and local regulations and restrictions (air quality regulations may soon prohibit open-field burning). Burning has the advantage of disposing of crop residue almost instantly, allowing the next field operation to proceed immediately with little expense to the grower. Burning also may help reduce certain pathogen and weed populations.

Variable amounts of straw are used annually in California as bedding for racetracks, for roadside slope stabilization by the California Department of Transportation, and as the carbohydrate base for compost by mushroom farms. Straw also can serve as a biofuel for cogeneration plants. Small grain straw is grazed in many areas by cattle and sheep and provides a cheap source of roughage. Barley straw has been used to inhibit algae blooms in ponds.

Sizable markets for wheat straw exist in the packaging, building, and construction industries. Wheat straw can be made into straw-board paneling and is used in place of wood products, typically where particle board would be used. Straw board holds screws better than many wood-based materials and is lighter and cheaper to transport. Wheat straw can replace some of the petrochemicals and fillers used in the production of plastics. Wheat straw can also be used for straw-bale home construction: the walls offer excellent insulation at a rating of about R48.

ORGANIC SMALL GRAIN PRODUCTION

Demand exists in California for organically produced small grain crops for feed and food products and to meet the requirements of farm certification for growers adhering to organic guidelines. No single approach is used for growing organic small grains; farming systems, soil types, and fertility programs vary widely. “Organic” denotes products produced under the federal Organic Foods Production Act of 1990. The general guidelines for organic production are to use materials and practices that enhance the ecological balance of natural systems and that integrate the parts of the farming system into an ecological whole. Organic production is based on minimal use of off-farm inputs. Certified organic products are grown and processed under strict uniform standards, including inspections of fields and processing facilities, detailed record keeping, and periodic testing of soil and water to assure that organic production standards are met. Use of any synthetic substance is prohibited unless it is specifically allowed, while use of any nonsynthetic substance (natural material) is allowed unless it is specifically prohibited, under the national list of allowed and prohibited substances of the National Organic

Program (see the Organic Farming Compliance Handbook Web site, http://www.sarep.ucdavis.edu/organic/complianceguide/). No prohibited materials can be applied to organic crops within 3 years of harvest for the production to be certified as organic.

An example of organic small grain production in California is organic wheat grown as a cash crop. Soft white wheat is the most commonly produced organic wheat, but hard and durum wheat classes are also grown. For successful production of organic wheat, the cultivars selected must be adapted to the area of production, have acceptable yield potential, show early (as well as season-long) vigor or be tall enough to compete effectively with weeds, and have adequate resistance to prevailing diseases and insect pests. The cultivars also need to have the desired end-use characteristics for the intended market. Organic whole grain products are an important niche for organic wheat.

Fertilization practices for organic small grain production include the use of cover crops, manures, compost, and crop rotation (e.g., including a legume crop appropriate for the region in the rotation scheme). Mineral amendments such as gypsum are occasionally added prior to planting.

Weeds are controlled by growing cover crops, sometimes by grazing or mowing, and by disking the weeds after the first fall rains and before planting. By sowing at a high rate and selecting cultivars with vigorous early-season growth, the small grain crop competes well with weeds and reduces their impact.

For successful organic production, segregation of organic specialty crops is essential, and it begins on the farm. An organic wheat grower expecting to sell a crop must be able to produce seed that has been thoroughly cleaned after it has been combine harvested, and must also be able to package and store it so that it is ready for milling without any further processing. Organic wheat growers are not permitted to use equipment, such as for tillage and harvesting, that has been used on nonorganic farms. The burden of owning equipment and providing storage facilities can be shared with other organic growers, for example, through grower cooperatives.

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E-mail inquiries: danrcs@ucdavis.edu

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PUBLICATION 8165

SMALL GRAIN PRODUCTION MANUAL
PART 2

Growth and Development of Small Grains

LEE JACKSON, Extension Specialist, Small Grains, University of California, Davis, Department of Plant Sciences; and **JACK WILLIAMS,** University of California Cooperative Extension Farm Advisor Emeritus, Sutter-Yuba Counties.

UNIVERSITY OF CALIFORNIA
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The growth and development of the small grains—wheat, triticale, barley, and oat—follow very similar patterns (fig. 1). Plant development is divided into several stages: germination and early seedling growth, tillering and vegetative growth, elongation and heading, flowering, and kernel development. Numerical scales have been devised for quantifying the growth stages of small grains. Those most commonly used are the Zadoks, Feekes, and Haun growth scales (table 1). The Zadoks system uses a 2-digit code to refer to the principal stages of growth from germination (stage 0) through kernel ripening (stage 9). The second digit subdivides each principal growth stage. For instance, "13" indicates that in principal stage 1 (seedling growth) subdivision 3, leaves are at least 50 percent emerged from the main stem; "75" indicates that in principal stage 7 (kernel development) subdivision 5, the grain is at the medium milk stage. The Feekes scale (1 to 11.4) numerically identifies stages from emergence through ripening. The Haun scale deals mainly with the pattern of leaf production, in which the length of each emerging leaf is expressed as a fraction of the preceding leaf. For more information on these scales, see Simmons, Oelke, and Anderson 1995.

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Table 1. Comparison of Zadoks, Feekes, and Haun growth scales for small grains

	Scale		
Growth stage	**Zadoks**	**Feekes**	**Haun***
planting	00	—	—
emergence	10	1	0.0
first leaf	11	1	0.0–1.0
second leaf	12	1	1.1–2.0
third leaf	13	1	2.1–3.0
tillering	21–29	2–4	3.1–6.0
jointing	31	6	6.1–10.0
flag leaf	37–39	8	8.1–9.0
boot	40–47	9–10	9.1–10.0
heading	51–59	10.1–10.5	10.1–11.0
flowering	61–69	10.5.1–10.5.3	—
grain formation	71	10.5.4	—
milk	71–79	11.1	—
soft dough	85	11.2	—
hard dough	87	11.3	—
harvest ripe	92	11.4	—

Source: Flint 1990, p. 12.
Note: * Values are for Yecora Rojo wheat

GERMINATION AND EARLY SEEDLING GROWTH

The kernel (seed), or caryopsis, consists of a seed coat surrounding an embryo and endosperm. The embryo contains the seedling root (radicle), stem, and growing points of the new grain plant. The endosperm provides nutrients for growth until the first true leaves emerge and the root system is established. When moisture conditions are favorable, the seed germinates with the emergence of the radicle and the coleoptile, the first leaf that forms a protective sheath around the first four leaves.

The primary root system includes the radicle and roots that develop from stem tissue near the kernel (see fig. 1). It may penetrate the soil up to 12 inches (30 cm) and provides the developing seedling with water and nutrients. The primary root system supports plant growth until tillering, when the secondary root system becomes the main root system of the plant. The primary roots may persist for the life of the plant and can support some plant growth through the heading stage. The first secondary roots appear at the tillering node about 1 inch (2.5 cm) below the soil line at the two- or three-leaf stage. These roots are always produced at about the same distance below the soil's surface, regardless of the depth at which the seed is planted. The secondary root system makes up the major part of the fully developed plant's root system. Root growth may continue at ½ inch (12.5 mm) per day for 60 to 70 days. With no competition, roots may spread 4 feet (1.2 m) horizontally and 6 feet (1.8 m) vertically, with most roots in the top 2 feet (60 cm) of soil. Horizontal root growth is less than 1 foot (30 cm) in wheat fields with normal plant

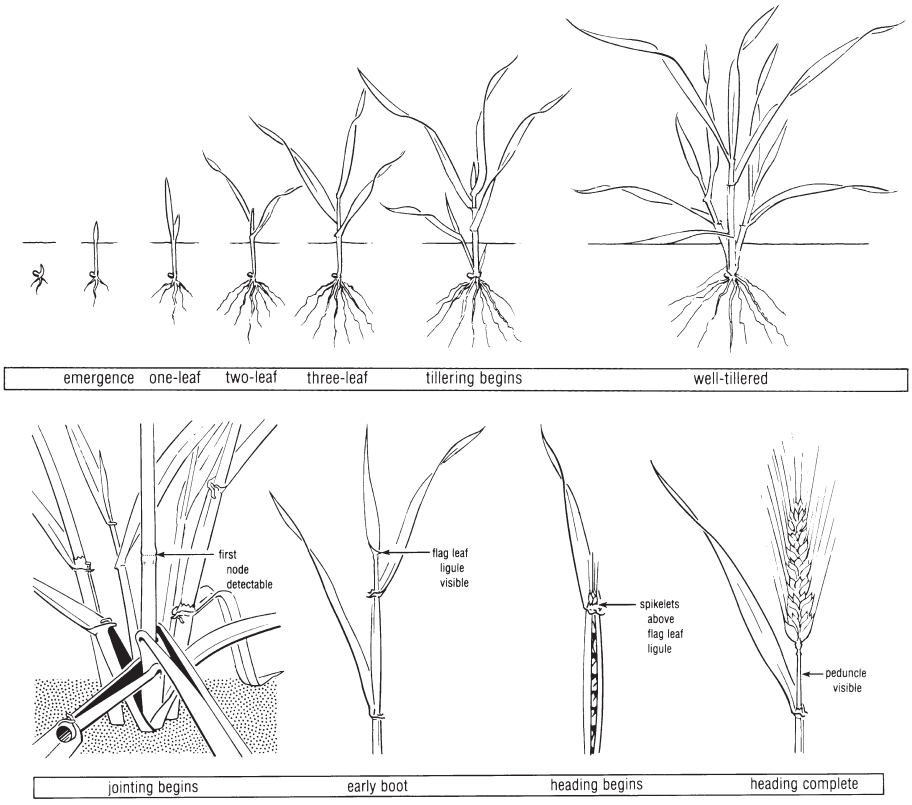

Figure 1. Small grain developmental stages. *Source:* Flint 2002.

population density. Root development approaches the maximum at about the boot stage. The "boot" represents the swollen flag leaf sheath within which the developing spike is located after being pushed up as the stem has elongated.

As the seedling root system is forming, the coleoptile grows upward and ruptures, allowing the first leaf to begin unfolding as soon as the coleoptile tip breaks the soil surface. Emergence usually occurs 6 to 20 days after sowing, depending on temperature and moisture. Emergence can be later than 20 days after sowing under prolonged cold or dry conditions. Initial formation of leaves and stems occurs at the shoot apex, which is located just below the soil surface.

TILLERING AND VEGETATIVE GROWTH

Branching in small grains is called tillering or stooling. Individual branches are called tillers, and the mass of tillers is the stool. Two to four primary tillers develop from buds in the crown area of the main stem. Secondary tillers develop from buds in the axils of leaves at the base of the primary tillers. Tertiary tillers may develop from buds in the axils of leaves at the base of the secondary tillers. Each plant has the potential to produce more than 50 tillers. Usually only two to four tillers survive to produce fertile spikes at normal seeding rates and growing conditions. The number of tillers that form is influenced by plant density (more with low plant density), soil moisture and nutrient supply (more with high supply), sowing date (more with early sowing), temperature (more under cooler temperatures), and cultivar. Water stress, nutrient deficiency, low temperatures, weed competition, and pest damage during early development reduce the number of tillers.

The emergence of primary tillers is synchronous with the emergence of leaves on the main stem of the plant. The first primary tiller begins developing as leaf 4 of the main stem emerges; the second primary tiller begins developing as leaf 5 emerges. Subsequent primary tillers begin developing when subsequent leaves emerge. Successive tillers develop fewer leaves; flowering and grain development is only slightly delayed on later-developing tillers. Before the main stem and tillers begin to elongate, the spikes (panicles in oat) differentiate. The precursors (primordia) of all florets (flowers with lemma and palea, the outer bracts) or spikelets (units consisting of several florets on a thin axis, subtended at the base by two bracts, or glumes) develop at this time. In wheat and oat, formation of new spikelets ends with the formation of the terminal spikelet, which usually occurs when leaf 6 appears. A terminal spikelet is not formed in barley.

Wheat, barley, and oat appear very similar in the vegetative stage. However, they can usually be easily distinguished based on auricle (a pair of clawlike projections at the junction of the leaf sheath and blade) characteristics. On barley, the auricles are long and clasping; on wheat, the auricles are short; on oat, auricles are absent.

STEM ELONGATION AND HEADING

Stem elongation, or jointing, occurs when stem internodes increase in length and bring the nodes above ground. The uppermost five or six internodes elongate, beginning with the lowest of these. The appearance of the first node above ground marks the beginning of jointing. Jointing begins about the time all spikelet primordia have formed. The flowering structure (inflorescence) of wheat, triticale, and barley is called a spike; that of oat is called a panicle. Inflorescences are composed of spikelets, each consisting of one or more flowers, called florets, at nodes along the spike or panicle. In barley, three spikelets form at each node, and each spikelet has a single floret. All three spikelets are fertile in 6-row barley; only the middle spikelet is fertile in 2-row barley. One spikelet forms at each node of the wheat and triticale spike, but each

spikelet consists of three to six potentially fertile florets. In the highly branched panicle of oat, individual spikelets form at the end of branches.

Figure 2. Stages of grain ripening in wheat. *Source:* Flint 1990, p. 14.

During stem elongation the spike or panicle increases in length from about 0.1 inch (3 mm) to its final size, and individual florets mature. All stages of spikelet development in wheat, triticale, and barley begin near the middle of the spike and proceed toward the base and tip. Development of oat florets begins at the tip of the panicle branches and proceeds toward the base. The last leaf of the small grain plant to emerge is called the flag leaf. When the flag leaf blade has completely emerged, the appearance of its ligule (a short membrane on the inside of the leaf at the junction of the blade and sheath) marks the beginning of the boot stage. During boot stage the enlarging spike swells and splits the sheath of the flag leaf. Heading begins when the spike begins emerging through the flag leaf collar and is complete when the base of the spike is visible.

FLOWERING AND GRAIN FILLING

The flowers of wheat, triticale, barley, and oat are self-pollinated; most of the pollen is shed before the anthers emerge from the florets. Flowering (anthesis, or pollen shed) usually occurs within 2 to 4 days after spikes have completely emerged from the boot (barley often flowers prior to emerging from the boot). If emergence occurs during hot weather, flowering may occur while spikes are still in the boot. Most cells of the grain endosperm are formed during a period of rapid cell division following pollination. These cells enlarge and accumulate starch during grain filling. Most of the carbohydrate used for grain filling comes from the photosynthetic output of the flag leaf. Developing spikelets compete for limited supplies of photosynthate and nitrogen. The smallest, slowest-growing florets, which occur at the tip of the barley spike and at the tip of each wheat spikelet, are often unable to obtain enough nutrients to keep growing. Some spikelets at the base of the wheat or barley spike also may fail to develop.

The stages of grain ripening are called milk, soft dough, hard dough, hard kernel, and harvest ripe (for wheat, see fig. 2). Dry matter begins accumulating in the kernel dur-

ing the milk stage. During early milk stage, a clear fluid can be squeezed from the kernel. During late milk stage, milky fluid can be squeezed from the kernel. Most of the dry matter accumulates during the soft dough stage. Loss of water gives the kernel a doughy or mealy consistency. At the end of the hard dough stage the kernel reaches physiological maturity, water content drops to about 30 percent, and the plant loses most of its green color. The kernel contents can be divided with a thumbnail. At the hard kernel stage the plant is completely yellow and water content of the kernel is 20 to 25 percent. The contents of the kernel are difficult to divide with a thumbnail, but its surface can be dented. When kernel moisture content has dropped to 13 to 14 percent, the grain is harvest ripe. The surface of the kernel cannot be dented with a thumbnail.

GROWTH HABIT

Wheat, triticale, barley, and oat are classified as having either a spring or a winter growth habit. Plants with a winter habit require a period of chilling, or vernalization, to induce the formation of reproductive structures. Without proper vernalization, winter-habit plants either fail to head or head much later than normal. Plants with a spring habit do not require vernalization. Most California production consists of fall-sown spring-habit small grain crops. However, since market classifications sometime refer to the season of production, not growth habit, California's production is often referred to as winter-type cereals (e.g., hard red winter wheat). True winter wheat and winter barley are produced on limited acreage in the intermountain area of north-central and northeastern California.

YIELD COMPONENTS

Grain yield is the product of plant density, tiller number, number of spikes per plant, number of spikelets per spike, number of kernels per spikelet, and kernel weight. Plant density is determined by seeding rate, germination percentage, and the number of seedlings that emerge and survive. Tiller number per plant depends on plant density, cultivar, sowing date, availability of moisture and nutrients, and temperature. The number of spikelets that can form is determined by when stem elongation is initiated; stress (weed competition, heat, cold, drought, nutrient deficiency, diseases) during this period reduces the number of spikelets that are formed. Florets are initiated during the stem elongation stage. The small grain plant is not able to produce enough photosynthate to allow development of all florets. The fastest-growing florets have first access to the available carbohydrate, nitrogen, and other nutrients and are the most likely to produce mature seed. Good growing conditions during stem elongation favor development of the maximum number of florets. The cells of the endosperm accumulate starch and protein during grain filling. Any stress or damage that reduces photosynthetic output or interferes with the transport of carbohydrate between flowering and hard dough stage will reduce kernel weight.

Timing of Field Activities

Table 2 gives approximate dates when important crop growth stages occur for wheat produced in key growing regions of California. The dates and corresponding growth stages are for common wheat cultivars sown at optimal planting dates with sufficient soil moisture to initiate germination. Seasonal weather conditions are considered average. Depending on the cultivar selected, crop development may vary 7 days on either side of the dates specified. Similarly, even under the most variable weather conditions, crop development will be within about 7 days of the dates specified. For barley, heading and grain-fill dates will be advanced by about 2 weeks. Herbicides for early-season weed control should be applied prior to the onset of tillering, when weeds are small (follow

Table 2. Approximate dates of selected wheat growth stages in key growing regions of California

	Date growth stage attained for region and approximate sowing date					
Growth stage	Intermountain Area (winter) mid Oct. to early Nov.	Intermountain Area (spring) mid April	Sacramento Valley mid Nov.	San Joaquin Valley late Nov. to Mid Dec.	Central Coast early Nov.	Imperial Valley mid Dec.
emergence	Nov. 10	May 1	Dec. 1	Dec. 30	Dec. 1	Dec. 30
tillering	Jan. 15	May 15	Jan. 1	Feb. 5	Jan. 1	Jan. 15
jointing	April 1	June 10	Feb. 15	Mar. 10	Feb. 18	Feb. 15
boot	May 15	June 20	April 1	April 1	April 10	March 15
heading/flowering	June 1	July 15	April 15	April 10	April 30	April 1
milk	June 15	July 20	May 1	April 25	May 15	April 10
soft dough	June 25	Aug. 1	May 15	May 10	May 30	April 20
hard dough	July 10	Aug. 15	June 1	May 25	June 15	May 1

the label). Herbicide applications for later-season weed control should be made when the crop is fully tillered. Fertilizer top-dressing should be made at the mid-tillering stage. Nitrogen top dressing to improve grain protein should be made at heading or flowering in conjunction with an irrigation. If fungicide applications to control foliar diseases are planned, they should be applied to protect the flagleaf and penultimate leaf (the leaf that emerges prior to the flagleaf), and thus should be made just prior to boot stage.

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E-mail inquiries: danrcs@ucdavis.edu

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SMALL GRAIN PRODUCTION MANUAL
PART 3

Seedbed Preparation, Sowing, and Residue Management

TOM KEARNEY, University of California Cooperative Extension Farm Advisor Emeritus, Yolo-Solano Counties; **BRIAN MARSH,** University of California Cooperative Extension Farm Advisor, Kern County; **STEVE WRIGHT,** University of California Cooperative Extension Farm Advisor, Tulare County; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California Davis

UNIVERSITY OF CALIFORNIA
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This publication is the third in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
- *Part 4: Fertilization*, Publication 8167
- *Part 5: Irrigation and Water Relations*, Publication 8168
- *Part 6: Pest Management—Diseases*, Publication 8169
- *Part 7: Pest Management—Insects*, Publication 8170
- *Part 8: Pest Management—Vertebrates,* Publication 8171
- *Part 9: Pest Management—Weeds*, Publication 8172
- *Part 10: Small Grain Forages*, Publication 8173
- *Part 11: Small Grain Cover Crops*, Publication 8174
- *Part 12: Small Grains in Crop Rotations*, Publication 8175
- *Part 13: Harvesting and Storage*, Publication 8176
- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

The main objective of seedbed preparation in small grains is to produce a firm, debris-free, weed-free seedbed for rapid germination and emergence. Good contact between the seed and the soil is necessary for quick imbibition and germination. Seedbed preparation varies among regions according to crop rotation, soil type, need for soil and moisture conservation, residue management, and growers' approach to tillage.

SEEDBED PREPARATION

Conventional Systems

Soil type and previous cropping pattern dictate the amount of tillage necessary to prepare the seedbed. A field with a large amount of residue from the previous crop, such as a crop produced on irrigated soil, requires deep plowing or deep tillage to help decompose the residue and to keep the surface soil free of debris. Soil should be plowed or disked as deeply as possible to help break up compaction and reduce the risk of herbicide carryover. Deep plowing, or at least two diskings, may be necessary. Disking and harrowing follow plowing or chiseling to complete seedbed preparation.

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Soils should not be tilled when wet since this contributes to soil compaction, large clods, and other physical conditions unfavorable for growth of small grains.

The seedbed should be several inches deep, and the soil clods should be small enough so that they do not interfere with grain drilling, such as by getting caught between disc openers. Seedbeds with large clods and heavy crop residue that do not pass freely through the conventional 6- to 7-inch drill spacing of grain drills produce a weak stand with uneven germination. Conversely, an overprepared seedbed creates a powdery surface soil that is prone to crusting, which can delay or prevent emergence. Seedbed preparation for broadcast seeding is less critical because the broadcasting equipment does not drag clods and residue.

Summer fallowing preceded by deep plowing or deep tillage is one system used in rainfed production areas. With summer fallowing, seedbed preparation can be completed well before the normal fall planting period, allowing seed to be planted before the onset of the rainy season. Seedbed preparation for summer fallowing begins with plowing or chiseling in spring followed by disking or harrowing. This process starts after volunteer cereals and weeds have made some growth but before weeds have produced seed and while there is ample moisture available for tilling. Soil can then be disked in early fall to break up large clods and harrowed after the first rain to help control germinating weeds.

Annual cropping is also used in rainfed areas. Seedbed preparation for annual rainfed cropping begins with disking or chiseling dry soil in early summer. The seedbed is prepared after fall rains begin and is completed with shallow disking or harrowing. There is more risk of crop failure with annual cropping than with summer fallowing because inadequate moisture conditions and increased weed and disease pressure are more likely under annual cropping.

Minimum-Till and No-Till

Minimum-till and no-till seedbed preparation can be very beneficial in rainfed cropping systems because the crop residue that remains on the soil surface helps retain moisture and prevent soil erosion. In addition, reduced-tillage systems generally have lower input costs than conventional systems. Seedbed preparation usually consists of applying chemical weed control if weeds are present and drilling seed directly through the residue of the previous crop. The amount of disking and harrowing needed to bury surface crop debris, kill emerging weeds, and incorporate seed or fertilizer is limited. Straw and chaff must be thoroughly chopped and spread during harvest of the previous crop in order for sowing to be successful. Also, care must be taken in setting up sowing equipment so that the drill is able to cut through surface residue. "Hairpinning" occurs when residue is not cut but stuffed into the seed slot by the openers, preventing the soil-seed contact necessary for optimal germination.

Mulching

Mulch may be used in irrigated production in the Southern California Desert Region or other regions where rain is not expected before stand establishment. Fields are prepared, leveled, fertilized, and irrigated approximately 2 to 4 weeks before sowing to allow enough time for the fields to dry sufficiently for mulching and seeding. A mulch layer of dry soil 2 to 3 inches (5 to 7.5 cm) thick is created and seed is drilled into the moist soil beneath the mulch layer. This system of mulching can provide excellent weed control.

SOWING

Sowing Flat Versus Sowing on Beds

Small grains grown under well-drained conditions can be successfully sown flat or on raised beds. Soil type and surface drainage determine the best method for a given field. If border-check irrigation is planned, border levees should be prepared before sowing, and seed should be drilled through or across the levees. Heavy winter rains can flood fields prepared in this manner, so drainage must be provided. In the Sacramento–San Joaquin Delta, small grains are sown flat and spud ditches are dug every 100 feet (30 m). Spud ditches are the smallest ditches in the drainage system used in peat soils, about 12 inches (30 cm) wide and 24 inches (60 cm) deep, and are connected to larger 4-foot (1.2-m) ditches. They provide both drainage and subirrigation.

Many small grain growers use raised beds to allow for better winter drainage and to provide for spring irrigation. Raised beds can be especially effective on heavy soils that hold moisture for long periods. They improve drainage, keeping the root system and plant crown aerated and reducing the chance of root rot, and they can also reduce nitrogen loss due to denitrification and leaching. The beds are spaced up to 60 inches (1.5 m) apart; the width of beds depends on the equipment used, rotation crops planted in the same field, soil type, and how well the soil moves water laterally to the center of the bed, or "subs," during irrigation. The tops of raised beds should be flat or rounded so that water does not accumulate around plant crowns, where it can cause waterlogging. Beds can be formed with listing shovels on a tool bar. Furrows should run with the field's slope, and drainage should be provided at the end of the field. Planting systems for raised beds include

- bedding and shaping the bed top followed by drilling the seed parallel or diagonally to the beds (the preferred method)
- bedding and shaping the bed top followed by broadcast seeding and harrowing to cover the seed
- broadcast or drilling the seed followed by harrowing and furrowing (which saves time)

Drilling Versus Broadcast Seeding

Most sowings on irrigated soils are drilled. The advantages of drilling over broadcasting include a more uniform depth, some reduction (up to 20%) of seeding rate, more uniform emergence, and the ability to place a starter fertilizer (a low-nitrogen, high-phosphorus fertilizer) with the seed. The advantage of broadcast seeding is that it permits large acreages to be sown in less time; the disadvantages are poor soil to seed contact, uneven planting depths (some seed too shallow for proper emergence of permanent root systems, and other seed too deep for germination), and, often, poor plant distribution. Broadcast seeding is successful when soil conditions are optimal, the seedbed is prepared properly, and rainfall or irrigation follows broadcasting and harrowing.

Seeding into Moisture from Irrigation or Rainfall

Some growers, particularly in the San Joaquin Valley and in the desert valleys of Southern California, preirrigate then sow into moist soil. Preirrigation of fine-textured soils such as clay loams and clays should be done early enough in the fall to allow time for the topsoil to dry sufficiently to permit seedbed preparation and sowing before rain begins in mid to late November. Preirrigation can be done later on loam and fine sandy loam soils that drain more quickly. One advantage of preirrigation is that weeds germinate before seeding and can be removed by tillage during seedbed preparation. Preirrigation can also provide ideal soil-water content in the seedbed so that uniform germination begins soon after seeding.

Seeding into a dry seedbed and then irrigating to germinate the seed is a second option. In the Central Valley, early seedings, in mid-November to early December, are more successfully germinated by irrigation. Irrigating early seedings assures warm soil temperatures at germination, while the risk of rainfall immediately after irrigating is relatively low. Significant rainfall after irrigating prolongs standing water and creates poor aeration around the seed, retards seedling growth, and may lead to seedling disease. Irrigating for germination is more successful on fine sandy loam and loam than on silt loam, clay loam, and clay. The advantage of irrigating to germinate seed rather than waiting for rainfall is that rainfall is unpredictable. However, in years when rainfall during December is insufficient for germination and the field is not irrigated to germinate the seed, emergence will be late, the production season will be shorter, and yields will be lower.

Seeding into a dry seedbed and waiting for rain is a third alternative. Seed retains its viability in dry soil for an extended time (several months), and stands will generally be adequate once rainfall induces germination. In California's Central Valley production region and similar areas, as long as seed germinates by the end of December, losses in yield potential will be minimal. This alternative is cost-effective in areas where surface water is unavailable and groundwater is expensive to pump or is of undesirable quality.

Sowing Depth

The recommended sowing depth is 1 to 1½ inches (2.5 to 4 cm) for wheat and triticale and 1 to 2 inches (2.5 to 5 cm) for barley and oat. If small grains are sown deeper than 2 inches, germination is delayed, emergence is impeded, and stands may be reduced. The sheath that surrounds and protects the embryonic plant as it emerges from the seed (the coleoptile) is only about 2 to 2½ (5 to 6.5 cm) inches long, and it can be buried at deep seedings.

Sowing Date

Most of California's small grain crop is sown in the fall (October through December) (see table 1) and harvested in late spring to early summer (May through July). One exception is in the Intermountain Region of Northern California, where both winter and spring cereals are produced. True winter cereals are seeded in this area in mid-October through November and harvested in July. Spring cereals are sown in the spring (early April to mid-May) and harvested in late summer (late August through mid-September). Choosing the correct sowing date can reduce the likelihood of damage by frost and certain diseases, make weeds easier to control, and increase yield. Sowing too early in the fall increases the risk of frost injury at flowering, damage by barley yellow dwarf virus (wheat, barley, oat), Septoria tritici leaf blotch (wheat), and net blotch and leaf scald (barley). Later-emerging crops are less likely to be damaged by frosts; the crop should be sown late enough to minimize the risk that the crop will be flowering when there is a significant chance of frost.

Table 1. Recommended sowing dates for small grain crops in California

Growing region	Wheat, triticale, and oats	Barley
Intermountain (winter grain)	mid-Oct. to early Nov.	mid-Oct. to early Nov.
Intermountain (spring grain)	early April to early May	early April to early May
Northern Sacramento Valley	early Oct. to mid-Nov.	mid-Nov to Feb. 1
Sacramento Valley, Delta, Northern San Joaquin Valley	late Oct. to Jan. 1	mid-Nov. to Feb. 1
Southern San Joaquin Valley, Southern Desert Valleys	mid-Nov. to mid-Jan.	Dec. to Feb.
Coastal, irrigated	mid-Nov. to mid-Dec.	mid-Nov. to mid-Dec.
Coastal, dryland	early Nov. to mid-Dec.	early Nov. to mid-Jan.

If soil type and weather permit, field preparation should be delayed until fall rains stimulate weed seed germination so that weed seedlings can be destroyed before or during sowing. Sowing should not be delayed too long, however, or fields may be too wet to sow and excessive soil compaction may occur. The highest yield of irrigated small grains in the Central Valley is obtained by sowing from late October through mid-December. Yields progressively decrease with sowing after January 1. Late-sown

grain produces fewer tillers and shorter plants; it is also likely to be damaged by barley yellow dwarf virus. In rainfed systems where growers must make maximum use of winter rainfall, sowing usually starts in mid to late October, early enough so that sowing can be finished before winter rains saturate the soil and prevent operation of equipment.

Replanting is necessary if stand establishment is poor. A good plant density for an irrigated field averages about 25 plants per square foot (270 per square meter). Consider replanting if the stand is less than half of that density.

Seeding Rate

The optimal seeding rate is determined by sowing method and growing conditions (see table 2). For wheat it ranges from about 1 million seeds per acre (2.5 million per ha) for rainfed crops to 1.2 to 1.5 million seeds per acre (3.0 to 3.7 million per ha) for irrigated crops.

Higher rates are used for broadcast sowing since a smaller proportion of broadcast seed emerges. Higher rates and narrower row spacing are recommended for late sowing to compensate for the fewer tillers that will form and because higher sowing densities tend to shorten the time to flowering. Higher rates are also recommended if poor growing conditions (e.g., competition from weeds) are anticipated. High seeding rates help control johnsongrass and swamp smartweed in the Sacramento–San Joaquin Delta. Lower seeding rates can help avoid lodging, especially with barley and oat, when optimal growing conditions are expected.

Seeding rates for barley are not as critical as for wheat because barley has a greater ability to compensate for a thin stand through increased tiller production. Cultivars can vary widely in seed size, as can different seed lots of the same cultivar, so the metering system of the grain drill must be calibrated before use. Certified seed tags may specify a thousand kernel weight (in grams), which can be converted to seeds per pound and seeds per acre. A seeding rate of 1.2 million seeds per acre equals about 28 seeds per square foot (300 per square meter), which equals about 106 pounds per acre (119 kg/ha) for a cultivar that has a thousand kernel weight of 40 grams.

Table 2. Recommended seeding rates for small grain crops in California

	Seeding rate*	
Crop	**lb/acre**	**kg/ha**
irrigated wheat	100–150	112–168
irrigated wheat, Delta	180–250	202–280
rainfed wheat	60–100	67–112
irrigated barley	80–120	90–134
rainfed barley	60–100	67–112
oat†	80–120	90–134
irrigated triticale	100–150	112–168
Cover Crops		
barley	90	101
cereal rye	60	67

Notes:
*Increase rate by 20 to 30 pounds per acre (22 to 34 kg/ha) for broadcast plantings. Increase rate by 25 to 50 pounds per acre (28 to 56 kg/ha) and use narrower row spacing for late plantings.
†Use higher rates for forage production, lower rates for grain production.

RESIDUE MANAGEMENT

When crop residues interfere with planting operations, management practices must remove or reduce them. These practices include baling and removing straw, grazing, plowing, or burning, alone or in combination. Choppers or spreaders should be attached to the combine unless the straw is to be baled. Removing, deep plowing, or burning residue may help reduce the buildup of disease-causing organisms that survive on crop residue, such as those that cause Septoria tritici leaf blotch (wheat) and net blotch and scald (barley). Incorporating crop residue improves soil structure and in many instances is a major benefit of a small grain crop.

Small grain crops are often followed by corn or summer vegetable crops such as beans or tomatoes in some parts of the Central Valley and similar areas. In these situations, open-field burning of small grain residue, where permitted, may expedite preparation of the field for the following crop. Agricultural burning is controlled by state and local agencies, which impose restrictions on the time of burning, acreage burned, and burning procedures. Before burning, permits must be obtained from county air pollution control districts, the agricultural commissioner, or other designated agencies.

Conservation tillage, defined as a tillage program that keeps at least 30 percent of the soil surface covered by crop residue at all times, is appropriate for many rainfed small grain production areas. Maintaining a surface cover of crop residue to reduce

soil erosion is an important part of conservation tillage operations. Straw chopper and spreader attachments should be used on the combine to spread crop residue uniformly. This helps control erosion and improves distribution of the straw. Areas of straw accumulation may tie up nitrogen fertilizer during the following crop season. In no-till operations, uniform distribution of crop residue is critical to providing favorable planting conditions for the next crop.

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SMALL GRAIN PRODUCTION MANUAL PART 4

Fertilization of Small Grains

DOUG MUNIER, University of California Cooperative Extension Farm Advisor, Glenn County; **TOM KEARNEY,** University of California Cooperative Extension Farm Advisor Emeritus, Yolo-Solano Counties; **G. S. PETTYGROVE,** Extension Specialist, Soils, Department of Land, Air, and Water Resources, University of California, Davis; **KENT BRITTAN,** University of California Cooperative Extension Farm Advisor, Yolo-Solano-Sacramento Counties; **MARSHA MATHEWS,** University of California Cooperative Extension Farm Advisor, Stanislaus County; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

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- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
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Nitrogen fertilizer is usually needed every season by small grain crops. The amount needed depends on soil type, previous crop, rainfall, irrigation, projected yield, and quality goals. Under some circumstances, it may be necessary to apply phosphorus, potassium, sulfur, or zinc; perform soil tests before sowing to determine whether fertilizers are needed. The nitrogen status of a small grain crop is best monitored during the season using tissue analysis. Since tillers and heads are formed in the very early growth stages, adequate nutrient levels in the root zone at this time are important for attaining maximum yield. Careful soil sampling and analysis are necessary for determining soil nutrient levels and fertilizer requirements.

UC PEER REVIEWED

SOILS AND SOIL FERTILITY

Small grain crops are grown on many soil types in California. Soil textures vary from gravel to clay to the Sacramento–San Joaquin Delta's peat soils. Crop rooting depths vary with soil texture, soil profile development, drainage, and the presence of restrict-

ing layers. Roots of small grains can penetrate 7 feet (2.1 m) deep on well-drained deep soils if there are no restricting layers, but penetration of 3 to 5 feet (0.9 to 1.5 m) at maturity is more common. Soils in many rainfed areas are shallow claypans or hardpans. Nitrogen loss can be very high on these soils during high-rainfall years since denitrification occurs under waterlogged soil conditions. Nitrogen losses can be minimized on shallow or coarse-textured soils by making split applications of nitrogen.

NITROGEN

Role of Nitrogen in the Plant

Adequate nitrogen stimulates vegetative growth and increases yield and protein content. Excessive nitrogen increases lodging, delays maturity, increases the severity of some diseases, contributes to groundwater pollution, and causes rainfed crops to deplete available moisture too early in the season. The nitrogen requirement of the crop is directly related to the final grain yield. Plants obtain nitrogen from residual nitrogen in the soil, from nitrogen released from decaying organic matter (including the residue of the previous crop), and from applied fertilizer. On most soils 100 to 180 pounds per acre (112 to 202 kg/ha) of nitrogen may produce 3 to 3.5 tons per acre (6.7 to 7.8 t/ha) of wheat grain, depending on the previous crop, winter soil moisture, and rainfall conditions. Durum wheat may require higher rates of nitrogen, up to 240 pounds per acre (269 kg/ha). Barley and oat require less nitrogen, with optimal yields attained with applications of 50 to 120 pounds per acre (56 kg/ha).

Nitrogen Deficiency Symptoms

Nitrogen deficiency symptoms are characterized by an overall yellowing of leaves, beginning with the bottom (older) leaves. Younger leaves remain green and appear healthy. Plants are smaller and produce fewer tillers than plants with adequate nitrogen.

Nitrogen Requirements and Rates

The amount of nitrogen required by the crop depends on the type of small grain, the previous crop in the rotation, the soil type, and weather conditions and cultural practices during the growing season. Barley, oat, triticale, and wheat require different amounts of nitrogen; the amount depends on the yield potential of the crop and the intended use (grain production requires higher nitrogen levels than forage production). More nitrogen is required when wheat follows crops such as rice, cotton, or wheat than when wheat follows vegetable crops, since more residual nitrogen normally remains after the harvest of vegetables. Large amounts of residue from any previous crop may require more nitrogen at sowing to provide enough available nitrogen for small grain growth and residue breakdown. Nitrogen may be lost on gravelly or sandy soils due to leaching below the root zone. Losses can occur from waterlogged soils when nitrogen is lost to the atmosphere as nitrogen gas (N_2) or nitrogen dioxide (N_2O) through a biological process called denitrification. Waterlogging is likely on heavy soils and/or soils with a hardpan or claypan. Excessive winter rains and excess irrigation can cause nitrogen loss from any soil. Sowing on raised beds rather than on flat ground provides better drainage, reduces nitrogen loss, and provides better soil conditions for root growth.

If the crop is sown in late fall and makes little growth before the onset of cold weather, little nitrogen uptake will occur during winter. In the Central Valley, a substantial amount of nitrogen uptake normally occurs beginning in late January to early February. The rate of accumulation increases through the spring, peaking at about flowering and then decreasing as the crop reaches maturity.

Rates for rainfed production

Three types of cropping are common in rainfed small grain production: 3-year or longer rotations (pasture-fallow-small grain), 2-year rotations (fallow-small grain), and annual cropping. Less nitrogen is applied under 3-year rotations than under annual cropping because nitrogen accumulates in soils during pasture and fallow years. Fields that produce abundant annual clovers require less applied nitrogen if annual clovers are pastured and plowed under as green manure crops. As little as 10 to 20 pounds per acre (11.2 to 22.4 kg/ha) of nitrogen at sowing is sufficient if legumes are plowed under as a summer fallow. If the fallow green manure crop consists entirely of grasses or broadleaf weeds, an application of 20 to 40 pounds per acre (22.4 to 44.8 kg/ha) of nitrogen is recommended at sowing. Residual soil fertility is adequate for optimal yield for some long-term rainfed rotation acreage.

Since moisture is generally the limiting factor for rainfed yield, nitrogen rates should be adjusted for lower yield potential, rainfall patterns, and soil moisture holding capacities. All nitrogen normally is applied preplant for rainfed production.

Split applications

Split applications of nitrogen are usually beneficial for irrigated production, although all nitrogen can be applied at once during sowing on well-drained soils not normally subject to leaching and waterlogging. When splitting the nitrogen on heavy or claypan soils, apply one-half to two-thirds of the nitrogen at sowing and apply the remainder as a topdressing. On extremely gravelly or sandy soils or on poorly drained soils of high clay content, split the nitrogen application with half applied preplant and half topdressed to reduce nitrogen losses. On peat soils, apply about half the amount of nitrogen normally used on mineral soils; no preplant nitrogen is required, but a low rate of nitrogen should be part of the starter fertilizer (high phosphorus content) at sowing.

Topdressing for yield

When topdressing, make one or two applications of 30 to 50 pounds per acre (33.6 to 56 kg/ha) of nitrogen, depending on the amount of rain during the winter. Nitrogen applications made during the tillering stage, followed by rain or an irrigation, are most effective for attaining maximum grain yield; applications made as late as boot stage are less effective, while applications made at heading or later have little affect on grain yield. If rain or irrigation occurs within a few days after application, little nitrogen is lost to the air. If conditions are dry and cold (typical during tillering), losses are minimal if rain or irrigation occurs within 2 weeks. Volatilization of nitrogen to the air is greatest under warm, moist conditions.

Stem nitrate-nitrogen (NO_3-N) tissue tests are an effective way to monitor the nitrogen status of the crop. Table 1 provides critical stem NO_3-N levels for wheat and barley as the crop develops from the third and fourth leaf stage to boot stage. These tests are not effective for managing nitrogen fertility after heading when the goal is to achieve high grain protein. Proper tissue sampling is important to attain a valid, informative analysis. Collect 20 to 40 stems at random from typical areas of the field. Cut off the roots and plant tops and send the bottom 1 to 2 inches (2.5 to 5 cm) of the stems to the laboratory for analysis. Be certain the stem tissue sample is not contaminated with soil or leaves. Submit the tissue samples for analysis the same day they are collected.

Table 1. Critical stem NO_3-N levels during vegetative growth for wheat and barley

	NO_3-N (ppm dry weight)		
Growth stage	**Deficient**	**Adequate**	**Excessive**
3 to 4 leaf	< 7,000	7,000–12,000	> 12,000
tillering	< 6,000	6,000–11,000	> 11,000
jointing	< 5,000	5,000–10,000	> 10,000
boot	< 4,000	4,000–9,000	> 9,000

Applications to improve grain quality

Wheat grown for bread flour should be managed to attain high bushel weight and a grain protein content above 13 percent, as well as maximum grain yield. An irrigated wheat crop with high yield potential should receive 100 to 180 pounds per acre (112 to 201.6 kg/ha) of nitrogen in a combination of preplant and topdressed (during tillering) applications. After heading, wheat may require one more nitrogen application of 20 to 50 pounds per acre (22.4 to 56 kg/ha) to produce a high protein content in the grain. Nitrogen can best be applied during the 3 weeks from just after the spikes have emerged from the flag leaf sheath to about 2 weeks after flowering. An application is effective only when coordinated with an irrigation or rainfall. Low rates are appropriate for low-yielding crops, while higher rates are best suited for yields above 3 tons per acre (6.7 t/ha).

Late-season application of nitrogen may not be needed to attain high grain protein content if the wheat grain yield potential is less than about 2.25 tons per acre (5.0 t/ha), and if nitrogen was applied preplant and topdressed during the tillering stage. Cool, dry weather during grain filling generally results in higher grain yields; management for protein is more critical under those conditions.

Nitrogen application near the boot stage (before heading) typically increases the grain protein content about 0.5 to 1.0 percent. The increase is not as large as when nitrogen is applied at flowering, when nitrogen applications usually increase grain protein content by 1.0 to 1.5 percent or more.

Water-run Nitrogen

Water-run applications of anhydrous ammonia, UAN-32, aqua ammonia, or urea applied at the beginning of an irrigation set are preferred for late-season fertilization. This provides an effective means of applying the necessary nitrogen and water for maximum yields. Foliar nitrogen applications are also effective at raising grain protein content but are usually more expensive and may damage the leaves under many conditions.

Forms and Costs of Nitrogen Fertilizers

The choice of fertilizer material depends on current weather conditions, weather forecasts, and fertilizer costs. Urea (46-0-0) is the highest-analysis nitrogen fertilizer available and is usually the least expensive dry form of nitrogen. It is particularly effective when broadcast and followed by at least 0.5 inches (2.5 cm) of rain within 5 days after application. Urea is converted to ammonium nitrogen and then to nitrate nitrogen by soil microbial processes, so it is released over a longer period of time and is less prone to leaching from the root zone than are some other forms of nitrogen. Urea is relatively unstable when broadcast onto the soil surface, however, and volatilization (loss to the air) can occur.

Ammonium nitrate (34-0-0) is an alternative to urea, if it is available, but it is more expensive. It is preferable to urea when the crop is severely deficient because both the nitrate and ammonium forms of nitrogen are readily taken up by the crop and recovery is more rapid. Ammonium sulfate (21-0-0) containing 24 percent sulfur is desirable if there is a likelihood of sulfur deficiency, but this material is usually more expensive than urea. A blend of mostly urea with some ammonium sulfate is available in some areas.

Applying Nitrogen in Dairy Lagoon Water

Dairy lagoon nutrient water (including liquid manure and wastewater) can supply most or all of the nitrogen, phosphorus, and potassium needs of small grain forage crops. However, these nutrients must be managed carefully. Misused, they can kill or

damage crops, contaminate ground and surface waters, and produce forage that is toxic to animals consuming it. It is critical to understand the forms and concentrations of nutrients and how they behave in the soil, and to apply the appropriate amount of nutrients during or just prior to the time the crop will take the nutrients up.

Forms of nitrogen in lagoon water

Lagoon water contains ammonium forms and organic forms of nitrogen. The ammonium in lagoon water behaves the same as ammonium in fertilizers. Ammonium is positively charged and adheres to soil particles, which are mostly negatively charged. When lagoon water is applied, most of the nitrogen remains in the upper foot of the soil because the ammonium adheres to the soil. As long as nitrogen is in the ammonium form, it is resistant to leaching. However, ammonium is converted to nitrate by microorganisms in the soil. This process occurs rapidly when the soil is warm and slowly when the soil is cold; ammonium applied in early fall on warm soils converts to nitrate within days of application. Nitrate is negatively charged and leaches readily during irrigation or heavy rainfall.

Organic nitrogen in lagoon water is bound up in particles of organic matter and must be broken down into ammonium or nitrate by microorganisms before it becomes available to the crop. The rate of breakdown depends on moisture content, soil temperature, and the resistance of the material to decay. The presence of organic nitrogen complicates the use of lagoon water on crops because if a crop does not take up organic nitrogen as it is released, the nitrogen may become a source of groundwater contamination. In determining rates of nitrogen fertilizer application, take into account the release of available nitrogen from current and past applications of lagoon water and reduce applications of available nitrogen accordingly.

Like ammonium, organic nitrogen also remains in the upper foot of soil because, depending on the porosity of the soil, the particles do not move far through the soil. If the lagoon water has a high level of solids, the largest particles may remain on the soil surface as a crust until incorporated by tillage.

Application rates and timing

Winter forages planted during November in the Central Valley typically take up less than 50 pounds per acre (56 kg/ha) of nitrogen in the aboveground portion of the crop prior to mid-January. Uptake is higher under conditions of increased growth, such as earlier planting or sustained unseasonably warm temperatures. Under normal circumstances, earlier-maturing winter forages begin to take up more significant amounts of nitrogen starting in late January to early February. The rate of nitrogen uptake peaks in March and April but continues until crop maturity. The nitrogen uptake pattern for later-maturing cereal forages is similar to the early-maturing types, but peak uptake occurs somewhat later than in the earlier types. Nitrogen applications should be timed to provide available nitrogen during or immediately prior to the period when the crop will use them.

Application rates of available nitrogen should not exceed the amount of uptake expected between the time of application and the next anticipated heavy rainfall or irrigation that exceeds the amount needed to refill the soil profile. A preplant irrigation containing lagoon water in early fall may not meet the demands of spring growth, especially in years with heavy winter rains. The bulk of lagoon water should be applied in late January to early February, with only light application in fall preplant irrigation. No more than about 120 pounds (54 kg) of available nitrogen should be applied at any one time; if more than this is needed, a second spring application should be made. If the fertilization history of the field includes dry manure or lagoon water containing significant organic nitrogen, in many cases the organic nitrogen will supply all the nitrogen the

crop needs until the early spring. On heavier soils it may be necessary to plant on beds to prevent crop waterlogging injury from midwinter lagoon water applications.

If it is necessary to apply lagoon water in the early fall, one way to use the nutrients is to sow cereal forages in late September or early October so that the crop will make sufficient growth and take up the applied nitrogen before the onset of cold temperature that slows growth. This forage can be cut during the winter and allowed to regrow during the spring. Forage yield and nitrogen uptake in such a system can be higher than in a single-cut system. The major drawback to cutting during the winter is that a period of dry weather is needed to dry the soil enough to allow access by equipment and to wilt the forage to a suitable moisture for ensiling. Sowing very early in the fall and leaving the crop uncut can lead to lodging and disease problems.

Applying undiluted lagoon water in most cases results in excess nutrient applications that not only threaten groundwater but also may reduce yields due to waterlogging, salt burn, and lodging. If high amounts of nitrogen remain in the soil near harvest, nitrates may accumulate in the crop to levels that are toxic to livestock.

In most cases, lagoon water must be blended with fresh water. This can be done by using a flow meter and throttling valve on the lagoon pump output to mix the correct amount of lagoon water into the irrigation water. Pipelines must be correctly sized to prevent plugging from solids when reducing the flow rate of lagoon water. In addition to installing a flow meter system, it may be necessary to increase lagoon capacity, install additional pipelines, or make other modifications. Separators, settling basins, and other technology that minimizes the buildup of solids in the pond are also important components of a lagoon nutrient management system. Changes to the irrigation system itself may also be necessary, because if the irrigation is not uniform, all parts of the field may not get the same amount of nutrient, resulting in excess nitrogen in some areas of the field (usually the head end) and not enough in others.

PHOSPHORUS

Role of Phosphorus in the Plant

Phosphorus is a component of cell membranes and plays a role in the transfer and storage of energy within plant cells. It makes up part of the structure of key molecules, including DNA. Phosphorus nutrition is particularly important for seedling vigor, root development, and early-season growth. Normal root and shoot growth and the rate of photosynthesis are governed by phosphorus status. Phosphorus also has a regulating role in tillering, leaf expansion, leaf size, and the rate of assimilate production per leaf area.

Phosphorus Deficiency Symptoms

Phosphorus deficiency is most likely on shallow upland (terrace and foothill) soils. Symptoms of phosphorus deficiency include slow early growth, lack of tillering, and sometimes a slight purpling of plants. As in nitrogen deficiency, symptoms appear first on older leaves and advance to younger leaves as phosphorus deficiency becomes more severe. Deficient plants usually mature later than normal plants.

Phosphorus Requirements and Rates

In California, small grains are generally grown when soil temperatures are low and phosphorus availability is reduced. If phosphorus is needed, placement with or near the seed is best. On mineral soils a soil test (sodium bicarbonate extraction method) on samples taken to plow-layer depth can serve as a guide for phosphorus fertilization. Responses to phosphorus application are likely if phosphorus levels are less than 6 ppm, variable if phosphorus levels are from 6 to 15 ppm, and unlikely if phosphorus levels are above 15 ppm. Many growers apply a low-nitrogen, high-phosphorus fertilizer, such

as 11-48-0, 11-52-0, 10-50-0, or liquid 10-34-0, at sowing time with or near the seed. Monoammoniun phosphate, with an approximate 1:4 to 1:5 nitrogen to phosphorus ratio, is more desirable than a diammoniun phosphate (1:3 ratio) because little, if any, toxic ammonia is released. Urea, urea phosphate, or diammonium phosphate (18-46-0) are more hazardous because the initial reaction in the soil releases ammonia that can kill seedlings.

If a soil test indicates phosphorus deficiency, apply 30 to 40 pounds per acre (33.6 to 44.8 kg/ha) of P_2O_5 drilled with seed for irrigated crops, and 20 to 30 pounds per acre (22.4 to 33.6 kg/ha) of P_2O_5 for dryland crops. To avoid injuring seed, no more than 25 to 30 pounds per acre (28 to 33.6 kg/ha) of nitrogen should be drilled. If phosphorus is broadcast, use higher rates, up to 80 pounds per acre (89.6 kg/ha) of P_2O_5. Application of nitrogen at rates greater than 10 to 15 pounds per acre (11.2 to 16.8 kg/ha) combined with the higher rates of phosphorus stimulates the growth of grassy weeds.

The bicarbonate extraction method and phosphorus levels cited above are not reliable if small grains are sown directly after a crop of rice. An increased yield response to phosphorus is nearly always expected following rice, particularly if rice has been grown for several seasons.

Phosphorus applications are often needed on peat soils because phosphorus becomes unavailable when soil pH is low, which is typical in peat soils. In the Sacramento–San Joaquin Delta, wheat yield increases of up to 800 pounds per acre (896 kg/ha) can often be obtained by applying 50 pounds per acre (56 kg/ha) of P_2O_5 with the seed at planting. Phosphorus also becomes unavailable in very alkaline soils; application rates on high-pH soils should be increased to 30 to 50 pounds per acre (33.6 to 56 kg/ha) of P_2O_5 and drilled with the seed.

Phosphorus and Dairy Lagoon Water

Soils that receive large amounts of dairy manure, especially solids and liquid high in solids, can develop high levels of phosphorus. In areas of the Central Valley where there is no surface runoff to carry away phosphorus particles, soils are heavier, and groundwater is deep, no deleterious effects of excess phosphorus in soil have been demonstrated. Do not overapply phosphorus in areas where soils are sandy, groundwater is shallow, and water applied to fields enters waterways through tile drains or direct connection.

SULFUR

Role of Sulfur in the Plant

Sulfur is an essential constituent of the amino acids cysteine, methionine (required for protein synthesis), several coenzymes (e.g., biotin, co-enzyme A, thiamine pyrophosphate, and lipoic acid), thioredoxins, and sulfolipids. Sulfur is an important factor in wheat bread-making quality (protein level, loaf volume, and loaf texture). Nitrogen and sulfur requirements are closely linked since both are required for protein synthesis.

Sulfur Deficiency Symptoms

Sulfur-deficient plants become spindly and develop a pale yellow color. The symptoms are very similar to nitrogen deficiency. Sulfur deficiency reduces the number of grains per spike; the number of tillers and grain weight are less affected unless the deficiency is severe.

Sulfur Requirements and Rates

Sulfur deficiency most often occurs on gravelly or sandy soils. It is more common during winter to early-spring periods when soils are cool and wet or waterlogged. Sulfur enters the plant through the roots in the form of sulfate. Nitrogen metabolism and sul-

fur metabolism are strongly interdependent: when sulfur is deficient relative to nitrogen, nonprotein compounds such as amines accumulate, resulting in a nitrogen to sulfur (N:S) ratio of greater than 15:1. Wheat is likely to be sulfur deficient if it has a total sulfur of less than 0.20 percent and a N:S ratio greater than 17:1 in the upper fully developed leaves at flag leaf to anthesis. The concentration of sulfur in grain and the N:S ratio have been used to retrospectively diagnose sulfur deficiency, with critical values of 0.12 percent and 17:1 N:S.

Small grains have a lower sulfur requirement, 10 to 30 pounds per acre (11.2 to 33.6 kg/ha), than many other crops, but an adequate level of sulfur is necessary for satisfactory crop growth and for optimal levels of S-containing amino acids in grain. Sulfur deficiency is best corrected by planting-time application of fertilizer that has nitrogen and sulfate-sulfur, such as ammonium sulfate (21-0-0). Applications of relatively low rates of readily available sulfate-sulfur sources can be effective corrective treatments during the active early spring growth period; elemental sulfur is much less effective. If elemental sulfur is used, applications must precede the growing season by sufficient time (probably several months) to allow conversion of sulfur to the sulfate form for plant use. Moisture is also required for this process. Gypsum is also an immediately available but slow releasing form of sulfur. Sulfur deficiency symptoms disappear in most instances as soil temperatures warm, moisture levels drop below saturation, and plant growth progresses.

POTASSIUM

Role of Potassium in the Plant

Potassium is essential for plant growth and development. It activates enzymes needed for growth and is necessary for the formation and transfer of starches, sugars, and oils; the absorption of nutrients; and the efficient use of water. It enables plants to grow strong roots and resist drought, winter-kill, and root diseases. It also helps develop strong stems and decreases lodging.

Potassium Deficiency Symptoms

Potassium deficiency symptoms generally appear on the older leaves first. Depending on the severity of the deficiency, the entire plant may be affected, and all leaves may have an unthrifty, spindly appearance. During the early states of deficiency, the leaf tips and margins are chlorotic. Necrosis appears on leaves under severe deficiency as speckling along the length of the leaf and spreads quickly to the tip and margins. An "arrow" of green tissue remains from the base upward to the center of the leaf. Complete death of older leaves is common, and plants appear to have dried prematurely, as with drought stress.

Table 2. Potassium sufficiency in wheat for selected growth stages

Growth stage	Plant part	Sufficiency range (low to high)
3 to 4 leaf	underground stem	2.0–3.0%
	whole plant	2.4–4.0%
tillering	aboveground stem, lower 2 inches (5 cm)	2.0–3.0%
	top 4 leaves	2.4–4.0%
jointing	aboveground stem, lower 2 inches (5 cm)	1.5–2.7%
	top 4 leaves	2.0–3.0%
boot	aboveground stem, lower 2 inches (5 cm)	1.0–2.4%
	top 4 leaves	1.5–2.7%

Sources: California Plant Health Association 2002.

Potassium Requirements and Rates

In California, yield responses by small grains to applications of potassium are highly unusual and occur only on the most deficient soils, such as soils with ammonium acetate extractable potassium levels less than 60 ppm. Plants need as much potassium as nitrogen during rapid growth periods. Potassium sufficiency in wheat depends on the stage of growth (table 2). Several sources of potassium (potash) are used as commercial fertilizers (table 3).

Table 3. Commercial fertilizer sources of potash

Fertilizer material	Formula	Water-soluble potash (K_2O) %	Other nutrients
monopotassium phosphate	KH_2PO_4	32–34	50–52% P_2O_3
potassium chloride (MOP)	KCl	60–62	—
potassium magnesium sulfate	$K_2SO_4 \cdot 2MgSO_4$	22	18% S, 11% Mg, 0.1% Ca
potassium nitrate	KNO_3	44–46	13% N
potassium sulfate (SOP)	K_2SO_4	50–53	18% S
potassium thiosulfate	$K_2S_2O_3$	25	17% S

Sources: California Plant Health Association 2002.

Potassium is rapidly absorbed and very mobile, making it a good additive to foliar fertilizers. The crop response to foliar nutrition depends on the soil, the crop, and environmental conditions.

ZINC

Role of Zinc in the Plant

Zinc is an essential micronutrient for crop growth. It is needed for the production of auxins, growth-promoting substances that control the growth of shoots. A critical level of zinc is required in the soil for roots to grow or function effectively.

Zinc Deficiency Symptoms

Zinc deficiency is probably the most widespread micronutrient deficiency in small grains. It can occur in cold and warm climates, acid and alkaline soils, and heavy and light soils. In general, stems and leaves of deficient plants fail to develop to normal size, and some of the tissues between leaf veins contain so little chlorophyll that they turn yellow. The first symptoms of zinc deficiency normally appear on middle-aged leaves. Initial symptoms include a change in leaf color from healthy green to muddy grey-green in the central portion of the blade. Leaves appear drought-stressed, and necrotic areas, beginning as small spots, develop and extend to the leaf margins. Leaves may take on an oily appearance, and the necrotic areas may become large and surrounded by mottled yellow-green areas. Zinc-deficient leaves eventually collapse in the middle regions. Severe zinc deficiency can result in stunted, chlorotic plants with many collapsed leaves due to necrosis in the center of the leaves.

Zinc Requirements

Zinc deficiency arises from a low content of zinc in soil, unavailability of zinc in high-pH soil, or management practices that depress the availability of zinc. Although most mineral soils contain 80 to 300 ppm of total zinc, DTPA extractable zinc is usually less than 1 ppm; the remainder is fixed in an unavailable form. The unavailability of zinc can be attributed to soil alkalinity: when the soil pH is above 7.0, zinc availability is generally reduced. Zinc availability is low in some soils with high organic matter, in some clay soils with high magnesium content (these soils fix zinc in an unavailable form by strong adsorption on the clay minerals in place of magnesium), and in soils high in phosphorus. Low zinc levels combined with high phosphorus levels enhance accumulation of phosphorus in old leaves to concentrations that are toxic; this enhances necrotic symptoms in old leaves. Yield responses to applications of zinc occur only on the most deficient soils, such as soils with zinc DTPA extractable levels below 0.3 ppm.

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SMALL GRAIN PRODUCTION MANUAL PART 5

Irrigation and Water Relations

ALLAN FULTON, University of California Cooperative Extension Irrigation and Water Resources Advisor, Tehama County; **KHALED BALI,** University of California Cooperative Extension Farm Advisor, Imperial County; **ZAK MOUSLI,** Former Superintendent, University of California Bay Area Research and Extension Center, Santa Clara; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

This publication, *Irrigation and Water Relations*, is the fifth in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
- *Part 3: Seedbed Preparation, Sowing, and Residue Management*, Publication 8166
- *Part 4: Fertilization*, Publication 8167
- *Part 6: Pest Management—Diseases*, Publication 8169
- *Part 7: Pest Management—Insects*, Publication 8170
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- *Part 13: Harvesting and Storage*, Publication 8176
- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

The majority of California's small grain acreage is irrigated, although rainfed grain production is also important, particularly in coastal growing areas and foothill regions of the Central Valley. The wide range of geographic locations and climate where small grains are produced determine the length of the growing season, crop water consumption, and irrigation requirements. Planned end use of the crop and stage of growth at harvest (grain or forage) also affect irrigation requirements. Recognizing and anticipating important stages of small grain growth and development is key to successfully managing irrigation.

SOWING AND SEEDLING EMERGENCE

Irrigation may be required at the onset of the growing season if residual soil moisture from the previous crop and rainfall are insufficient for germination and establishment. A grower must decide whether to preirrigate and then sow the seed into moist soil, to sow the seed and irrigate to germinate the seed, or to sow the seed into dry soil and rely on rainfall for germination. Timely preirrigation during warm, dry weather provides soil moisture for rapid seedling emergence and growth. Preirrigation a month or so before planting (depending on soil type and cropping sequence) is often used in low-rainfall areas such as the southern San Joaquin Valley and the Imperial Valley where soil moisture is likely to be low at planting time. However, preirrigation fol-

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lowed by extensive rainfall can result in inefficient water use, less efficient nitrogen uptake, and higher irrigation costs. If extensive rainfall follows preirrigation, soils may become waterlogged and anaerobic and in turn reduce seedling establishment. In a worst-case scenario, farmlands preirrigated late in the fall and then followed by extensive rainfall may require delayed planting past optimal dates or not be able to be planted at all. Sowing to a dry seedbed and then irrigating risks poor germination and crop loss, particularly on slow-draining soils and if irrigation is followed by an extended period of rainfall. Irrigation can saturate and cool the seedbed to the extent that seed will not germinate and may rot. Where sprinkler irrigation is used and amounts of applied water are more easily controlled, there is less risk of oversaturating the soil. If irrigation is used to germinate the seed, it should be timed for when the chance of rainfall occurring for several days after irrigation is low, thereby giving the soils a chance to drain, aerate, and warm. In general, sowing seed into a dry seedbed and relying on rainfall for germination is more commonly practiced than pre-irrigation or irrigating immediately after planting. Optimal planting dates in late November and December coincide with a time frame when it is reasonable to expect enough rainfall to germinate shallow planted seed and establish sufficiently rooted seedling plants that can then be irrigated in January or February with less risk to crop health. The greatest risk to this approach is that in severe drought years, germination may be substantially delayed and result in a shorter growing season and reduced yields. In fall-sown areas in the northern part of the Central Valley, the Central Coast, and in Northern California intermountain valleys, reliability and quantity of rainfall is usually sufficient to germinate small grains and irrigation is not a concern.

MOISTURE STRESS

Moisture Stress at Vegetative Growth Stages

Early moisture stress may cause the crop to head about 7 to 10 days prematurely; the shortened growth period can reduce yield. Plants tend to increase tillering under early moisture stress, but many tillers die without producing grain-bearing heads. If severe moisture stress occurs during the initiation of tillers, those tillers never develop and plants may produce only the main stem (i.e., one head per plant). The spike that emerges from each tiller is formed during the tillering stage, and by the time the fifth vegetative leaf is visible on each stem, the potential number of spikelets that can grow into mature kernels has been determined. Plants at this stage are sensitive to moisture stress. Plants under moisture stress between the double-ridge stage (the stage in apical development when the primordia that differentiate to become spikelets are visible) and terminal spikelet formation (see Part 2, *Growth and Development*) are likely to form fewer spikelets. Plants under moisture stress during stem extension form fewer florets. Plants sacrifice tillers, spikelets, and/or florets if moisture stress develops after these parts have formed but before development of the parts is complete. As a rule of thumb, the most recently formed tillers, spikelets, or florets are sacrificed first. Small grains are also sensitive to moisture stress at the boot stage.

Moisture Stress at Reproductive Growth Stages

Moisture stress during pollination results in underdeveloped kernels or sterility. The milk stage of kernel development is not as sensitive as the pollination stage, but severe moisture stress should be avoided. Moisture stress during the soft dough stage may result in smaller or shriveled kernels. Adequate moisture extends the grain development period and results in higher grain yields and kernel weights. The kernels begin to dry by the time plants reach the soft dough stage. The hard dough stage signifies the end of grain filling. Plants reach physiological maturity at the end of the hard dough

stage. Accurately anticipating this stage of development is important for determining irrigation cutoff and minimizing irrigation costs without compromising yield.

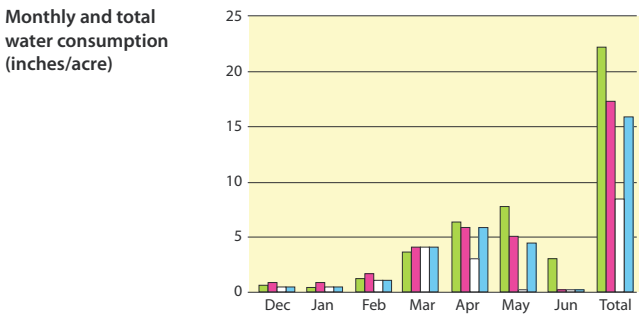
Recognizing Symptoms of Moisture Stress

Early symptoms of moisture stress include dark blue-green leaf color, wrinkled leaf margins, and slight rolling or cupping of leaves. More severe symptoms include a deep blue-green canopy, dead tissue along leaf margins, obvious leaf rolling, shortened and spindly stems, and small immature heads. By the time symptoms of severe moisture stress are apparent, the adverse effect on production is irreparable. Moisture-stressed plants are more susceptible to common root rot and damage by Russian wheat aphid and greenbug. Irrigation before critical growth stages assures that moisture is present when plants reach those critical periods. Checking soil moisture at different depths and different growth stages and knowing crop water needs at critical growth stages are important to avoid yield loss. Among the most common methods for checking soil moisture in the root zone are

- soil feel and appearance
- gravimetric sampling
- tensiometers
- resistance blocks
- neutron scattering
- time domain reflectometry (TDR)

PATTERNS OF WATER CONSUMPTION

Understanding general patterns of crop water consumption is important for anticipating when to irrigate and avoiding moisture stress. Small grain water consumption varies depending on grain type, cultivar, geographic production region and climate, and end use for the crop. Figure 1 provides historical estimates of crop water consumption for fall-sown semidwarf wheat cultivars grown for grain, barley grown for grain, and small grains grown for forage (harvested at boot stage or harvested at soft dough stage) in the Sacramento and San Joaquin Valleys. These historic averages are typically within 20 percent of the actual crop water use in a given year. Despite the inexactness, these estimates represent important patterns of water consumption from germination through maturity and can assist with irrigation decisions, especially if rainfall is monitored and consideration is given to root zone depth and water-holding capacity of the soil. Total crop water consumption is defined here as the quantity of water consumed from germination to harvest or maturity by a healthy, productive small grain crop by plant transpiration and evaporation from the soil surface. Crop water consumption also is referred to as crop evapotranspiration (ETc). Crop water consumption is lower than the irrigation requirement because more irrigation water must be applied to ensure that all parts of the field are adequately irrigated. Typically, an efficiently designed and managed flood, furrow, or sprinkler irrigation system applies about 15 to 35 percent more water than the estimate of crop water consumption.



	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Wheat grain, Dec. 15 emergence	0	0.5	1.1	3.5	6.2	7.8	3	22.1
Barley grain, Dec. 1 emergence	0.5	0.7	1.6	4.1	5.8	4.6	0.1	17.3
Wheat/triticale boot forage, Dec. 1 emergence	0	0.5	1.1	4.1	2.9	0	0	8.6
Wheat soft dough forage, Dec. 1 emergence	0	0.5	1.1	4.1	5.8	4.4	0	15.9

Figure 1. Historical average water consumption by irrigated small grains for the central San Joaquin and Sacramento Valleys.

Water consumption by wheat or triticale in the Central Valley can range from as little as 8 to 9 inches per acre (50 to 56 cm/ha) if the crop is harvested at the boot stage for forage to as high as 22 inches per acre (139 cm/ha) if harvested for grain (see fig. 1). Barley consumes

less water than wheat or triticale because it has a shorter growing season, resulting in a seasonal estimate of water consumption in the Central Valley of about 17 inches per acre (107 cm/ha). Crop water consumption on a monthly basis increases gradually, reflecting use during developmental stages from germination through dough stage. When normal or above-normal rainfall occurs, precipitation may be sufficient to meet the crop water consumption needs without irrigation from December through March in the Sacramento and San Joaquin Valleys and other regions of fall-sown small grains, except for desert areas. The months of April and May (corresponding to boot stage through soft dough) are the primary months when irrigation is needed in those areas, but the amount of irrigation depends on rainfall patterns and crop development stage.

ROOT ZONES OF SMALL GRAINS

Small grains have a fibrous root system. Most roots in a fully developed small grain plant's root system are in the top 2 feet (0.6 m) of soil. Under ideal conditions small grains can root to 7 feet (2.1 m) deep by the end of the season. Generally, rooting depths will be deeper in uniform soils than in soils with distinctly different soil layers. The soil layers are physical barriers to both root growth and drainage of water and aeration. Digging backhoe pits to evaluate soil uniformity, soil textures, and evidence of roots following a small grain crop is an effective way to characterize root zone depths for specific fields. Soil texture and structure and the depth of the root zone influence irrigation frequency and the ability to irrigate efficiently. Crops with deeper root zones and finer soil textures require less-frequent irrigation and sometimes less total applied water. Less-frequent irrigation is needed because these conditions provide more stored water for crop consumption between irrigations. Irrigation efficiency is generally greater on deep, fine-textured soils because less of the applied water is lost to percolation. More rainfall can be stored within the root zone and can contribute to the seasonal water consumption, postponing the first irrigation and enabling earlier irrigation cutoff. Table 1 illustrates the available soil water for a range of soil textures.

Table 1. Amount of water available for selected soil textures at field capacity

Soil texture	Average available soil water capacity (in/ft of depth)	(cm/m of depth)
sand	0.7	5.8
loamy sand	0.9	7.5
sandy loam	1.4	11.7
fine sandy loam	1.5	12.5
loam	2.0	16.7
silty loam	2.2	18.3
clay loam	2.2	18.3
sandy clay	2.3	19.2
silty clay	2.3	19.2
clay	2.3	19.2
peats and mucks	2.5	20.9

TIMING THE FIRST IRRIGATION

As discussed earlier, the first irrigation may have to be applied before or near the time of sowing to ensure timely seed germination and stand establishment. If rainfall is relied upon for germination, the first crop irrigation can be delayed. Timing largely depends on seasonal rainfall patterns and amounts. Since one growing season is seldom like the next, what is appropriate timing one year may not be for another. Once the rainfall season has ended, stored soil moisture will provide the water for crop consumption until the reserve is depleted. How long this reserve will sustain crop growth before irrigation is needed depends on soil texture and root zone depth. The first postemergence irrigation is needed after about 40 to 50 percent of the stored soil moisture in the crop root zone is consumed. Using a rain gauge to monitor rainfall and a soil sampling tube or auger to estimate soil moisture content (soil moisture depletion), understanding crop water consumption patterns and root development, and recognizing how soils feel as they dry can be used to time the first crop irrigation and avoid crop moisture stress.

DETERMINING IRRIGATION FREQUENCY AFTER THE FIRST IRRIGATION

The small grain root system usually is near full development by about 60 to 70 days after germination, and it reaches maximum development at about boot stage. Only one irrigation is normally needed during that period in most areas. Once the root zone is fully developed, the interval between irrigations is fairly consistent up to irrigation cutoff. Depending on soil texture and water-holding capacity, there are 3 to 10 inches (7.5 to 25.5 cm) of available stored water in a root zone 2 to 4 feet (0.6 to 1.2 m) deep. About 1.5 to 5 inches (4 to 12.5 cm) of soil moisture is available to sustain the crop between irrigations since about one-half of the stored water can be consumed from the crop root zone before moisture stress occurs. This amount is enough to sustain an irrigation frequency ranging from about 7 to 10 days for sandy and sandy loam soils, 12 to 18 days for loam soils, and up to 25 days for silt loams, clay loams, clays, peats, and mucks. Warm, windy spring days deplete soil moisture quickly, so it should be replenished more frequently under such conditions, especially if the crop was previously exposed to wet soil conditions that limited root development. Irrigation frequency should be verified by checking soil moisture and watching for the earliest signs of crop stress, possibly in a particularly sensitive area of a field.

IRRIGATION METHODS, IRRIGATION UNIFORMITY, AND AMOUNTS

Several methods are used to irrigate small grains in California, including border check, furrow, and sprinkler systems. For border check irrigation, the optimal strip width and check length depend on soil type and slope of the field. Shorter and narrower strips with steeper slopes are used on light-textured soils, while longer and wider strips with lesser slopes are used on heavy-textured soils. The check length can range from 200 feet (61 m) for a sandy soil with a slope of about 1 percent to more than 1,200 feet (366 m) for a clay soil with a 0.3 percent slope. Strip width can range from 20 to 100 feet (6 to 30 m) for the above soil types and slopes, respectively. Borders or furrows should be made at planting time. When border flood or furrow irrigation systems are used, extra irrigation water is usually applied near the head of the field to prevent underirrigation in the middle and the tail end of the field. Subirrigation with spud ditches is used in the Sacramento–San Joaquin Delta. Spud ditches are the smallest ditches in the irrigation system used in peat soils, about 12 inches (30 cm) wide and 24 inches (60 cm) deep and connected to larger 4-foot (1.2-m) ditches, placed about 100 feet (30 m) apart. Table 2 gives the number of irrigations recommended for small grains in the main growing regions of California.

Irrigation practices that ensure ample soil water storage during early stages of crop development promote a deep, extensive root system. In general, flood or furrow irrigation should bring the upper 3 feet (1 m) of the soil profile to field capacity. Usually about 4 to 8 inches (10 to 20 cm) of water is applied per flood or furrow irrigation event. Less water, usually 2 to 4 inches (5 to 10 cm), may be applied per sprinkler irrigation. Table 3 provides a general guide for the amount of water needed to bring soil moisture to field capacity for different soil types.

Table 2. Number of irrigations recommended for small grain regions of California

Region	Number of irrigations
Central Coast	1–3
Sacramento Valley	1–3
Intermountain Area	1–4
San Joaquin Valley	3–6
Imperial Valley	5–7

DETERMINING IRRIGATION CUTOFF

Timely irrigation cutoff prevents yield losses and assures adequate kernel weight. It also helps minimize irrigation costs and prevents irrigating too late, avoiding problems with field access by heavy combines. Irrigation that continues too late in the season results in more severe lodging and black point disease, stimulates late-season weed growth, causes yield reductions, slows harvest, and delays ground preparation for the sub-

Table 3. Approximate amount of water needed to bring selected soil textures to field capacity

Available soil water remaining (%)	Inches of water needed for soil texture (in/ft)*				
	Loamy sand	Sandy loam	Silt loam and clay loam	Sandy clay and silty clay	Peats and mucks
0–25	0.9–0.7	1.4–1.1	2.2–1.7	2.3–1.7	2.5–1.9
25–50	0.7–0.5	1.1–0.7	1.7–1.1	1.7–1.2	1.9–1.3
50–75	0.5–0.2	0.7–0.4	1.1–0.6	1.2–0.6	1.3–0.6
75–100	0.2–0	0.4–0	0.6–0	0.6–0	0.6–0
At field capacity	0.9	1.4	2.2	2.3	2.5

Note: *1 in/ft = 8.33 cm/m.

sequent crop. The appropriate irrigation cutoff date depends on the soil water-holding capacity and root zone depth. The optimal irrigation cutoff is determined by patterns of dry matter accumulation in the grain after heading, crop water consumption during grain filling, and weather. Sufficient moisture must be available from the last irrigation to carry the crop through the late dough stage (the end of dry matter accumulation). For sandier soils and crops with shallow root zones, this period may be 7 to 10 days before the late stages of dough development. For finer-textured uniform soils and crops with deeper root systems, the irrigation cutoff may be 14 to 21 days or more before the late stages of dough development.

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E-mail inquiries: danrcs@ucdavis.edu

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SMALL GRAIN PRODUCTION MANUAL
PART 6

Pest Management of Small Grains—Diseases

LEE JACKSON, Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

UNIVERSITY OF CALIFORNIA
Division of Agriculture and Natural Resources
http://anrcatalog.ucdavis.edu

This publication, *Pest Management of Small Grains—Diseases,* is the sixth in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

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INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) involves coordinating crop management practices with pest management techniques to achieve economical and sustainable control of pest problems. The goal of an IPM program is to protect the crop from economic damage while interfering as little as possible with the long-term viability of the production system. The most reliable way to do this is to anticipate pest problems and prevent them whenever possible. When pesticides are needed, materials and application methods that are effective, economical, and have a minimum of harmful side effects should be used. Key management methods include

- clean and/or certified seed
- resistant cultivars
- field sanitation
- crop rotation
- residue management
- proper cultural practices (timing and amounts of irrigation, fertilization, etc.)

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Several diseases and weed seeds can contaminate small grain seed. Sowing clean seed, or seed certified as free from seedborne diseases and weeds, reduces the likelihood of introducing diseases or weeds into a field. Growing pest-resistant small grain cultivars can provide economical, long-term protection from some diseases and pests. Reactions of cultivars of small grains to diseases and pests are updated on an annual basis; the information can be viewed online in *UC IPM Pest Management Guidelines, Small Grains* (http://www.ipm.ucdavis.edu/PMG/selectnewpest.small-grains.html).

Many cultural practices have significant impacts on pest management. Infestations of many pests, particularly weeds, result from contaminated seed, soil, water, or machinery. Precautions for preventing the introduction of pests include using high-quality seed, avoiding irrigation water that may contain weed seeds or pest organisms such as nematodes, cleaning equipment before moving it from infested fields, denying livestock access to fields after they have grazed in weedy areas, and destroying stands of problem weeds along field borders before they produce seed that can infest the cultivated area. Practices that produce the most vigorous, competitive stands possible make control of weed pests easier and reduce the susceptibility of crops to disease and insect pests. Important considerations are crop residues, cropping patterns, leveling of irrigated fields to assure uniform water distribution and drainage to avoid flooding, sowing dates, and fertilization.

Crop rotation and fallow periods between crops are effective pest management practices. The most useful rotations for small grain crops are broadleaf crops because these crops are generally not hosts for most small grain pathogens and insects, and herbicides that cannot be used in small grain crops are available for controlling problem grassy weeds. Cultivation of the rotation crop provides additional weed control. Fallow periods are valuable in rainfed production areas: they allow for tillage or broad-spectrum herbicides for weed control, conserve soil moisture, and allow some accumulation of soil nitrogen.

Full descriptions of the most important diseases and pests of small grains in California and their management can be found in Wiese 1987; Mathre 1997; Strand 1990; and Davis and Jackson 2002. Brief descriptions of important diseases are given in the following sections.

SEPTORIA TRITICI LEAF BLOTCH

Septoria tritici leaf blotch is caused by the fungus *Mycosphaerella graminicola* (= *Septoria tritici*). It can be particularly severe on wheat in the Sacramento and northern San Joaquin Valleys in years of higher than average rainfall. It is especially damaging when late-spring rains persist after emergence of the flag leaf. Symptoms (fig. 1) develop on all aerial parts of the plant. Chlorotic flecks become visible on the lowermost leaves and expand to irregularly shaped lesions. The lesions first appear water-soaked, then become dry, yellow and, finally, red-brown with gray-brown ashen centers. The disease reduces grain yield and/or bushel weight.

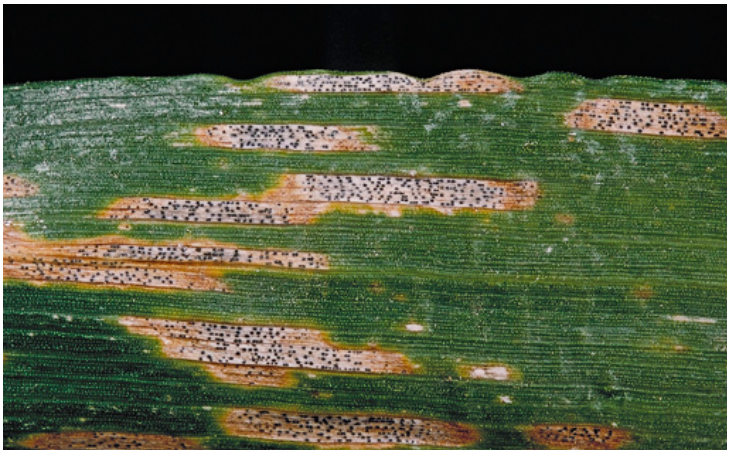

Figure 1. Septoria tritici leaf blotch symptoms. Photo by Jack Kelly Clark.

Residue of previous wheat crops, seed, and volunteer wheat plants are sources of primary inoculum. The fungus survives between cropping seasons on wheat residue. After the first fall rains, the spores (ascospores) of *M. graminicola* are discharged into the air from sexual fruiting bodies (pseudothecia) in wheat residue from the previous crop.

Figure 2. Leaf scald of barley symptoms. Photo by Jack Kelly Clark.

The spores can spread long distances and are carried by wind to infect the developing wheat crop. Lesions containing *Septoria tritici* pycnidia (small, dark structures about the size of pepper grains) appear 3 to 4 weeks later. Spores (conidia) formed within pycnidia are dispersed by splashing and wind-driven rain and spread the disease within fields.

The major factors affecting disease severity are temperature and moisture during the growing season. Spore germination and disease development are optimal at 60º to 77°F (16º to 25°C) when free moisture is present on the foliage. Secondary cycles of infection occur every 21 to 28 days. Dry periods and warm weather prevent infection and disease spread.

The disease is most severe on early-sown (October) wheat. Later sowings (November to December) are less likely to be severely affected. Resistant cultivars and disease-free seed, along with elimination of wheat residue and volunteer wheat plants, help control this disease. Rotations in which wheat appears every third year eliminate most carryover inoculum but do not provide protection from infection by ascospores from distant fields. Fungicides can provide partial disease control. Applications should be made between tillering and heading to protect the flag leaf from infection.

LEAF SCALD OF BARLEY

Leaf scald of barley, caused by the fungus *Rhynchosporium secalis*, is most severe in years of high rainfall. Lesions first appear on foliage as dark, pale, or bluish gray spots. These spots expand into oval lesions with bluish gray centers and dark brown margins (fig. 2). The lesions enlarge and coalesce, giving the appearance of rapid scalding. Entire leaves may be covered and killed if the disease is severe. When conditions favor severe disease, lesions also may develop on spikes.

The fungus survives between seasons primarily on barley residue and volunteer barley plants, and to a lesser extent on some grasses and barley seed. Infection, development, and spread occur during cool, 40º to 77°F (4º to 25°C), wet weather. Spores are formed in a thin layer of slime on the surface of lesions and are spread short distances by splashing and wind-driven rain. Spores that land on plant surfaces germinate and infect the leaf if the surface remains wet for at least 24 hours. Secondary cycles of infection can occur every 21 to 28 days. If infected seed is sown, coleoptiles can be infected after seed germination.

Control measures include crop rotation to any crop other than barley, clean seed and resistant cultivars, and elimination of barley residue, volunteer barley plants, and grass hosts. Avoid early (October to November) sowings that expose the crop to a long period when weather conditions are favorable for disease development. Late (December to January) sowings are less vulnerable.

NET BLOTCH OF BARLEY

Net blotch of barley, caused by the fungus *Pyrenophora teres*, is most severe in years of high rainfall. Symptoms first appear as tiny spots that may be dark green and watersoaked initially, but turn light brown as the spots mature. Later, symptoms appear as narrow brown blotches

Figure 3. Net blotch of barley symptoms. Photo by Jack Kelly

with a netted or cross-hatched appearance (fig. 3). Surrounding tissue becomes yellow. When the disease is severe, lesions spread over the entire leaf and kill it. Lesions may occur on the spikes as the crop matures.

The fungus survives between seasons on barley residue, volunteer barley plants, some grasses, and seed. Barley residue and volunteer barley plants are the main sources of inoculum for new infections each season. After initial infections, spores are produced on lesions when humidity is near 100 percent and temperatures are mild, 60º to 80ºF (16º to 27°C). Spores are windblown to other plants for secondary spread. Secondary cycles of infection can occur every 21 to 28 days. If infected seed is sown, coleoptiles can be infected after seed germination. Free moisture and cool spring weather favor disease development.

Control measures include crop rotation (to any crop other than barley), clean seed and resistant cultivars, and elimination of barley residue, volunteer barley plants, and grass hosts. Avoid early (October to November) sowings that expose the crop to a long period when weather conditions are favorable for disease development. Late (December to January) sowings are less vulnerable.

LEAF RUSTS OF WHEAT, BARLEY, AND OAT

Leaf rusts, caused by the fungi *Puccinia triticina* (wheat), *P. hordei* (barley), and *P. coronata* (oat), are late-season diseases that are most severe in years with lower than normal late-spring temperatures and high humidity. The fungi grow only on living host plants and have narrow host ranges (wheat leaf rust does not affect barley; barley leaf rust does not affect wheat). Symptoms on wheat, barley, and oat are similar. Pustules on barley are small, round, and yellowish brown (fig. 4). Pustules on wheat are reddish orange and are scattered or clustered on the upper leaf surface (fig. 5). Pustules on oat are oblong and orange colored (fig. 6). As the plants mature, the pustules turn dark and shiny, indicating

Figure 4. Barley leaf rust symptoms. Photo by Lee Jackson.

Figure 5. Wheat leaf rust symptoms. Photo by Jack Kelly Clark.

Figure 6. Oat crown rust symptoms. Photo by Lee Jackson.

the formation of teliospores. Teliospores do not play a role in disease development or survival in California because they infect only the alternate hosts (different broadleaf shrubs for each rust species), which are rare in California cereal-producing areas.

Volunteer small grain plants and distant small grain fields are the sources of primary inoculum. Spores (urediospores) produced in pustules on leaves are dispersed over long distances—hundreds of miles—by wind and cause initial infections. Urediospores from initial infections are windblown to initiate secondary cycles at 7- to 10-day intervals. Leaf rust is most severe when temperatures are 60º to 72°F (16º to 22ºC) and humidity is high or rainfall is intermittent. It causes the greatest reductions in yield if infections occur prior to spike emergence and continue for 30 to 40 days during the grain fill period.

Control is through the use of resistant cultivars. If new races develop that render current resistant cultivars ineffective, fungicides can be used for control. Applications should be made between tillering and heading to protect the flag leaf from infection.

STRIPE RUSTS OF WHEAT AND BARLEY

Stripe rust, caused by the fungus *Puccinia striiformis,* has been responsible for the most devastating disease epidemics on wheat and barley in California. Different forms (*formae speciales*, or f. sp.) of *P. striiformis* affect wheat and barley but symptoms are identical. Rust pustules are yellow-orange, occur mostly on leaves, and are oriented linearly between vascular bundles, forming conspicuous stripes (fig. 7). Glumes also can be infected. Stripe rust symptoms usually appear earlier in the season than symptoms of leaf rust because the stripe rust fungus develops at lower temperatures. As the plants mature, the pustules turn dark and shiny as teliospores are formed. These spores do not play a role in disease development or survival because unlike other cereal rust pathogens, the stripe rust pathogen does not have an alternate host for the teliospores to infect.

The fungus grows only on living host plants and survives between seasons on volunteer wheat or barley, some wild grasses, and distant small grain fields. Spores (urediospores) produced in pustules are spread over long distances by wind to initiate infections. Disease development is most rapid at cool temperatures of 50º to 60°F (10º to 16°C) with intermittent rain and dew; secondary cycles occur at 7- to 10-day intervals. The disease can continue to develop where daytime temperatures are higher than this as long as nighttime temperatures are not higher than about 60°F (16ºC).

Figure 7. Stripe rust symptoms. Photo by Jack Kelly Clark.

Control is through the use of resistant cultivars. If new races develop that render current resistant cultivars ineffective, fungicides can be used for control. Applications should be made between tillering and heading to protect the flag leaf from infection.

POWDERY MILDEW

Powdery mildew, caused by the fungi *Blumeria graminis* (*Erysiphe graminis*) f. sp. *tritici* (wheat), *B. graminis* f. sp. *hordei* (barley), and *B. graminis* f. sp. *avenae* (oat), is most severe when winter weather is mild and damp. Symptoms are most apparent on lower leaves. Patches of white, cottony fungal growth (mycelium and spores) develop opposite chlorotic spots on leaf surfaces. These patches later turn dull gray-brown. As plants mature, small, dark brown structures (cleistothecia) develop

Figure 8. Powdery mildew symptoms. Photo by Jack Kelly Clark.

among the cottony patches (fig. 8). Infected plants are low in vigor. Growth, heading, and seed filling are affected. If disease is severe, entire plants can be killed.

Volunteer wheat, barley, and oat plants serve as hosts between summer and fall, when the crop is sown. Spores (ascospores formed within cleistothecia and conidia) serve as primary inoculum. Infections produce superficial sporulating colonies. Spores (conidia) are wind-dispersed to initiate secondary infections. The spores germinate over a wide temperature range without requiring free moisture. Disease development is optimal at 59º to 72°F (15º to 22°C) and is retarded above 77°F (25°C). Secondary cycles occur at 7- to 10-day intervals. Dense stands, excess nitrogen, high humidity, and cool temperatures favor disease development.

Control measures include resistant cultivars; elimination of crop residue, volunteer small grain plants, and weed hosts; and crop rotation. Fungicides also can be used for control. Applications should be made between tillering and heading to protect the flag leaf from infection.

BARLEY YELLOW DWARF

Barley yellow dwarf is an aphid-transmitted viral disease of wheat, barley, oat, and other grasses. Symptoms include uneven, blotchy leaf discoloration in various shades of yellow, red, or purple, progressing from leaf tip to base and margin to midrib (fig. 9). Wheat and barley leaves usually turn yellow, while oat leaves usually turn red. Plants can be stunted, and those infected as seedlings may be killed. Infected plants have less flexible leaves and less developed root systems than healthy plants. Oat panicles can be blasted (florets become sterile).

The virus survives in most common grain aphids (including bird cherry-oat aphid, English grain aphid, rose grass aphid, corn leaf aphid, and greenbug) and on numerous cereal and grass hosts. The Russian wheat aphid is not a vector of the virus. The virus is spread through vector movement. Aphids can acquire the virus in a feeding period as short as 30 minutes, although 12 to 30 hours is more typical. Transmission can occur 1 to 4 days after acquisition following a feeding period of 4 hours or more. Epidemics are most likely to occur in cool, moist seasons that favor grass and cereal growth and aphid multiplication and migration. Plants can be infected throughout the growing season.

Control is through resistant cultivars and avoiding very early (September to October) or very late (February to March) sowing dates for fall-sown small grains. Sowing the crops during these times exposes plants to active aphid populations when plants are most vulnerable (early growth stages) to damage from infection. Seed treatment with imidacloprid can prevent early-season build-up of aphid infestations and can minimize subsequent transmission and spread of the virus.

Figure 9. Barley yellow dwarf symptoms. Photo by Lee Jackson.

Figure 10. Loose smut symptoms. Photo by Jack Kelly Clark.

LOOSE SMUT

Loose smut, a flower-infecting disease, is caused by different species of the fungus *Ustilago: U. tritici* infects wheat, triticale, and rye; *U. nuda* infects barley; and *U. nigra* infects barley and oat. Symptoms are most visible at heading, but before heading infected plants show dark green erect leaves, sometimes with chlorotic streaks. Infected spikes emerge slightly earlier than healthy spikes. Normal spike tissue is replaced by olive-black masses of spores (teliospores) that are enclosed in a fragile gray membrane (fig. 10) that ruptures near flowering time, releasing the spores and leaving only a bare rachis at maturity.

The fungus survives as dormant mycelium inside infected seed (the black loose smut fungus, however, survives as teliospores on the surface of contaminated seed). When infected seed germinates, the previously dormant mycelium resumes growth and becomes systemic in the plant. When smutted spikes emerge at heading, the fungal membrane soon ruptures, and windborne spores land on healthy plants, where they infect developing kernels (no symptoms are visible). Infection is most likely during cool, moist conditions. Plants are most vulnerable to infection from flowering to about 8 days later.

Control is through seed treatment with systemic fungicides and/or certified smut-free seed. Hot water treatment can eliminate smut fungi from contaminated seed, but it must be used carefully to avoid reducing seed vitality.

COVERED SMUT

Covered smut of wheat, caused by the fungi *Tilletia caries* and *T. foetida*, is a flower-infecting disease that also is called common bunt or stinking smut. Covered smut of barley and oat is caused by different races of *Ustilago hordei*. Infected plants are slightly stunted, and spikes emerge later than normal. Bunted spikes are slender and maintain a green color longer than healthy spikes. Glumes on infected spikes spread apart as kernels are replaced by bunt balls (spherical gray-brown masses of spores encased in fragile pericarps) (fig. 11). The spore masses have a distinctive odor, similar to that of decaying fish, when crushed.

Figure 11. Covered smut symptoms. Photo by Jack Kelly Clark.

Covered smut spore masses burst during harvest, dispersing spores and contaminating healthy grain and soil. The fungi survive between seasons on the surface of infested seed or in the soil. Spores germinate in response to moisture and infect coleoptiles before seedlings emerge.

Control is through seed treatment and/or certified smut-free seed. Hot water treatment can eliminate smut fungi from contaminated seed, but it must be used carefully to avoid reducing seed vitality.

KARNAL BUNT OF WHEAT

Karnal bunt, caused by the fungus *Tilletia indica* (= *Neovossia indica*), infects only wheat and triticale, not other small grains such as barley and oat. Symptoms are first visible at the soft dough stage in the form of blackened areas surrounding the base of the grain; however, the disease is usually not noticed until the grain is threshed and the partially smutted kernels are exposed

Figure 12. Karnal bunt symptoms. Photo by Lee Jackson.

Figure 13. Root and foot rot symptoms. Photo by Jack Kelly Clark.

(fig. 12). Usually only a few florets per spike are affected, and diseased spikes are not conspicuous because the glumes are not noticeably distorted. In severely infected spikes, however, the glumes spread apart near maturity, exposing the infected seed. Diseased seed usually retain a partial seed coat, but the embryo and part of the endosperm are converted to masses of black spores that emit a fishy odor. Karnal bunt has a minimal affect on yield and grain quality, but many countries have a zero tolerance for its presence; consequently, the disease has regulatory significance.

The fungus survives as spores (teliospores) on infected seed and in soil contaminated by the previous crop. A delicate outer membrane that encloses the spore mass on infected seed is easily broken during harvest, dispersing the spores and contaminating healthy seed and soil. Teliospores require a dormant period of up to 6 months before they can germinate and can remain viable in the soil for up to 45 months. Teliospores germinate in response to moisture and produce numerous sporidia at the soil surface. Sporidia are forcibly ejected and dispersed by wind, splashing water, and insects to plants, where they cause infections. Plants are most susceptible to infection when spikes emerge from the boot, but infection can occur throughout the flowering period. Rainy, cool weather and high humidity are ideal for spread of Karnal bunt.

Disease-free seed and seed treatments are important to prevent the introduction of Karnal bunt to noninfested areas. In areas where the soil has become infested, rotate to crops other than wheat and triticale for at least 5 years. Sowing dates also can be adjusted so that heading does not occur when weather conditions are conducive to infection.

ROOT AND FOOT ROT

Root and foot rot, also called common root rot, crown rot, and culm rot, has a complex etiology. In California the fungi *Bipolaris sorokiniana (Helminthosporium sativum), Fusarium culmorum,* and *F. graminearum (F. roseum)* are most important. Diseased plants occur randomly or in irregular patches and appear stunted and lighter green than nondiseased plants. Lower leaf sheaths, culms, crowns, subcrown internodes, and roots are discolored and rotted (fig. 13). Diseased plants are brittle; when pulled, they break off easily near the soil level. Severely affected plants may senesce prematurely and produce few tillers and small white or bleached heads that contain shriveled kernels. Early infections can result in pre- and postemergence seedling blight.

The fungi survive on host residue and in soil as mycelium and/or resting spores and are favored by warm weather. Primary infections occur on coleoptiles, primary roots, and subcrown internodes. Moisture or high relative humidity is required for root infection, but subsequent disease development depends on warm temperature and moisture stress. Scab, or head blight, is caused by strains of the same *Fusarium* species that cause root rot. Spores splash onto spikes and infect flower parts if the parts remain continually wet for several days. Blighted spikes

Figure 14. Take-all symptoms. Photo by Jack Kelly Clark.

appear prematurely bleached and usually are sterile or contain only partially filled seed. Scab is rare in California, but it is an important disease in humid areas, especially where rainfall is common during heading, flowering, and grain development stages.

Planting clean or treated seed can reduce seedling infections. Planting fall-sown small grains late in the fall decreases exposure of seedlings to warm soil temperatures. Disease is minimized if adequate soil fertility is maintained for vigorous root and shoot growth. Provide adequate nitrogen but avoid excessive fertilization. Avoid oversaturated soil conditions by providing for adequate drainage for fields subject to flooding during heavy rains. Irrigate to avoid moisture stress. Elimination of crop residue and volunteer small grain plants and crop rotation help reduce inoculum levels.

TAKE-ALL

Take-all, caused by the fungus *Gaeumannomyces graminis* f. sp. *tritici*, is a basal stem, crown, and root disease. Symptoms first appear as stunting and reduced tillering early in the growing season. Later, infected plants prematurely form white (sterile) heads. Roots and crowns are darkened. The presence of a layer of dark brown or black fungal mycelium underneath the lowest leaf sheaths (fig. 14) distinguishes take-all from common root rot.

The fungus survives on crop residue and on roots of certain grass weeds, including bentgrass, quackgrass, and some species of brome. Under conditions of high soil moisture, the fungus spreads to adjacent plants by root contact. Infection is favored by cool weather. Take-all is more severe on plants grown on alkaline soil or soil deficient in nutrients.

Control is through crop rotation and by providing good field drainage and optimal soil fertility. Avoid excessive nitrate fertilizer, which aggravates take-all. Oat and rye are acceptable rotation crops because they are not hosts for the take-all pathogen.

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SMALL GRAIN PRODUCTION MANUAL
PART 7

Pest Management of Small Grains—Insects

LARRY GODFREY, Extension Specialist, Department of Entomology, University of California, Davis; **ERIC NATWICK,** University of California Cooperative Extension Farm Advisor, Imperial County; **STEVE WRIGHT,** University of California Cooperative Extension Farm Advisor, Tulare County; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

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This publication, *Pest Management of Small Grains—Insects*, is the seventh in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
- *Part 3: Seedbed Preparation, Sowing, and Residue Management*, Publication 8166
- *Part 4: Fertilization*, Publication 8167
- *Part 5: Irrigation and Water Relations*, Publication 8168
- *Part 6: Pest Management—Diseases*, Publication 8169
- *Part 8: Pest Management—Vertebrates*, Publication 8171
- *Part 9: Pest Management—Weeds*, Publication 8172
- *Part 10: Small Grain Forages*, Publication 8173
- *Part 11: Small Grain Cover Crops*, Publication 8174
- *Part 12: Small Grains in Crop Rotations*, Publication 8175
- *Part 13: Harvesting and Storage*, Publication 8176
- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

APHIDS

Aphids are the most common insect pests of small grains (for a key to aphids commonly found in small grains in California, see Summers and Newton 2003). They cause damage by feeding on the small grain crop and, except for the Russian wheat aphid, by serving as vectors of barley yellow dwarf virus. When small grain aphids become abundant, their feeding reduces plant vigor and results in yield loss. Damage results from early-season infestations before heading and late-season infestations in the heads shortly after heading. Significant losses can occur if aphid populations exceed 50 to 60 aphids per tiller (stem) before heads emerge from the boot. Heavy deposits of honeydew, particularly in the heads, may prevent grain or trash separation at harvest. High temperatures tend to reduce aphid populations.

UC PEER REVIEWED

Figure 1. Bird cherry-oat aphid. Photo by Jack Kelly Clark.

Figure 2. Corn leaf aphid. Photo by Jack Kelly Clark.

Figure 3. Greenbug. Photo by Jack Kelly Clark.

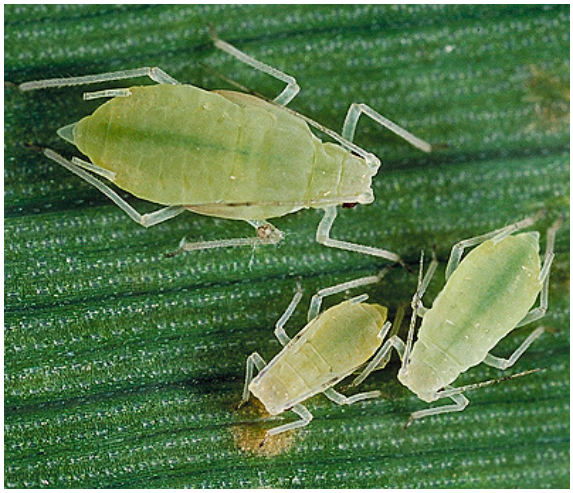

Figure 4. Rose-grain aphid. Photo by Jack Kelly Clark.

The bird cherry-oat aphid *(Rhopalosiphum padi)* (fig. 1) is the most damaging aphid species in California small grain production and may reach injurious levels from late winter to early spring. Aphids first appear on lower leaves and stems and frequently colonize the underside of lower leaves. As plants grow, infestation progresses upward, with aphids feeding on stems and leaves and eventually colonizing the heads. The aphid has an olive-green body, which may vary from black to pale green, giving it a mottled appearance; a prominent reddish-orange patch between and at the base of the cornicles; pale green legs and cornicles with dark tips; and relatively long, black antennae.

The corn leaf aphid *(R. maidis)* (fig. 2) is found in the plant's whorl. This aphid has a greenish blue body with darker areas surrounding the base of the cornicles, which are short and broad. The head and short antennae are dark; cornicles and legs are black.

The greenbug *(Schizaphis graminum)* (fig. 3) is found on the underside of lower leaves. It often is the major aphid pest of small grains in the Imperial Valley and the Intermountain Region of Northern California. It has a light green body with a dark green stripe down the middle of the back. The antennae are black; the cornicles and legs are pale green, with the legs having black tips. The greenbug can damage plants by injecting toxins; these toxins usually do not affect yield unless greenbug populations are very high before tillering (the first 4 weeks after planting).

The rose-grain aphid *(Acyrthosiphum (Metopolophium) dirhodum)* (fig. 4) is an elongate green or yellow-green aphid with a distinct bright green stripe down its back. It resembles the greenbug but is larger, the joints in the antennae are darker than the middle portion of the antennae, and the antennae usually reach beyond the base of the cornicles. Unlike the greenbug, the rose-grain aphid doesn't produce toxins and usually appears later in the season, after full tillering.

Figure 5. English grain aphid. Photo by Jack Kelly Clark.

Figure 6. Russian wheat aphid. Photo by Jack Kelly Clark.

The English grain aphid *(Macrosiphum avenae)* (fig. 5) appears later in the season, usually after heading, and is found principally on the maturing heads. It is larger than other aphids common on small grains. The body is light green to tan with black antennae, cornicles, and leg joints. The cornicles are long and narrow. Small black markings may be present on the abdomen.

The Russian wheat aphid *(Diuraphis noxia)* (fig. 6) is small, light green, and lacks prominent cornicles. It can be distinguished from all other cereal aphids by a second taillike appendage directly above the cauda, giving it a twin-tailed appearance when viewed with a hand lens. The Russian wheat aphid can damage plants by injecting a toxin that is responsible for many damage symptoms, the most characteristic of which are longitudinal white streaks on the leaves and sometimes on the stem. Heavily infested plants are stunted and sometimes exhibit a flattened appearance, with tillers lying almost parallel to the ground. Infested leaves curl up like a soda straw and remain in a rigid upright position rather than assuming the typical drooping posture, preventing access by common natural enemies (syrphid fly larvae, lady beetle adults and larvae, and lacewing larvae). The aphid is frequently found within these curled leaves. If the awns are trapped in the curled flag leaf, the head is usually distorted and assumes a fishhook appearance. Aphid populations tend to be higher and more damaging on moisture-stressed plants and on late-sown fields (late-sown fields can easily become moisture stressed). Wheat and barley are the most susceptible; rye and triticale, while susceptible, are usually less damaged; and oats appear to sustain little or no injury. Treatment thresholds for irrigated wheat are shown in table 1. Thresholds for irrigated barley may be similar, but thresholds have not been developed for rainfed wheat or barley. Injury is normally most severe on rainfed grain.

Table 1. Russian wheat aphid treatment thresholds for irrigated wheat

Growth stage	Treatment thresholds (number of aphids)
2-leaf	5 per plant
early tillering	5 per tiller
late tillering	10 per tiller
first node	10 per tiller
boot stage	20 per tiller
heading and later	30 per tiller

Aphid control can be achieved through the activity of natural enemies or, when needed, the use of insecticides (see Summers et al. 2002 for recommended insecticides and rates). Natural enemies include insects such as parasitic wasps (indicated by aphid mummies) and various predators (syrphid fly larvae, lady beetle adults and larvae, and lacewing larvae) as well as entomophagous fungi. These fungi can spread rapidly through an aphid population under proper temperature and humidity conditions and virtually eliminate the aphids within a week. The natural enemy complex is usually sufficient to control aphids; in any case, their effectiveness and relative numbers should be evaluated before insecticides are used. Insecticide

use should be avoided if possible because natural enemies associated with small grains aid in pest control not only in this crop but in other crops as well.

CEREAL LEAF BEETLE

The cereal leaf beetle *(Oulema melanopus)* was first found in the eastern United States in the 1940s. Its range now includes the northwestern United States, and it is a threat to enter California. Adults and larvae feed on a variety of small grains and wild grasses, skeletonizing leaf surfaces and reducing photosynthetic area. Feeding also contributes to water loss by plants. Plants senesce earlier, produce fewer tillers, and have lower yields. Oat, barley, and wheat are preferred hosts. Adult beetles are approximately 3/16 inch (5 mm) long and have shiny, metallic blue forewings and a bright red thorax. Adults spend the winter in leaf litter and duff near infested fields. They leave the overwintering site in the spring, mate, and begin to lay eggs. The small, yellowish eggs are placed individually on the upper surface of the leaf, and yellow, grublike larvae emerge in about a week at temperatures near 80°F (27°C). The larvae cover their bodies with a slimy brown substance comprised of mucus and fecal matter as a defense against predators. The larvae feed on the upper surface of a leaf, leaving only a thin membrane. Pupation occurs in an earthen cell about ½ to 2 inches (1.2 to 5 cm) below the surface. Adults emerge from the pupae after about 15 to 20 days and move out of the grain field to protected places. They return to grain fields the following spring.

Figure 7. Brown wheat mite. Photo by Jack Kelly Clark.

Figure 8. Winter grain mite. Photo by Jack Kelly Clark.

The treatment threshold used in many states is more than one cereal leaf beetle egg or larva per two stems if larvae have begun to hatch (damage assessments have not been done in California since this pest has not yet invaded California). Several insecticides provide good control. Since beetles prefer thin stands, agronomic practices that promote full stands are desirable. Natural enemies, including an egg parasite *(Anaphes flavipes)* and a larval parasite *(Tetrastichus julis)* aid in control of cereal leaf beetle in some areas.

MITES

The brown wheat mite *(Petrobia lateens)*, winter grain mite *(Penthaleus major)*, and Banks grass mite *(Oligonychus pratensis)* occur on small grains. The brown wheat mite (fig. 7) is about 0.025 inch (0.6 mm) long, oval shaped, and dark red or brown in color. The winter grain mite (fig. 8) is larger, 0.04 inch (1 mm) long, and dark bluish black with red-orange legs and a reddish patch on the upper side. The Banks grass mite is extremely small, 0.001 inch (0.025 mm) long, and yellow to cream in color.

Leaves injured by brown wheat mite first appear silvery and later take on a scorched appearance. Injury caused by the winter grain mite results in yellowish leaves and stunted plants, symptoms similar to cold temperature injury. Banks grass mite turns leaves silvery, and the tips and margins later turn brown; webbing is an additional sign that injury is caused by the Banks grass mite. Both brown wheat mite and Banks grass mite cause the greatest injury to water-stressed plants. A timely irrigation usually alleviates the problem. Crop rotation helps control the winter grain mite. The brown wheat mite, winter grain mite, and Banks grass mite seldom cause significant damage in California.

Figure 9. Wheat stem maggot. Photo by Jack Kelly Clark.

Figure 10. Small grain wireworm. Photo by Jack Kelly Clark.

The straw itch mite *(Pyemotes tritici)* parasitizes a variety of insects, including stored grain pests such as the Angoumois grain moth *(Sitotroga cerealella)*. It also attacks humans. Infestations can occur on alfalfa, barley, oat, and wheat hay and can produce irritation on livestock and humans. People who handle infested straw, crops (beans, cotton, small grains), or crop residues can be severely affected. Symptoms are similar to those caused by chiggers and develop into a hivelike rash over much of the body. Intense itching can last a week or so and may be accompanied by fever, headaches, and mild diarrhea. Infestations of storage facilities can be treated with insecticides containing pyrethroids. No economical chemical controls are available for baled hay.

WHEAT STEM MAGGOT

The wheat stem maggot *(Meromyza americana)* (fig. 9) larva is about 0.25 inch (6 mm) long and is pale green or cream. It is a legless maggot that is generally found inside the stem. The adult is a small, yellowish white fly with bright green eyes and three black stripes across the thorax and abdomen.

Eggs are laid in September and October and hatch later in fall. The young maggots overwinter. When development resumes in spring, damage is caused by maggots feeding in the upper portion of the stem, which cuts off nutrient flow. The wheat heads turn a whitish color, and they easily pull free from where they have been chewed and slide out of the leaf sheath. Infested plants also have fewer tillers than healthy plants. Injury caused by the wheat stem maggot is obvious but usually not serious, so control is not needed.

WIREWORMS

Small grain wireworms (*Aeolus* sp., *Anchastus* spp., *Melanotus* spp., and *Limonius* spp.) (fig. 10) are found in the soil. Damage is done by the larval stage, which is a thin, yellowish brown worm that has a shiny, tough skin. Wireworms feed on roots of emerging plants, killing the seedlings and reducing the stand. As plants mature, wireworms may girdle the stem, causing white heads. This damage is similar in appearance to that caused by common root rot, take-all, and wheat stem maggot. Wireworm infestations are difficult to detect prior to visible plant injury. Infestations of small grains are most likely following a long-term legume crop or natural or temporary pasture.

Fallowing during summer with frequent tillage (springtooth or disk) should be done on fields known to contain wireworm larvae. Small grain fields damaged in the seedling stage can be replanted if replanting occurs before existing plants begin to tiller. Rotation to nonhost crops is useful. Chemical controls, if used, must be applied preplant or as seed treatments.

OTHER INSECTS

Other insect pests such as cutworms, grasshoppers, and armyworms can occasionally damage small grains, but damage is not regular or widespread.

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SMALL GRAIN PRODUCTION MANUAL
PART 8

Pest Management of Small Grains—Vertebrates

DESLEY WHISSON, Former Extension Specialist, Wildlife Ecology, Department of Wildlife, Fish, and Conservation Biology, University of California, Davis; **TERRELL SALMON,** Extension Specialist, Wildlife Damage, and Director, University of California Cooperative Extension, San Diego County; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

UNIVERSITY OF CALIFORNIA
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This publication, *Pest Management of Small Grains—Vertebrates*, is the eighth in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

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Small grain crops provide an attractive habitat and food source to a variety of vertebrate pests. The burrows and soil mounds created by some vertebrate pests cause problems with irrigation (primarily in flood-irrigated fields) and can damage harvest equipment and disrupt harvest operations. Meadow mice, ground squirrels, and pocket gophers are the most serious vertebrate pests in small grains in California. Rabbits, hares, deer, wild pigs, and migrating waterfowl can also cause serious damage. The potential for damage varies between fields and can depend on cultural practices (irrigation, field rotation), soil type, the location of the field, and the surrounding habitats. Fields near rangeland, forested areas, and other uncultivated weedy areas are generally at higher risk and are invaded more quickly than fields bordered by frequently cultivated land.

UC PEER REVIEWED

The most successful vertebrate control practices keep vertebrate pest populations below levels at which significant damage occurs. This requires knowledge of the biology and behavior of the potential pests and regular monitoring for them in and around fields. Historical records of pest population levels, control measures imple-

mented, and the success of methods used can help determine the best management approach, as can consideration of the presence of nonpest species. In many areas, the presence of endangered species limits the choice of control measures.

Because control options vary with the pest, it is important to correctly identify the species that is causing damage before implementing a management program. To identify pests, observe the location and type of damage within the field; examine signs such as feces, tracks, burrows, and mounds; and observe the animal itself if at all possible. More than one method (table 1) is available to manage populations of most vertebrate pests, and natural biological controls can help keep some vertebrate pests from reaching damaging levels. Predators such as hawks, owls, foxes, coyotes, and snakes feed on some of the vertebrate pests of small grains. Predators alone, however, usually cannot keep vertebrate pests from reaching damaging levels. The high reproductive rate of small rodents allows their populations to quickly compensate for losses to predation. In addition, a predator usually modifies its diet according to relative abundance of prey species. Therefore, enhancing habitat to attract predators should only be a small part of an integrated pest management program.

The legal aspects of vertebrate pest management must be considered before initiating control measures. Under the California Fish and Game Code, pocket gophers, meadow voles, California ground squirrels, black-tailed jackrabbits, and cottontails may be lethally removed at any time by the property owner or tenant if the vertebrate is causing or about to cause crop depredation. Deer and wild pigs may be lethally removed only during the hunting season or under a depredation permit obtained from the Department of Fish and Game. Only pesticides that are registered with the U.S. EPA's Department of Pesticide Regulation (DPR) can be legally used for vertebrate pest control (see the California DPR Web site at http://www.cdpr.ca.gov/). The use of certain vertebrate pest control measures may be restricted in areas where endangered species are present. Use restrictions are outlined in county bulletins that are available through the DPR's Web site or from county agricultural commissioners. Live traps are also sometimes used for managing vertebrate pests. Under the California Fish and Game Code, it is illegal to trap and relocate an animal. Live-trapped pest animals should be euthanized humanely. Methods considered humane by the American Veterinary Medical Association include gassing with carbon dioxide, shooting, or a sharp blow to the head (see Salmon et al. 2006 for more information).

Table 1. Control options for vertebrate pests in small grains

Pest	Habitat modification	Trapping	Fencing	Shooting	Baiting	Burrow fumigation
pocket gopher	X	X			X	X
meadow vole	X				X	
ground squirrel		X		X	X	X
rabbit/hare	X	X	X	X	X	
feral pig		X		X		

Figure 1. Voles (meadow mice). Photo by Jack Kelly Clark.

MEADOW VOLES

Meadow voles (*Microtus* spp.), also called meadow mice (fig. 1), feed on the succulent parts of small grains, cutting down older plants to feed on the seed. They may consume most of the grain in forage crops that are harvested and windrowed at the soft dough stage and then left in the field too long. Meadow voles have a body length of 4 to 6 inches (10 to 15 cm) when mature, heavy bodies, short legs and tail, small eyes, and small, partially hidden ears. Their soft, dense fur is blackish brown to grayish brown. Meadow voles are active year-round. They dig short, shallow burrows and make underground nests of grass, stems, and leaves. Well-worn trails 2

inches (5 cm) wide leading to unplugged entrance holes are a good indication that significant numbers of meadow voles are present. Meadow voles reproduce very rapidly, and populations fluctuate considerably. Populations usually reach high levels every 7 to 10 years. A female can produce from 2 to 5 litters per year, with an average of 4 or 5 young. In an expanding population, breeding occurs throughout the year, with peak reproduction evident in the spring.

Meadow voles invade crops from noncrop areas such as ditches, grasslands, and orchards that support them year-round. Practices that make surrounding areas less favorable to meadow voles, such as controlling weeds, reducing ground cover, and cultivating fence rows, roadsides, and ditch banks, can be effective in preventing serious problems. If a forage crop must be harvested at the soft dough stage, remove it from the field as quickly as possible. Where meadow vole problems are serious, applying bait is the only effective control. Zinc phosphide and the anticoagulants diphacinone and chlorophacinone are registered for meadow vole control but cannot be used within crops during growing periods. Bait may be applied mechanically or by hand.

Figure 2. Belding's ground squirrel. Photo by Jack Kelly Clark.

GROUND SQUIRRELS

Ground squirrels occasionally damage small grains that are planted adjacent to rangelands, orchards, or other squirrel-infested areas. Damage usually occurs only on the perimeters of crops, although populations occasionally spread to rainfed fields. Ground squirrels may cause damage any time during the year when they are active. They may remove seedlings shortly after planting and may also remove plants in mature fields. Damage can be especially severe in the vicinity of squirrel burrow systems. Ground squirrel burrows may interfere with irrigation and may damage ditchbanks and levees.

Belding's ground squirrel (*Spermophilus beldingi*) (fig. 2), found in northeastern California, is a relatively small squirrel with a head and body 5 to 9 inches (12.5 to 23 cm) long and a short tail that is not bushy. The California ground squirrel (*S. beecheyi*) (fig. 3), found throughout most of the rest of California, is a large ground squirrel with the head and body 9 to 11 inches (23 to 28 cm) long, gray-brown fur mottled by light flecks, and a semibushy tail. Belding's ground squirrel prefers to feed on green plants while the California ground squirrel prefers green foliage during the spring but generally eats seeds later in the season. As a result of these feeding differences, the Belding's ground squirrel is much more difficult to control with grain baits.

Figure 3. California ground squirrel. Photo by Jack Kelly Clark.

Ground squirrels spend much of their time sunning, feeding, and socializing. Burrows provide protection as well as a place to sleep and rest, rear young, and store food. Entrances are always unplugged. Ground squirrels live in colonies. Females have 1 litter averaging 7 to 8 young per year in the spring. About 6 weeks after birth the young ground squirrels emerge from the burrows and begin to graze on green vegetation. During the hottest and driest part of the summer and fall, many adult squirrels go into a resting state (estivation) until temperatures become more favorable. Most squirrels, especially the adults, hibernate in the winter. Because of these periods of inactivity, ground squirrel numbers seem much greater in spring and early fall than at other times of the year.

Monitor fields and adjacent areas regularly for signs of ground squirrel activity and take control actions when populations are small.

Burrow fumigants, poison baits, and trapping are the three major control options. The success of these practices varies and depends largely on correct timing. Burrow fumigation is most successful in the spring or after irrigation, when soil moisture is high. Fumigation is not as effective during periods in the summer and winter when most of the ground squirrels are inactive. At these times the squirrels seal themselves in their nesting chambers in the burrows and are not exposed to the gas. Fumigants should be placed in burrows that show sign of recent squirrel activity, and the burrow entrance should be sealed with a wad of newspaper and tamped soil. Several fumigants are currently registered for ground squirrel control. Acrolein is a restricted-use material that is injected into burrows through a dispensing rod using nitrogen gas as the propellant. Aluminum phosphide in the form of tablets or pellets, also a restricted-use material, reacts with atmospheric and soil moisture to produce phosphine gas. Gas cartridges (smoke bombs) are relatively easy and safe to use.

Poison baits are either acute (squirrels die after a single feed) or chronic (squirrels need to consume bait over a period of up to 5 days). Zinc phosphide (a restricted-use acute poison) and the anticoagulants diphacinone and chlorophacinone (chronic poisons) are currently registered for ground squirrel control in California. The poison is applied on grain (loose or as a pellet), so it is most effective in the late spring and fall when seeds are the ground squirrels' preferred food. Baits are not registered for broadcast application on small grain fields, but they may be applied to noncrop perimeters. Where practical, anticoagulant baits offered in bait stations can be used within the crop. Ground squirrels may travel 500 feet (152 m) or more from rangeland to a grain field to secure a highly preferred food. Bait stations along the margins of the field are particularly useful for controlling these invaders.

Trapping sometimes provides satisfactory control of small numbers of squirrels in late summer or early fall. A number of kill traps (Conibear trap, modified pocket gopher trap) are available. Shooting may be effective where population levels are low or to control survivors of other control operations, but it is seldom effective with large infestations.

POCKET GOPHERS

Pocket gophers (*Thomomys* spp.) (fig. 4) are burrowing rodents whose name is derived from the pair of large, external, fur-lined cheek pouches in which they carry food and nest material. Adult gophers are 6 to 8 inches (15 to 20 cm) long and have bodies that are well adapted to an underground existence. They have small external ears, small eyes, and lips that close behind their large incisors, enabling them to keep soil out of their mouth while burrowing. They use their short whiskers and tails to help navigate tunnels. They seldom travel above ground, but sometimes may be seen feeding or pushing dirt out of their burrow system. They are generally more active excavating soil in the spring and fall than they are during the heat of summer. In uncultivated and nonirrigated areas, females normally produce 1 litter per year averaging 5 or 6 young during the rainy season when green forage is plentiful. In areas where a source of nutritious green vegetation is available year-round, pocket gophers may breed continuously.

Figure 4. Pocket gopher. Photo by Jack Kelly Clark.

Pocket gophers have a maximum life span of about 5 years. They are extremely territorial and antisocial. As soon as young are weaned, they leave their mother's burrow and establish their own territory. A burrow system can cover an area from a few hundred feet up to more than 1,000 square feet (93 square meters). Tunnels are 2 to 3 inches (5 to 7.5 cm) in diameter, and most are from 8 to 12 inches (20.5 to 30.5 cm) below the ground, with nests and food storage chambers somewhat deeper. Crescent-shaped mounds of fresh soil indicate their presence. The mounds are formed as the animals push soil out of their burrows through lateral tunnels up to the surface. They plug the burrow soon after digging it to preserve a fairly constant temperature and humidity within the burrow system. Gophers may dig secondary tunnels off the main burrow for occasional aboveground grazing. In these cases, no distinctive mounds are formed. Fresh mounds of loose, finely textured soil indicate an active pocket gopher system. Because gophers also backfill old tunnels, the number of fresh mounds is not an indication of the number of gophers in an area. Pocket gopher populations may reach high densities in small grains, especially when small grains are planted after alfalfa. High gopher populations should be controlled prior to the planting of small grains. Pocket gophers feed on grain plants, and the burrows and soil mounds they produce cause problems with irrigation and harvesting equipment.

Successful pocket gopher control depends on early detection of increasing populations. Limiting the number of burrow systems by controlling gophers as they appear reduces treatment costs in the long term. Most growers rely on poison baits or the fumigant aluminum phosphide for gopher control. Control efforts should be concentrated in late winter to early spring, before the gophers' main breeding period. Pocket gophers should be controlled around the perimeters as well as within the fields to reduce the potential for population increase by invasion. Place bait of an acute toxicant such as strychnine in the pocket gophers' main burrow, which is generally found 8 to 12 inches (20.5 to 30.5 cm) away from the plug on fresh, fan-shaped mounds. Treat two or three different places in the burrow system. If gopher activity continues for more than 3 days after treatment, the burrow should be treated again.

When large areas of a field are infested, mechanical burrow builders provide the most economical method of control. The burrow builder is a tractor-drawn device that constructs an artificial burrow and deposits poison bait at preset intervals and quantities. These artificial burrows are made at depths similar to burrows created by pocket gophers and in parallel rows spaced 20 to 25 feet (6.0 to 7.6 m) apart so that they may intercept many natural pocket gopher runways. The pocket gophers readily explore these artificial tunnels and consume the poisoned bait. The success of this method depends largely on soil moisture. If the soil is too wet, the tunnel may not close and may allow sunlight to penetrate the burrow; if the soil is too dry, the burrow may collapse. The burrow builder should be used only in areas where gophers are present, not as a preventative measure. The burrow builder is particularly useful for reducing populations prior to planting and to slow gopher invasion from neighboring fields following planting.

Trapping can control gophers over small areas and can remove animals remaining after a control program. It generally is more effective in spring and fall, when pocket gophers are most active. Several types and brands of gopher traps are available, the more common being the two-pronged pincer trap (Macabee) and the box trap. Traps should be inspected at least daily and moved to a different location if 3 days elapse without catching a gopher.

Burrow fumigation with aluminum phosphide or acrolein may be effective, depending on the soil type and condition and the extent of the burrow system. Fumigants are less effective if soils are dry or porous or if burrow systems are so extensive that it is difficult to maintain a toxic concentration. Sealing burrow openings after

treatment is recommended to maintain a high concentration of lethal gas inside the burrow system. Gas cartridges (smoke bombs) are not effective; pocket gophers detect the gas and quickly seal off that part of the burrow system.

Flood irrigation may reduce the potential for large pocket gopher populations to develop. Deep tillage when a field is taken out of production may also reduce the potential for pocket gopher problems by disrupting burrow systems.

HARES AND RABBITS

Hares (*Lepus* spp.) and rabbits (*Sylvilagus* spp.) occasionally feed on small grain seedlings or young plants along field perimeters. They are most active at night, with peak feeding periods at dusk and dawn. The blacktailed jackrabbit *(Lepus californicus)* (fig. 5), a true hare, has very long ears, short front legs, and long hind legs. The cottontail *(Sylvilagus audubonii)* (fig. 6), a true rabbit, is smaller than the jackrabbit and has much shorter ears. Rabbits and hares are classified as game mammals and can be taken by legal sport hunting methods during hunting seasons. Owners and tenants of agricultural lands may take hares or rabbits any time they cause or are about to cause agricultural damage.

Anticoagulant baits (diphacinone and chlorophacinone) are registered for use in bait stations against jackrabbits but are not registered for use against cottontails. Because jackrabbits will not enter enclosed stations, the bait should be presented in a feeder in areas frequented by jackrabbits such as runways or resting or feeding areas. Prebaiting with untreated bait may encourage jackrabbits to become accustomed to feeding from the station. Once they feed on the untreated bait (usually after 5 to 8 days) and begin to consume all untreated bait in a single night, replace the untreated bait with poison bait. Provide bait until all evidence of feeding has ceased. Cover bait stations during daylight hours to help exclude nontarget animals from the bait.

Rabbit fences may be the only effective means of minimizing damage due to rabbits, but they are usually too expensive to use on a large scale. The cost of such a fence could be justified if small grains were being rotated with a higher-value crop and rabbit damage were severe. Rabbit fences should be made out of 1-inch woven wire mesh supported by posts, with the top of the mesh at least 36 inches (90 cm) above the ground.

Figure 5. Jackrabbit. Photo by Jack Kelly Clark.

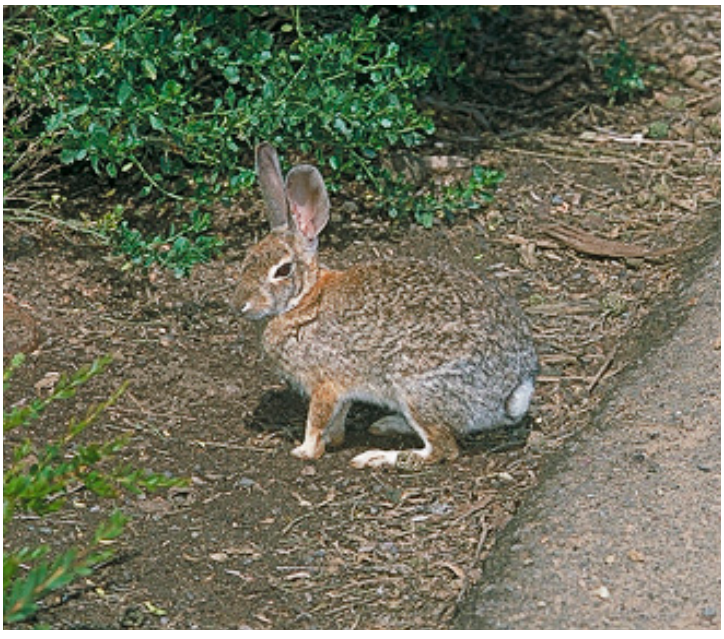

Figure 6. Cottontail rabbit. Photo by Jack Kelly Clark.

The bottom 6 inches (15 cm) of the mesh should be bent at a right angle away from the field and buried 6 inches (15 cm) beneath the soil surface.

Trapping, although labor intensive, may be a solution to cottontail damage. Cottontails, unlike jackrabbits, are easy to trap with Conibear traps in tap boxes or with cage-type live traps. Shooting, just prior to dusk, is effective for both jackrabbits and cottontails, but, like trapping, it is time consuming.

FERAL PIGS

Wild boars were brought from Europe to the eastern United States in 1912 and were subsequently introduced to Monterey County in 1925. Since then, they have interbred with feral (wild) pigs *(Sus scofa),* and these hybrids continue to expand both naturally and with the aid of humans throughout California. Wild boars are brown to blackish brown, with grizzled guard hairs, a mane of hair 3 to 6 inches (7.5 to 15 cm) long running dorsally from the neck to the rump, a straight and heavily tufted tail, and ears covered with hair. Hybrids take on the appearance of the wild boar. In this discussion, wild boars, feral pigs, and hybrids are referred to as feral pigs.

Feral pigs are most abundant in areas where a source of water and cover are present. When conditions are optimal (abundance of food resources, water, etc.), sows can produce 2 litters of 5 to 6 piglets per year; populations can triple every year. Feral pigs are omnivorous and consume a wide variety of available foods, including acorns, grasses, forbs, berries, bulbs, tubers, invertebrates, reptiles, birds, eggs, and animal carcasses. They cause damage by rooting in crops and pastures, and their activities can encourage soil erosion. A passel of 3 or 4 wild pigs may damage half an acre or more of a field or vegetable crop in a single night.

Feral pigs are classified as game mammals under the California Fish and Game Code. Except under certain circumstances (e.g., a feral pig encountered in the act of killing livestock or causing other agricultural damage; see the Fish and Game Code for other exceptions), it is unlawful to take any feral pig without first obtaining a permit from the Department of Fish and Game (DFG). Sport hunting can reduce wild pig densities in certain areas and can be a source of revenue for ranchers. As with all game species, feral pig behavior tends to change as hunting pressure increases. Where hunting is rare, feral pigs are active both night and day, though they become less active during the day in hot weather. Where hunting pressure is high, they generally feed only at night. Depending on the density and abundance of cover, feral pigs tend to leave an area where hunting pressure becomes severe. Consequently, crop depredations may cease after one or two pigs are shot or trapped or they are subjected to intermittent hunting pressure.

Trapping, especially where pig densities are high, is the most effective control method. Trapping is not effective, however, during fall and winter when acorns or other preferred foods are available. Stationary corral-type and box-type traps have been used with success. These traps are permanent and should be constructed in locations where large populations of pigs are evident. A portable trap with a drop gate also is effective and may be moved as necessary. These traps have been used successfully in California, with as many as 14 pigs caught in a trap in one night. Persistence and dedication are required if a control program is to be successful. Traps must be checked daily to be reset and to replace bait when needed. When conducting a trapping program, all hunting in the area should cease before traps are set up.

Fencing is generally not practical except in small areas around yards and gardens. Heavy wire and strong posts must be used; if feral pigs are persistent, exclusion is almost impossible.

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SMALL GRAIN PRODUCTION MANUAL PART 9

Pest Management of Small Grains—Weeds

MICK CANEVARI, University of California Cooperative Extension Farm Advisor, San Joaquin County; **STEVE ORLOFF,** University of California Cooperative Extension Farm Advisor, Siskiyou County; **RON VARGAS,** University of California Cooperative Extension Farm Advisor, Madera County; **STEVE WRIGHT,** University of California Cooperative Extension Farm Advisor, Tulare County; **ROB WILSON,** University of California Cooperative Extension Farm Advisor, Lassen County; **DAVE CUDNEY,** Extension Weed Scientist Emeritus, Botany and Plant Sciences, University of California, Riverside; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

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This publication, *Pest Management of Small Grains—Weeds*, is the ninth in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

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Weed control is important in small grains because weeds compete with developing plants, reducing grain or forage yield; green weeds that emerge late in the season can impede harvest operations and reduce grain quality; and weed seeds can contaminate the grain, making extra cleaning necessary. Effective weed control in small grains also helps reduce weed infestations in subsequent crops. Many weeds are more economical to control in small grains than in other crops. The distinction between winter and spring small grains and among different classes of cereal crops is important because some herbicide labels give different application rates or crop injury potentials for different small grains or cereal crops. Labels should be checked before an application is made and all label instructions must be followed. Table 1 gives the major weeds of importance in various regions of California (see also *UC IPM Pest Management Guidelines: Small Grains*, http://www.ipm.ucdavis.edu/PMG/selectnewpest.small-grains.html).

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Table 1. Problem weeds by region in California

Scientific name	Common name	Inter-mountain	Sacramento Valley	San Joaquin Valley	Coast	Southern California
Broadleaf weeds						
Amaranthus spp.	pigweed	•				
Amsinckia intermedia	coast fiddleneck	•	•	•	•	•
Anthemis cotula	mayweed chamomile		•	•		
Bassia hyssopifolia	fivehook basia			•		
Brassica spp.	mustard	•	•	•	•	•
Calandrinia ciliata	redmaids		•	•	•	
Capsella bursa-pastoris	shepherd's purse	•	•	•	•	•
Cardaria draba	hoary cress	•			•	
Centaurea solstitialis	yellow starthistle	•	•	•	•	
Chenopodium album	common lambsquarters	•		•	•	•
Chenopodium murale	nettleleaf goosefoot	•				•
Cirsium arvense	Canada thistle	•				
Cirsium vulgare	bull thistle	•		•	•	
Claytonia perfoliata	miner's lettuce		•	•	•	
Conium maculatum	poison hemlock	•			•	
Convolvulus arvensis	field bindweed		•	•		
Cyperus spp.	nutsedge			•		
Descurainia sophia	tansy mustard	•				•
Erodium spp.	filaree	•	•	•	•	
Hypericum perforatum	St. Johnswort				•	
Kochia scoparia	kochia	•				
Latuca serriola	prickly lettuce	•	•	•		•
Lepidium latifolium	perennial pepperweed	•				
Malva parviflora	little mallow	•	•	•		•
Matricaria matricariodes	pineappleweed		•	•		
Polygonum argyrocoleon	silversheath knotweed	•		•		•
Polygonum coccineum	swamp smartweed		•	•		
Raphanus raphanistrum	wild radish		•	•	•	
Salsola iberica	Russian thistle	•		•	•	
Senecio vulgaris	common groundsel		•	•	•	•
Silybum marianum	blessed milkthistle		•	•		
Sisymbrium irio	London rocket		•	•	•	•
Solanum spp.	nightshade	•				
Sonchus oleraceus	annual sowthistle		•	•	•	•
Stellaria media	common chickweed		•	•	•	
Taraxacum officinale	dandelion		•			
Urtica urens	burning nettle	•	•	•	•	
Grasses						
Avena fatua	wild oat	•	•	•	•	•
Bromus spp.	bromes	•	•	•	•	•
Cynodon dactylon	bermudagrass					
Elytrigia repens	quackgrass	•		•		•
Hordeum jubatum	fo•tail barley	•				
Hordeum leporinum	hare barley	•	•	•	•	
Lolium multiflorum	Italian ryegrass, annual ryegrass		•	•	•	
Phalaris minor	littleseed canarygrass			•		•
Phalaris paradoxa	hood canarygrass		•	•	•	
Poa annua	annual bluegrass			•		
Poa bulbosa	bulbous bluegrass	•				
Polypogon monspeliensis	rabbitsfoot grass		•	•		•
Secale cereale	cereal rye	•				
Setaria pumila	yellow foxtail		•	•	•	
Setaria viridis	green foxtail		•	•	•	
Sorghum halepense	johnsongrass		•	•	•	
Taeniatherum caput-medusae	Medusahead	•			•	

TYPES OF WEEDS

Broadleaf Weeds

A wide range of broadleaf weeds infest small grains (see table 1). The more common weeds are mustards (*Brassica* spp., especially black mustard, *B. nigra)*, wild radish *(Raphanus raphanistrum)*, London rocket *(Sisymbrium irio)*, shepherd's purse *(Capsella bursa-pastoris)*, coast fiddleneck *(Amsinckia intermedia)*, annual sowthistle *(Sonchus oleraceus)*, prickly lettuce *(Latuca serriola)*, burning nettle *(Urtica urens)*, pineappleweed *(Matricaria matricariodes)*, miner's lettuce *(Claytonia perfoliata)*, common chickweed *(Stellaria media)*, field bindweed *(Convolvulus arvensis)*, swamp smartweed *(Polygonum coccineum)*, common lambsquarters *(Chenopodium album)*, and yellow starthistle *(Centaurea solstitialis)*. Broadleaf weeds vary in their ability to compete with small grains. For example, an average of 1 wild radish plant per square foot (10 per sq m), when established at the same time a wheat crop emerges, can reduce yield by as much as 66 percent by completely overtopping the wheat canopy and competing for light. Low-growing weeds such as common chickweed, henbit *(Lamium amplexicaule)*, and miner's lettuce are generally less competitive, but even high populations of common chickweed can smother small plants, reduce yield, and remove soil nutrients and moisture. Poor weed management also causes weed problems in succeeding crops.

Grasses

Grass weeds are difficult to control in small grains because they mimic the growing cycle and growth habit of the crop. Many grass weeds germinate at the same time as small grains and mature slightly before or at the same time as the crop, assuring an ample supply of seed for next year's weed crop. These weeds compete for light and space and also remove soil moisture and nutrients needed for crop growth. Winter annual grassy weeds in California's small grains include wild oat *(Avena fatua)*, Italian, or annual, ryegrass *(Lolium multiflorum)*, ripgut brome *(Bromus diandrus)* and downy brome *(B. tectorum)*, hare barley *(Hordeum leporinum)*, rabbitsfoot grass *(Polypogon monspeliensis)*, and hood canarygrass *(Phalaris paradoxa)* and littleseed canarygrass *(P. minor)*.

Wild oat emerges throughout the cool season from autumn through spring. In small grains it causes lodging, slows harvest, clogs harvester screens, and lowers yields. An average of 7 wild oat plants per square foot (70 per sq m) can reduce wheat yields by 3,000 pounds per acre (3,360 kg/ha) in a crop with a yield potential of 6,000 pounds per acre (6,720 kg/ha). Barley, because of its more competitive early growth, is less affected by wild oat than is wheat. In one study a wild oat density averaging 14 plants per square foot (140 per sq m) reduced barley yield by 27 percent and wheat yield by 39 percent (Cudney et al. 2001). Ripgut brome is a particular problem in rainfed production areas. The weed reduces yield by competing with the crop, and its seed can contaminate the grain and reduce its marketability. Italian ryegrass is a major weed in the central and northern valleys of California. Infestations of hood and littleseed canarygrass can reduce yields by more than 50 percent. Hood canarygrass occurs in the central region and coast rainfed production areas, while littleseed canarygrass is most prevalent in the Imperial Valley and Southern California. Canarygrass is a prolific seed producer, and populations of canarygrass in fields continuously cropped to small grains often exceed 100 plants per square foot (1,000 per sq m). Hare barley and rabbitsfoot grass are common in the southern part of the state, although hare barley is sporadically found elsewhere in California.

CULTURAL PRACTICES THAT REDUCE WEED PRESSURE

An integrated weed management system combines crop rotation, fertilization, irrigation, tillage, herbicide applications, and high plant populations to help control weeds. Field sanitation is a prerequisite for weed control. Planting and tillage implements

should be free of weed seeds and other plant propagules to avoid spreading weeds from field to field. Field perimeters should be kept free of weeds because they serve as a reservoir for seed to infest the field.

A properly prepared seedbed can increase yield and reduce weed pressure (see part 3, *Seedbed Preparation, Sowing, and Residue Management*). Plant high-quality, vigorous, weed-free certified seed. Using noncertified seed risks the introduction of new weed infestations. The sowing date can influence weed competition. Late sowing produces shorter small grain plants that have fewer tillers and are less competitive with weeds. Lower seeding rates also can intensify weed pressure. Studies in the Sacramento–San Joaquin Delta have shown that higher seeding rates are very effective at reducing competition by swamp smartweed, johnsongrass, mustard, wild oat, canarygrass, and common chickweed. Row spacing should be as narrow as feasible to promote early development of a solid, competitive crop canopy.

Mulch planting can give a small grain crop a head start over weeds. In mulch planting, a shallow cultivation is done following rainfall or irrigation, when weed seeds germinate before planting. The crop seed is then sown into moist soil below the mulch layer of dry soil that resulted from the cultivation. Because the crop seed is placed into moist soil, it germinates quickly, ahead of weeds.

Fertilization is essential to maximize small grain vigor and health and is an excellent weed suppression practice (see part 4, *Fertilization*). Starter fertilizer (low nitrogen and high phosphorus content) may be required in some areas. Place starter fertilizer near the seed to provide early availability to the crop, not to weeds. Broadcast-applied starter fertilizer enhances weed growth, especially for wild oat and canarygrass; broadcast applications are less efficient and should be avoided.

Irrigation and proper drainage keep small grains in a vigorous growing condition for maximum competition with weeds (see part 5, *Irrigation and Water Relations*). In areas where flooding and high water tables occur, small grains should be sown on 30- to 60-inch (0.75- to 1.5-m) raised beds. For rainfed production systems, fields can be fallowed every other year to prevent weed seed buildup and to conserve moisture for maximum small grain growth. Weeds should not be permitted to produce seed during the fallow period. Tillage operations before planting should be delayed until the first fall rains germinate the weed seeds so that tillage can kill the first flush of weeds before sowing. Weeds may also be treated with an herbicide during the fallow period (chemical fallow).

Rotating small grain crops with other crops reduces infestations of johnsongrass, wild oat, Italian ryegrass, and other weeds that are important in small grains (see part 12, *Small Grains in Crop Rotations*). Crop rotation allows weed populations to be reduced chemically, mechanically, and physically in the alternate crop. Growing different crops at different times of the year helps break the reproduction cycle of some problem weeds. Small grains are often grown so that weeds important in higher-value crops can be controlled. For example, small grains grown in rotation with vegetable crops allow postemergent broadleaf herbicides to be used to control nightshades and sowthistle, major problems in vegetable crops.

CHEMICAL CONTROL

Good cultural practices help reduce weed competition, but an integrated approach involving these measures as well as herbicide applications is often needed for complete weed control. An integrated approach reduces weed seed production and aids weed control in succeeding crops. The effectiveness of a chemical weed control program depends on the weed species present, application timing, thoroughness of spray application, environmental conditions at the time of application, herbicide use rate and spray volume, and crop management after the application is made. For example,

weeds may again cause problems if late-winter rains stimulate additional weed seed germination after a herbicide application is made. Also, drought-stressed weeds are very difficult to control with postemergent herbicides, especially if they are beyond the seedling stage. Susceptibility of problem weeds to available herbicides is given in the susceptibility table in *UC IPM Pest Management Guidelines, Small Grains* (http://www.ipm.ucdavis.edu/PMG/selectnewpest.small-grains.html). This table is kept up to date with the latest available herbicides.

Postemergence Broadleaf Weed Control

Only postemergent herbicides, which are applied after the crop has emerged, are used for weed control in small grains. Fall-sown small grains are usually treated between December and mid-March, depending on the sowing date and growing conditions. Spring-sown small grains in the intermountain area of northern California are treated between April and June. Several postemergent herbicides are registered for use in small grains.

Phenoxy herbicides, including 2,4-D and MCPA, are commonly used in small grains alone or in combinations. Dicamba, another hormonal-type herbicide, is often included in the phenoxy herbicide group because of its similar mode of action. These herbicides are most effective when applied to small, succulent weeds. Small grains vary in their sensitivity to these herbicides; for example, oat is more tolerant to MCPA than to 2,4-D. Ester and amine formulations of 2,4-D and MCPA amine formulations control most broadleaf weed species encountered in small grains. The ester form is usually more effective than the amine form. However, ester use is not permitted in most counties, or applications are limited to certain times of the year. Figure 1 illustrates the proper application timing of these herbicides. Phenoxy herbicides should be applied after the small grains are well tillered but before they reach the boot stage in order to avoid yield reductions caused by phytotoxicity (see part 2, *Growth and Development*). Best control is obtained when weeds are small and before the crop has reached the jointing stage. Late applications are sometimes ineffective because the crop canopy shields the weeds, preventing herbicide contact. Dense weed populations require a more thorough application with a greater spray volume to ensure contact between the herbicide and weeds. The use of aircraft often facilitates timely herbicide application, but care must be taken to make applications at the appropriate

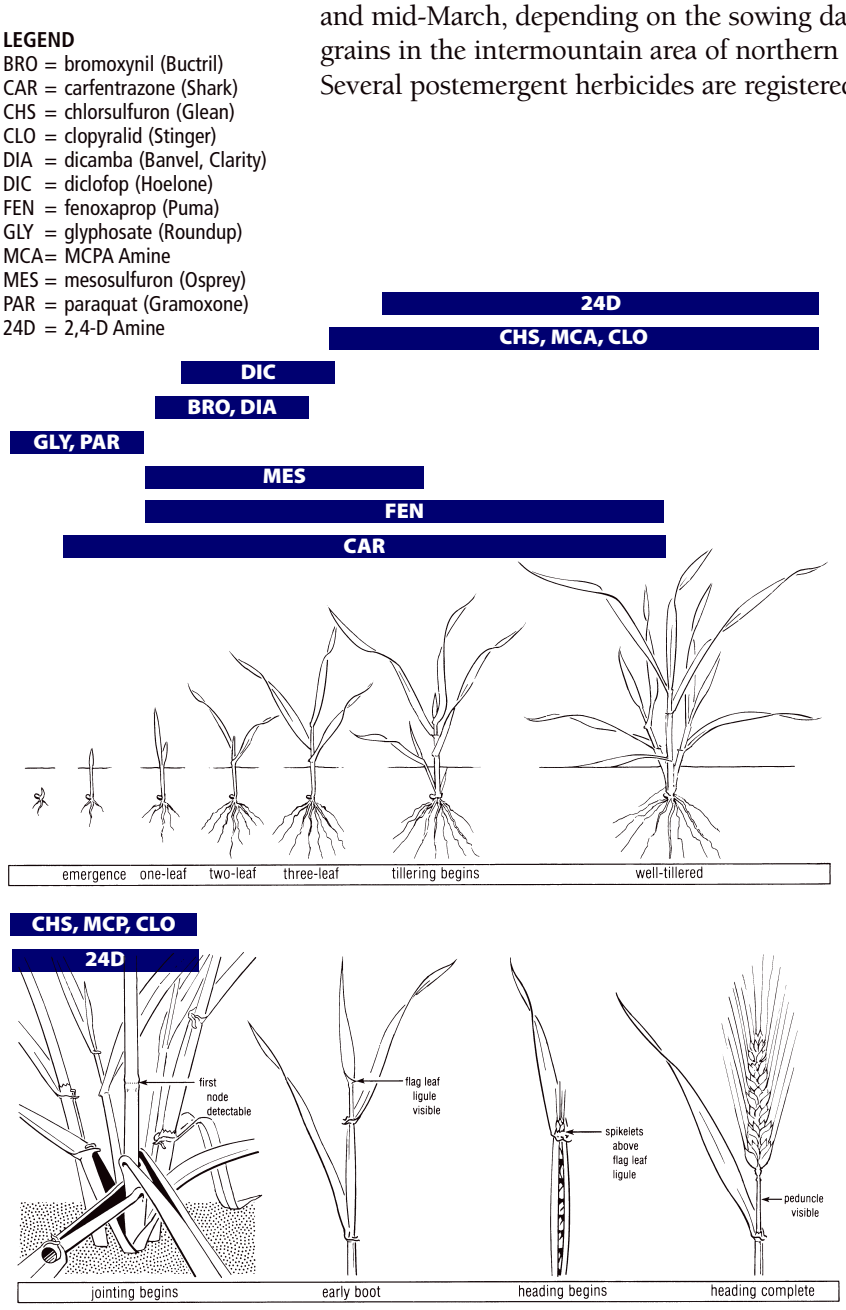

Figure 1. Timing of herbicide applications. *Source:* adapted from *UC IPM Pest Management Guidelines, Small Grains: Developmental Growth Stages, http://www.ipm.ucdavis.edu/PMG/r730000111.html.*

time to avoid injury to adjacent crops from drift or volatilization. MCPA does not control large weeds as well as 2,4-D amine and 2,4-D ester herbicides, but it has greater crop safety, especially when applied to small grains in early growth stages.

Dicamba (Banvel, Clarity) is effective for broadleaf weed control; however, small grains are generally more sensitive to it than they are to 2,4-D. Dicamba is safer when applied at early growth stages (2- to 5-leaf stage). It cannot be used on fall-sown barley. Dicamba controls small plants of common chickweed and coast fiddleneck, which are not controlled by 2,4-D or MCPA. It usually is combined with bromoxynil and MCPA. When applied early, this combination is very effective and increases the weed spectrum controlled compared with either of the herbicides used alone.

Bromoxynil (Buctril), a contact herbicide, is effective on young seedling weeds with no more than 2 to 4 leaves. It is less effective on older weeds and must be tank-mixed with other herbicides, for example, when larger mustards are present. Bromoxynil is not translocated (moved) from the site of absorption like the phenoxy herbicides. Therefore, higher-volume application and thorough coverage is more important with bromoxynil than with phenoxy herbicides. An advantage of bromoxynil is that it controls the toxic weed coast fiddleneck when applied at early growth stages of the weed; phenoxy herbicides often fail to control coast fiddleneck. Bromoxynil is also recommended in areas with phenoxy-sensitive crops such as grapes, cotton, and tree crops.

Chlorsulfuron (Glean) is registered for use on wheat in a wheat-fallow rotation. It is a sulfonyl urea herbicide with a very low application rate. It is not widely used in California because it has a long soil life (at least 18 months), which prevents its use in areas where many different crops are grown. This herbicide controls most broadleaf weeds, including coast fiddleneck and common chickweed. It should be applied to small weeds when the small grain crop is in the 2 to 3 leaf stage to boot stage and should not be used on soils with pH above 7.5.

Clopyralid (Stinger), a picolinic acid, is registered for use on wheat, barley, and oats. It translocates systemically through weeds, similar to phenoxy herbicides. It has a longer soil persistence than phenoxy herbicides, which limits planting of some broadleaf crops before 12 to 18 months after application. It is effective on a different spectrum of weeds than 2,4-D, MCPA, or dicamba. Chlopyralid is especially effective for control of legumes and composites such as Canada thistle *(Cirsium arvense),* and yellow starthistle. Because it does not control many common broadleaf weeds such as mustards, it must be tank-mixed for complete control of the wide range of broadleaf weeds found in small grains. On wheat, clopyralid should be applied from the 3-leaf stage to early boot stage, complimenting the timing of 2,4-D and MCPA.

Carfentrazone (Shark) is a contact herbicide that controls weeds by disrupting cell membranes. It is effective at very low application rates on coast fiddleneck, little mallow, burning nettle, and other weeds that are difficult to control with other herbicides. Adding surfactants to carfentrazone often causes temporary crop burn. Tank mixing with UN-32 (urea-ammonium nitrate) may enhance weed control. Tank-mixing carfentrazone with dicamba provides good control of common chickweed. Combining carfentrazone with phenoxy herbicides broadens the weed spectrum controlled, lowers herbicide application rates, and can reduce the risk of weeds building up herbicide resistance.

Preemergent Grass Weed Control

Preemergent herbicides are not commonly used in small grains in California, but they can be effective in certain situations. Trifluralin (Treflan, Trilan) is a preemergent herbicide used for wild oat and canarygrass control in wheat and barley. It is applied before or after sowing and must be incorporated no deeper than 2 inches (5 cm). A double incorporation is more effective than a single incorporation. Small grains must be planted below the 2-inch herbicide zone (for semidwarf wheat, this depth is near the limit for

successful emergence). Results can be erratic if the zone of treatment does not have adequate moisture. Crop safety is marginal.

Postemergent Grass Weed Control

Diclofop (Hoelon) controls wild oat, canarygrass, and Italian ryegrass in wheat and barley. Diclofop controls wild oat and ryegrass in the 1 to 4 leaf stage and canarygrass in the 1 to 2 leaf stage. Avoid applications under saturated soil conditions or cold weather.

Fenoxaprop ethyl (Puma) controls canarygrass, wild oat, and several foxtails, including yellow foxtail *(Setaria pumila)* and green foxtail *(S. viridis)*. It also suppresses mustards. It has a wide window of application, providing effective control when applied between the 1 to 6 leaf stage of grasses. For best control of wild oat, delay application until most wild oat plants have emerged. A tank mixture with bromoxynil allows for a wide range of weed control at an early timing. Fenoxaprop cannot be tank-mixed with phenoxy herbicides since reduced grass control often results when such tank mixtures are used.

Mesosulfuron (Osprey) controls most grassy weeds and many broadleaf weeds in wheat. It is especially effective on Italian ryegrass, wild oat, littleseed and hood canarygrass, and annual bluegrass. It controls ripgut brome and other brome species, depending on weed size at application. Most California wheat cultivars have good tolerance to the herbicide. However, wheat plants will turn a lighter green color for a couple of weeks following application. If soil nitrogen levels are low, this symptom will persist longer, and supplemental nitrogen should be applied. When treated beyond the 1 tiller stage, temporary growth suppression and shortening of the wheat plant will occur. The crop will recover more quickly from these symptoms under good growing conditions. Mesosulfuron is effective on certain broadleaf weeds, including common chickweed, wild radish, and mustards. It also provides partial control of many other broadleaf weeds, including common groundsel *(Senecio vulgaris)*, little malva, coast fiddleneck, yellow starthistle, and blessed milkthistle. Mesosulfuron can be tank-mixed with bromoxynil and MCPA and may be applied from the 1 leaf to 1 tiller wheat stage and up to the 2 tiller stage of grasses. A methylated seed oil or a nonionic surfactant is required; adding ammonium sulfate or low rates of UN-32 enhances weed control on difficult-to-control weeds. Restrictions on crop rotations are greater than with fenoxaprop.

Controlling Weeds before Planting and Crop Emergence

Weeds that have germinated can be chemically removed using paraquat and glyphosate before cereal planting or emergence. These nonselective herbicides have no soil-residual effects on germinating small grain plants as long as they are applied before plants emerge through the soil. If the herbicide comes into contact with wheat or barley plants, severe injury will occur. Glyphosate can also suppress perennial weeds such as johnsongrass, nutsedge (*Cyperus* spp.), bermudagrass *(Cynodon dactylon)*, and dandelion *(Taraxacum officinale)* when they are growing before grains are planted or emerge.

Controlling Weeds before Harvest

The presence of green weeds late in the season can cause harvest and postharvest problems. Green weeds can slow the progress of combines, raise the moisture content of the harvested crop, and discolor or even cause off-flavors of the harvested grain. Weeds that often cause problems at harvest include field bindweed, Russian thistle, fivehook bassia *(Bassia hyssopifolia)*, kochia, common lambsquarters, knotweed, swamp smartweed, and johnsongrass. Problems with green weeds at harvest can be avoided by using a preharvest herbicide application (2,4-D or glyphosate where permitted) or by swathing the crop before combining. In both cases the green weeds should be allowed to dry before the crop is combined.

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SMALL GRAIN PRODUCTION MANUAL
PART 10

Small Grain Forages

CAROL COLLAR, University of California Cooperative Extension Farm Advisor, Kings County; **STEVE ORLOFF**, University of California Cooperative Extension Farm Advisor, Siskiyou County; **MARSHA MATHEWS**, University of California Cooperative Extension Farm Advisor, Stanislaus County, **STEVE WRIGHT**, University of California Cooperative Extension Farm Advisor, Tulare County; and **LEE JACKSON**, Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

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This publication, *Small Grain Forages,* is the tenth in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
- *Part 3: Seedbed Preparation, Sowing, and Residue Management*, Publication 8166
- *Part 4: Fertilization*, Publication 8167
- *Part 5: Irrigation and Water Relations*, Publication 8168
- *Part 6: Pest Management—Diseases*, Publication 8169
- *Part 7: Pest Management—Insects*, Publication 8170
- *Part 8: Pest Management—Vertebrates*, Publication 8171
- *Part 9: Pest Management—Weeds*, Publication 8172
- *Part 11: Small Grain Cover Crops*, Publication 8174
- *Part 12: Small Grains in Crop Rotations*, Publication 8175
- *Part 13: Harvesting and Storage*, Publication 8176
- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

Small grains are important forages in California. They are fed to a wide range of livestock classes, including dairy cows, beef cows, horses, sheep, and goats. The nutritional requirements of these livestock classes vary, as do the species and quality of small grain forage grown to feed them. The main small grain forages are wheat, triticale, oat, barley, and rye. Each forage type has many cultivars with unique agronomic characteristics and nutritional attributes that makes it suitable to a particular region and end use. As a winter crop, small grain forages make efficient use of soil moisture and are less vulnerable to drought than are summer forages. If rains are timely, a crop can be produced with little or no irrigation. Although some small grain cultivars have been developed specifically for forage production, many of the cultivars used for forage in California are the same as those grown for grain. This gives growers the option of harvesting the crop as grain or forage, depending on market opportunities. Annually, about 600,000 acres (243,000 ha) of small grains are harvested as forage in California.

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USES OF SMALL GRAIN FORAGES

Small grain forages are versatile. They can be harvested as silage, hay, green chop, or grazed. In the Central Valley, home to the majority of the state's dairy cows, small grain forages are typically ensiled in large covered stacks. The resulting silage is an important and economical component of rations for milk cows, dry cows, and heifers. Planting takes place in November and December, and harvest occurs in April or May. Small grain "winter" forages fit well in double cropping systems that include corn for silage (a summer crop). Together, the corn and winter forage crops recycle manure nutrients and water from dairy farms and provide feed all year long. Wheat is the most common forage choice among dairy producers in the southern San Joaquin Valley; wheat, oat, and forage mixes are common farther north in the Central Valley. Triticale is accepted for use as silage, hay, or even grazing. Now that disease-resistant cultivars are available, barley is also a valuable forage.

Compared to dairy farms, other animal enterprises tend to be smaller and less intensive, so forage is more often used in the form of hay and pasture. Oat hay is commonly produced throughout the state, especially in the coastal and mountain foothill regions, and sold for consumption by horses. A variety of small grain forages are produced for beef cattle. In the northern part of the state and the intermountain region, triticale or other small grains are planted in early fall for late-fall and early-spring grazing and for hay production. Some small grain forages are fed to sheep, goats, and even zoo animals, but these uses are relatively minor compared with use by dairy and beef cows and horses.

CHOOSING A SMALL GRAIN FORAGE

Agronomic characteristics such as tolerance to drought, salt, and manure, as well as resistance to diseases and pests, are important attributes for forage cultivars. Crop production plans, growing conditions of the region, and the nutritional requirements of the livestock to which the forage will be fed should also be considered. The intended market—whether the crop will be sold or used on-farm—is another important consideration.

Cultivars differ greatly in time of maturity, which affects the timing of harvest. Select a cultivar that is likely to be in the desired stage of development during the optimal harvest window. For example, in the Central Valley, if boot stage forage is desired, choose a mid- to late-maturing cultivar that does not reach boot stage until the risk of rain is reduced (because the cut forage must be field-wilted for a few days). For dough stage forage, an earlier-maturing cultivar that allows adequate time to prepare for a following corn crop is a better choice.

Other attributes to consider are tillering, leaf to stem ratio, grain to stem ratio, and nutrient content. If the forage will be harvested at boot stage, choose tall, leafy, heavily tillered cultivars. Grain production is not important in this case, since the crop will be harvested long before it produces grain. If the forage is to be harvested at the soft dough stage for milk cows, grain to stem ratio is very important: the most nutrient-dense component of the plant at this stage is the grain, so a short-stature, heavy-grain-producing cultivar is a good choice for this use. For dry cows and heifers, cultivars that have high total plant yields at the soft dough stage are appropriate.

The presence of awns after the late heading stage can present a palatability problem if forage is fed as hay or grazed after heading. Therefore, awnless, awnletted, or hooded cultivars of wheat, triticale, and barley are preferred. Another trait to consider for hay is stem diameter. Fine-stemmed cultivars dry more uniformly than thick-stemmed cultivars and are preferred in the marketplace. Small grain cultivars selected for grazing should produce heavy growth of tillers and leaves, withstand trampling,

and regrow well after grazing. Growth rate also is important since forage for grazing must be available at the desired times. Forages that are planted early in order to provide late-fall and spring cuttings (double-cut winter forage) are at greater risk from barley yellow dwarf disease; plant resistant cultivars for these uses. Another important trait for double-cut forages is regrowth following the first cutting. Characteristics of current California small grain cultivars (updated annually) are given in *UC IPM Pest Management Guidelines: Small Grains*, available online at the UC IPM Web site, http://www.ipm.ucdavis.edu/PMG/selectnewpest.small-grains.html.

TWO HARVEST STAGES: BOOT AND SOFT DOUGH

The yield and nutritional value of forages are greatly affected by the stage of development at harvest. Two primary growth stages, boot and soft dough, are the optimal times to harvest. Each harvest stage produces a uniquely different product to meet the nutritional needs of different types of animals. Dairy cows producing large volumes of milk require nutrient-dense feeds that can supply needed energy. The forage needs of high-producing milk cows can best be matched by cultivars that are suited for boot stage harvest or cultivars with high grain yields and high grain to stem ratio at the soft dough stage. Dry dairy cows and growing heifers have much lower nutritional requirements. The most economical forage match for the needs of dry cows and heifers are cultivars that have high total plant yields when harvested at the soft dough stage.

HARVEST METHODS AND END PRODUCTS

Silage production involves swathing, chopping, and stacking the forage in a large pile, or "bunk," for ensiling. This harvest method works well for large dairies in the Central Valley where the forage crop is produced in close proximity to its final destination. Producing silage from the crop enables large quantities of nutrients to be preserved, stored, and fed throughout the year. If the harvest is at boot stage, field wilting to about 65 to 70 percent moisture is required after swathing before the forage can be chopped and ensiled. Soft dough stage forage is usually already at optimal moisture for ensiling at harvest, so it can be direct-chopped or swathed and then immediately chopped for ensiling.

Other harvest options include green chopping, baling, and pasturing. Green chop is forage that is taken directly to animals for feeding as soon as it is harvested. During green chopping, only as much forage as will be fed to the animals that day is harvested at a time. This harvest method is more commonly used for alfalfa or crops that have multiple harvests than it is for small grain forages. However, some producers green chop early-planted oat or triticale in the late fall and make another cutting in the spring (double-cut winter forage). Oat is the most common small grain used for baled hay, although other small grains can also be baled. The advantage of harvesting forage as hay is that the product can be hauled longer distances more economically. Grazing forage is an option where animals are close to the pasture and fencing is available. Grazing is common among beef and sheep producers statewide and among dairy producers in Northern California. Rye and triticale are the small grains most commonly grown in pastures.

RELATIONSHIP BETWEEN GROWTH STAGE AT HARVEST AND YIELD AND FORAGE QUALITY

The nutritional value of a small grain crop is generally greatest at boot stage, and it drops rapidly as the plant matures to the flower and milk stage. After the flower and milk stage, the forage quality of many cultivars improves as the grain spikes fill with starch at the dough stage and the energy-rich seed begins to dilute the fibrous stems

and leaves (see figs. 1 and 2). As the plant matures through flower and seed production, the total yield also increases. As with most forages, growers often trade yield for quality. Nevertheless, small grain forages represent a diverse pool of feeds that can be selected and managed to fit a wide variety of uses. Some cultivars may be better suited to boot stage harvest and others to dough stage harvest. For example, a short, high-grain-yielding wheat cultivar may produce extremely low yields at boot stage but exceptional yields of high-energy forage at dough stage. The grain component dilutes the less-digestible fiber, enabling the forage to fit in a milk ration. At the other end of the spectrum, a tall, late-maturing triticale cultivar may produce respectable yields of lush, superb-quality boot stage forage, but the dough stage does not occur until June, when the forage quality is likely to be unacceptable. Boot stage small grain forage has not been widely accepted by the livestock industry. An important reason for this may be that its feeding value has been underestimated by standard forage quality tests that predict energy from fiber.

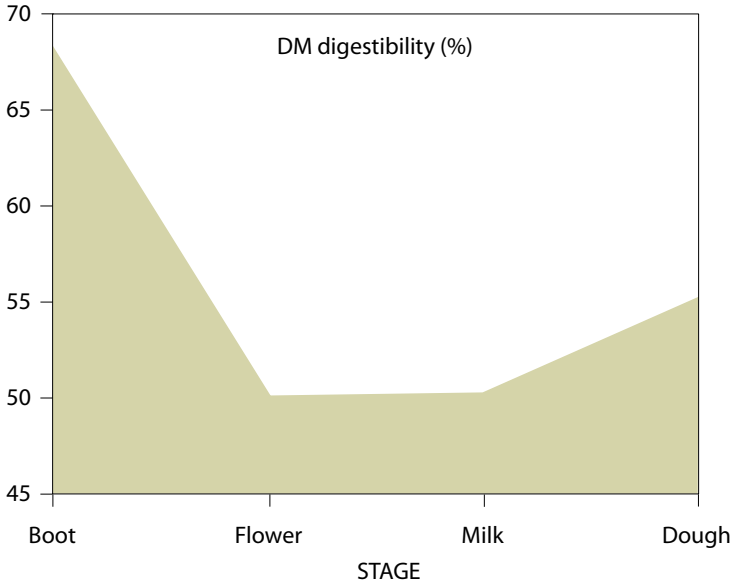

Figure 1. Effect of small grain forage growth stage on apparent dry matter digestibility.

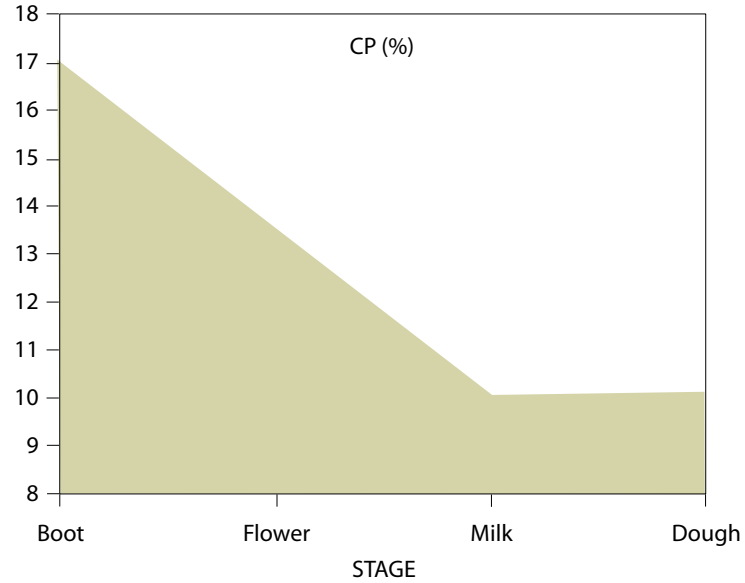

Figure 2. Effect of small grain forage growth stage on crude protein.

Standard forage quality tests are not accurate for small grains

Dairy producers have long recognized the difference in feeding value between alfalfa harvested at bud stage and alfalfa harvested at mid-bloom or full-bloom. Quality testing programs for alfalfa have been in place for decades based on research that has shown greater digestibility, faster weight gains, and higher milk production in cattle fed alfalfa harvested at an immature stage. The maturity of alfalfa is positively correlated to its fiber content: as the stage of maturity increases, so does its fiber content. However, for alfalfa, there is a negative correlation between digestibility and fiber content: as fiber content rises the alfalfa becomes less digestible. Laboratories that test alfalfa hay often predict TDN (total digestible nutrients) and energy from its fiber content, and these values are used to establish the relative economic value of different lots of hay.

Small grain forages are very different from alfalfa in that the percentage of fiber does not always increase with increasing maturity. In fact, the fiber level is usually lower or about the same at the soft dough stage as it is at the boot stage. As the plant matures, grain development contributes nonstructural carbohydrates (starch) that dilute the fiber component. Digestibility is greatest at immature stages, when fiber levels may be highest. Digestibility is positively correlated with fiber content, the opposite of the relationship seen in alfalfa: as the fiber content rises, small grains become more digestible. Energy prediction equations used for alfalfa can't be used to accurately describe the TDN or energy value for small grain forages. Other methods have been developed that predict the energy value of small grain forages more reliably.

These methods involve in vitro digestion, a procedure in which samples of the forage are incubated with rumen fluid from a cow.

Effects of maturity at harvest on yield

Dry matter yields of small grain forages are 30 to 60 percent lower at boot or early harvest stages than they are at the soft dough stage. This relationship is highly dependent on the cultivar. Late-maturing cultivars tend to have higher boot stage yields because they have more time to accumulate dry matter. The tremendous yield difference is the main reason for the reluctance to harvest at boot stage despite its superior feeding value. Unless growers are compensated for the higher quality, they have little incentive to suffer such a large reduction in yield.

Other challenges to boot stage harvest or use of boot stage forage include

- difficulty with field wilting because of unfavorable weather
- potentially high nitrate content
- potentially high potassium content
- poor ensiling characteristics

Cool temperatures and rain often occur in early spring. Unlike forage in the soft dough stage, which can be direct-chopped for silage, boot stage forage is very wet (80 to 85% moisture), so it must be field-wilted prior to ensiling. The weather, however, is not always conducive to field wilting; selecting a late-maturing forage may help. Boot stage forage swathed in mid-April has better weather conditions for field wilting than does boot stage forage swathed in March.

Small grain crops, especially oats, may contain high levels of nitrate. High levels of nitrate can be toxic to cattle, sheep, goats, and other ruminant animals. Sudangrass and certain weeds, such as lambsquarters and pigweed, can also accumulate toxic levels of nitrate. How does this happen? Plants take up nitrate from the soil and convert it to protein, but weather conditions may slow down or prevent this conversion, causing nitrate to accumulate to high levels in the leaves and stems. Forage grown in fields that receive heavy applications of manure or high levels of commercial fertilizer, as well as forage that is harvested at boot stage, have a greater risk for accumulating potentially toxic levels of nitrate. Cool, cloudy weather at harvest can contribute to the problem, since these conditions reduce the ability of the plant to convert nitrate to protein.

Certain management practices can be followed to prevent exposing livestock to nitrate toxicity. Routine analysis for nitrate concentration of all diet components, but especially of the forages, is highly recommended before feeding. Nitrate levels in forage up to 1,000 ppm on a wet basis are generally safe to feed. Nitrate levels from 1,000 to 4,000 ppm require limiting the amount of high-nitrate forage fed, especially for pregnant animals. Forage containing nitrate levels over 4,000 ppm is potentially toxic. There are several ways to express nitrate concentration, so laboratory reports should be carefully reviewed. To reduce the risk of high levels of nitrate in harvested forages, do not overapply nitrogen from fertilizer or manure. If the weather at harvest has suddenly turned cool and overcast, foggy, or rainy, wait for a few days of sunshine before cutting or allowing animals to graze the forage. Ensiling is the best method for low-

SMALL GRAIN FORAGE FACTS

The yield and nutritional value of small grain forages vary tremendously depending on which growth stage is chosen for harvest. The following generalizations can be made.

- Percent crude protein (CP) and digestibility are higher at the earlier, less-mature growth stages.
- Percent acid detergent fiber (ADF) and neutral detergent fiber (NDF) are higher at boot stage than at soft dough stage; the digestibility of these constituents also is much higher at boot stage.
- Standard forage quality tests that predict energy from fiber are not accurate for small grain forages.
- Percent starch, or nonstructural carbohydrate (NSC), is lowest at the early growth stages and highest at the soft dough stage.
- Percent lignin is lowest at the early growth stages and highest at the soft dough stage.
- Dry matter yields are low at the boot stage and higher at the soft dough stage.
- Depending on the type of feed needed, the best stage to harvest a small grain is either boot or soft dough.

ering plant nitrate levels after harvest; the extent to which the nitrate concentration is reduced varies with the crop and the length of time in the silo. Nitrate concentrations cannot be lowered in forage that is cut for hay. Hay or silage that has been found to be high in nitrates can be blended in a mixed ration with low-nitrate feeds to keep the overall nitrate in the diet below toxic levels.

Forage from fields that receive heavy manure applications may contain relatively high levels of potassium. A high potassium level in dairy forage is a concern for managing milk fever, a metabolic disorder in dairy cows that occurs around calving time. Dairy producers can adjust minerals in the dry cow ration to counteract high potassium levels and reduce the risk of milk fever, but identifying forages that are low in potassium may be more economical and effective. High potassium levels are not unique to boot stage forage; soft dough forage can have high levels as well.

Fermentation of boot stage forage during ensiling may be poor if moisture levels are too high. Ideally, the forage should field-wilt from about 85 percent moisture to around 70 percent moisture before chopping. This requires warm, dry weather. If a grower has an especially high-yielding boot stage crop, field wilting may be especially difficult because of the large mass of forage in each swath. Poorly fermented forage is more apt to spoil and cause feed intake problems.

SUMMARY

Small grain forages in California are extremely versatile and economical sources of feed. The tremendous diversity of forage types and cultivars provides growers throughout the state with numerous options for matching the feed to the nutrient requirements of cattle, horses, sheep, and goats. Yield and feeding value are greatly affected by stage of maturity at harvest. The end use of the forage determines the optimal harvest time, either the boot stage or the soft dough stage of maturity. Opportunities for varied harvest and storage methods (silage or hay) contribute to the versatility of these forages. Improved methods for predicting energy value can help producers and nutritionists develop rations for animals to take full advantage of the nutritional attributes of small grain forages.

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SMALL GRAIN PRODUCTION MANUAL
PART 11

Small Grain Cover Crops

JEFF MITCHELL, Extension Specialist, Vegetable Crops, University of California Kearney Research and Extension Center, Parlier, CA; **MARK VAN HORN,** Director, Plant Science Teaching Center, Student Farm, University of California, Davis; **DOUG MUNIER,** University of California Cooperative Extension Farm Advisor, Glenn County; **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

UNIVERSITY OF CALIFORNIA
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This publication, *Small Grain Cover Crops,* is the eleventh in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
- *Part 3: Seedbed Preparation, Sowing, and Residue Management*, Publication 8166
- *Part 4: Fertilization*, Publication 8167
- *Part 5: Irrigation and Water Relations*, Publication 8168
- *Part 6: Pest Management—Diseases*, Publication 8169
- *Part 7: Pest Management—Insects*, Publication 8170
- *Part 8: Pest Management—Vertebrates*, Publication 8171
- *Part 9: Pest Management—Weeds*, Publication 8172
- *Part 10: Small Grain Forages*, Publication 8173
- *Part 12: Small Grains in Crop Rotations*, Publication 8175
- *Part 13: Harvesting and Storage*, Publication 8176
- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

A cover crop is a crop grown to improve the soil, repress weeds, or benefit subsequent crops grown in rotation. It is not intended to be harvested or grazed, although when small grains are used as cover crops a side benefit is that the timing of operations for cover cropping makes possible their use as forage (see Part 10, *Small Grain Forages*). Small grains (including wheat, barley, oat, triticale, and rye) are useful as cover crops in many cropping systems because seed is relatively inexpensive, they produce large amounts of biomass quickly, and they have important soil-preserving properties. Small grains are excellent candidates as cover crops for many situations, including orchard, vineyard, and row crop acreage. Cultural practices (planting rates and dates, tillage, fertilization, and irrigation) for producing small grain cover crops are similar to practices for producing a regular grain or forage crop, except that lower fertilization and irrigation inputs are required and crop termination (through herbicide application or plowing under) is geared to the timing of the subsequent crop. Specific cultural practices vary from region to region of California, as does crop development (see Part 2, *Growth and Development*; Part 3, *Seedbed Preparation, Sowing, and Residue Management*; Part 4, *Fertilization*; and Part 5, *Irrigation and Water Relations*).

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BENEFITS OF COVER CROPS

Cover crops can increase soil organic matter content and improve soil physical properties, enhance soil fertility and biological activity, provide soil cover and thereby reduce erosion, scavenge nutrients and prevent leaching losses, suppress weeds and diseases, and, in certain cases, enhance biological control of various pests. Keeping the soil surface covered by a cover crop during the off-season is vital in reducing soil losses by both water and wind and may improve air quality due to reduction in airborne particulates. Driving safety may be improved in areas such as California's Central Valley, where blowing dust storms are common during the winter when fields are typically bare.

Cover crops help maintain and improve soil quality in a number of ways. Residues of cover crops that are included in annual cropping systems are typically incorporated before the cover crop reaches maturity (thus the name "green manure"). Because small grains usually contain a low amount of nitrogen (about 1.5%) relative to legume cover crop species, they are not used as cover crops for their nitrogen contribution but for their carbon. Increasing soil carbon content improves several aspects of soil physical quality. Underirrigation, such as is used in California's Central Valley, moist soil and high temperature conditions favor rapid decomposition of soil organic matter, so increases in soil organic matter may be small. Under these conditions cover cropping may increase soil organic matter by only a few tenths of a percent. Such increases, however, still contribute to improvements in soil aggregation, water infiltration rates, reduced soil surface crust strength, and improved tilth.

NITROGEN INTERACTIONS

Small grain cover crops can serve as "sinks" for scavenging and storing residual nitrogen from fertilizer applied to previous crops. Residual soil nitrate is particularly vulnerable to loss during the winter, when it can be moved by leaching through the soil profile. Nonlegumes are more efficient than legumes at reducing this nitrogen leaching. "Catch" cover crops with deep, dense rooting and high nutrient scavenging capacities, such as small grains and mustards, can be helpful in areas prone to leaching. See Part 2, *Growth and Development*, in this series for a description of the fibrous root system of small grains, which can grow 6 to 7 feet deep (about 2 m) with no competition.

Establishment of small grain cover crops may require nitrogen inputs, depending on residual soil nitrogen, the previous crop, and growing season conditions. However, the rates required are far less (probably less than half) than those recommended for small grain crops grown for grain production (see Part 4, *Fertilization*). Lower inputs are required because of the expected early termination of the cover crop and because it is not necessary to provide adequate nutrition for grain-fill. Nitrogen (residual in soil and/or fertilizer nitrogen), however, is necessary for establishment and vigorous vegetative development of a small grain cover crop in order to attain the full benefits of cover cropping.

PEST INTERACTIONS

Cover crops may suppress certain plant pathogens, nematodes, and weeds and provide habitat for beneficial insects. Cover crops suppress weeds by smothering or outcompeting them as either living or dried surface mulches. Some cover crop residues contain compounds known as allelochemicals, which suppress the growth of other plants. Rye is an example of an allelopathic cover crop. It may suppress the growth of certain broadleaf weeds, but it also may inhibit germination of small-seeded vegetables such as onions and carrots. The allelopathic effects of a cover crop are difficult to separate from competition effects.

Cover cropping also may suppress plant parasitic nematodes. In certain cases, the cover crop acts as a nonhost, preventing nematodes from reproducing. In other instances, the roots of cover crops may emit compounds that stimulate nematode activity, but in the absence of a suitable host, the nematodes die.

WATER REQUIREMENT

Because the inclusion of a small grain cover crop in a crop rotation affects numerous aspects of the management, biology, and economics of a production system, the potential advantages must be carefully weighed against the disadvantages. Water use by a cover crop is a major factor that must be considered, particularly in California's Central Valley (see Part 2, *Growth and Development*, and Part 5, *Irrigation and Water Relations*). Although water use by fall-sown small grain cover crops is relatively small because evapotranspiration during the winter is generally low, rainfall may be insufficient or too erratic to establish and support a winter cover crop and provide optimal early-winter growth. Supplemental irrigation may be necessary if it is available and if the expected benefits of cover cropping warrant the investment in irrigation water. Many areas of California receive adequate winter rainfall for the growth of small grain cover crops. Although depletion of stored water under small grains grown during the winter as cover crops is relatively small, it may impact preirrigation needs and the growth and productivity of subsequent crops. Thus, long-term water budgeting at a cropping systems level is essential to successfully integrate cover crops into crop rotations, especially in arid and semiarid areas.

AGRONOMIC FACTORS

Small grains used as cover crops are typically sown from mid-October through November in most California cropping systems, prior to the onset of winter rains (see Part 2, *Seedbed Preparation, Sowing, and Residue Management*), and are terminated (harvested) at a time determined by the field preparation requirements for the subsequent crop. Small grain cover crops are generally easily established and tend to produce more biomass during a typical winter cover crop "window" (the time from the fall sowing of the cover crop to termination in the spring before the sowing of the subsequent crop) than most other crops grown during this period. Seeding rates tend to be similar to those used when small grains are sown for grain production: 1.2 to 1.5 million seeds per acre (3.0 to 3.7 million/ha) for irrigated crops, 1.0 million seeds per acre (2.5 million/ha) for rainfed crops. These rates should yield the plant density needed to exploit the cover crop benefits, including reduction of erosion risk by providing rapid soil cover, scavenging nutrients and preventing leaching losses, and suppressing weeds. The seeding rate required to achieve the desired plant density averages about 120 pounds per acre (135 kg/ha) for wheat and triticale, 100 pounds per acre (112 kg/ha) for oat, 90 pounds per acre (101 kg/ha) for barley, and 60 pounds per acre (67 kg/ha) for rye; the rate varies from cultivar to cultivar, however, because cultivars vary widely in seed size. When sown in mixtures with legumes (such as vetch) or other crops (such as mustard, canola, or bell beans) reduce the seeding rates depending on the relative competitive ability of each crop in the mixture in order to achieve the desired mixture composition and biomass. The performance of a particular small grain cultivar as a pure cover crop or as a component of a mixture is difficult to predict because a variety of factors, including soil properties, sowing date, seeding rate, and growing season conditions, interact to influence the growth of each crop.

SELECTION OF A SMALL GRAIN CULTIVAR FOR USE AS A COVER CROP

Mid-October-sown small grain cover crops that are terminated in mid-March typically produce between 9,000 and 11,000 pounds per acre (10,100 to 12,300 kg/ha) of dry matter. Among current small grain cultivars, triticale cultivars produce the most biomass. Biomass production varies widely and is highly influenced by growing season conditions, soil properties, inputs of irrigation and fertilization, and growing region. Reports documenting the productivity of current California small grain cultivars are published annually in the series *UC Davis Agronomy Progress Reports: Regional Barley, Common and Durum Wheat, Triticale, and Oat Performance Tests in California,* available online at the UC Agronomy Research and Information Center Small Grain Workgroup Web site, http://agric.ucdavis.edu/crops/cereals/cereal.htm.

No one small grain cultivar is the best choice to use for all cover cropping situations in all regions of the state, since individual cultivars are adapted to different growing regions. Rapid establishment of ground cover through tillering, appropriate maturity class for the area, disease resistance, and biomass production potential are important selection criteria. Characteristics of current California small grain cultivars (updated annually) are given in *UC IPM Pest Management Guidelines: Small Grains*, available online at the UC IPM Web site, http://www.ipm.ucdavis.edu/PMG/selectnewpest.small-grains.html.

CONCLUSIONS

Whether to use a small grain cover crop depends on

- the specific objectives for growing the cover crop (soil quality improvement, organic matter input, scavenging residual nitrogen and reducing nitrate leaching, suppressing weeds and other pests)
- the timing of planting and other crop management practices that must be altered
- the effect that integrating the cover crop in a rotation may have on weeds, diseases, and pests
- the investments in equipment and inputs that may be required

Small grain cover crops must be compatible with the scheduling and management requirements of a given cropping system in order to provide long-term benefits. A great deal remains to be learned about how best to select and manage small grain cultivars as cover crops in specific rotations and environments. Farmers interested in cover cropping small grains should start by experimenting on a relatively small scale at first and by working with other farmers, University of California advisors and specialists, and other people with experience using small grain cover crops.

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PUBLICATION 8175

SMALL GRAIN PRODUCTION MANUAL
PART 12

Small Grains in Crop Rotations

BRIAN MARSH, Farm Advisor, University of California Cooperative Extension, Kern County; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

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This publication, *Small Grains in Crop Rotations,* is the twelfth in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
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- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

Small grain crops are grown on virtually all cultivated soils and in many different crop rotation systems in California. Rotations differ depending on the relative importance of specific crops in different regions. In low-rainfall areas small grains may be grown in a summer-fallow system with or without tillage or chemical fallow, or they may be cropped annually with minimum tillage. Rainfed production in higher-rainfall areas occurs in rotation with pasture (sometimes with 3 or more years of pasture). Under irrigation, small grains are rotated with a wide assortment of crops, including cotton, tomato, potato, sugar beet, rice, safflower, sunflower, melons, lettuce, onions, and alfalfa. Small grains can be double-cropped with a summer crop of corn, grain sorghum, or beans.

Small grain rotations can help reduce pest problems in other crops and provide agronomic benefits that improve the long-term stability and performance of agricultural systems. Weeds, pathogens, and nematodes are the pests most commonly affected by small grain rotations. Small grains help improve soil structure, aid water penetration and retention, and reduce erosion on sloping land. They may also help retain residual soil nitrogen in the root zone by decreasing the potential for leaching losses of nitrogen during the rainy season.

Barley can be grown in some cases to reduce salt levels in saline soils so that other crops less tolerant of salt can be grown. This is an important part of a reclama-

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tion program for saline and sodic soils. If irrigation water is not high in salts, irrigation can leach excess salt from the upper portion of the soil profile, and a few seasons of barley production to leach salts from the soil may be sufficient to allow other crops to be grown. When water penetration is a problem because of poor water quality, incorporating barley straw into the soil improves water penetration. An amount of residue equal to 10 to 30 percent by volume of the upper 6 inches (15 cm) of soils is recommended.

The deep, fibrous root system of small grains helps build soil structure, improve water penetration, and control soil erosion. Straw residue and roots left after harvest decompose slowly, which is important for erosion control and for improving soil physical characteristics. Incorporating the residue increases soil organic matter, improving soil tilth. Residue cover on the soil surface also slows runoff and improves water retention, which is particularly important on sloping land. Water penetration to deeper soil layers is improved by the root penetration of small grains and the biological activity associated with decomposition of crop residue. Small grain crops may mobilize potassium and phosphorus from deeper in the soil, making it available to the following crops in the rotation.

Crop rotation helps make weed management easier by changing growing conditions that favor the buildup of specific weeds and by allowing the use of different herbicides according to crop labels. The improvement of soil tilth by the small grain crop allows the rotation crop to grow more vigorously and compete more effectively with weeds. Small grain crops are especially useful for helping control broadleaf weeds that emerge during the small grain crop and perennials that emerge prior to grain harvest. Small grain crops are highly competitive with weeds, and most broadleaf weeds are easily controlled with selective herbicides that can be applied to the small grain (see Part 9, *Pest Management—Weeds*). This helps reduce the populations of weeds that are difficult to control in winter broadleaf crops such as cole crops, lettuce, and sugar beets. Sunflower family weeds such as cudweed, common groundsel, mayweed chamomile, prickly lettuce, and sowthistle are common problems in all broadleaf crops. Available herbicides control these weeds in small grains. Mustard family weeds such as London rocket, kaber mustard, black mustard, shepherd's-purse, and wild radish are common problems throughout California but are easy to control in small grains with available herbicides. Small grains also help reduce infestations of field bindweed, curly dock, Canada thistle, bermudagrass, johnsongrass, and nutsedges.

Crop rotation is an important tool for managing some diseases. If a pathogen does not survive for more than a few years in the absence of a host plant or host plant residue, rotation to a nonhost crop is effective in reducing disease. Rotating small grain crops with other crops can help reduce diseases of small grain crops such as Septoria tritici blotch of wheat, Fusarium crown and root rot, barley scald, and barley net blotch (see Part 6, *Pest Management—Diseases*). Small grain rotations are useful for managing a number of diseases of vegetable crops and broadleaf field crops such as alfalfa, beans, cotton, and sugar beets, and they also can help reduce inoculum of some diseases of tree and vine crops (table 1).

Small grain crops in a rotation can also reduce populations of several nematode species that can be harmful to trees, vines, or broadleaf crops (table 2).

Table 1. Disease control by small grain rotations for selected crops

Crop	Disease	Scientific name	Reduce inoculum below damaging levels	Reduce inoculum and/or keep inoculum levels from building up
beans	anthracnose	*Colletotrichum lindemuthianum*	x	
	Fusarium root rot	*Fusarium solani* f.sp. *phaseoli*	x	
beets	leaf spot	*Cercospora beticola*	x	
carrots	foliar blight	*Alternaria dauci*	x	
	leaf spot	*Cercospora carotae*	x	
celery	late blight	*Septoria apicola*	x	
cole crops	bacterial diseases	*Pseudomonas syringae* pv. *maculicola; Xanthomonas* spp.	x	
	black leg	*Phoma lingam*	x	
cotton	Verticillium wilt	*Verticillium dahliae*	x	
lettuce	anthracnose	*Marssoninia panattoniniana*	x	
melons	damping off, fruit and stem rot, and sudden wilt	*Pythium* spp.		x
	Fusarium root rot	*Fusarium solani* f.sp. *cucurbitae*	x	
peas	Aschochyta blight	*Aschochyta* spp.	x	
potato	ring rot, bacterial wilt	*Corynebacterium sepedonicum*		x
	scab	*Streptomyces scabies*		x
	stem rot	*Sclerotium rolfsii*		x
sweet potato	scab	*Monilochaetes infuscans*	x	
tomato	corky root	*Pyrenochaeta lycopersici*		x
	Phytophthora root rot, fruit and seedling blight	*Phytophthora* spp.		x
trees, vines, and caneberries	crown gall	*Agrobacterium tumefaciens*		x
	southern blight	*Sclerotium rolfsii*		x
vegetable crops	stem rot, white mold, and lettuce drop	*Sclerotinia minor; S. sclerotiorum*	x	
	southern blight	*Sclerotium rolfsii*		x
	Verticillium wilt	*Verticillium dahliae*		x

Table 2. Nematode control by small grain rotations for selected crops

Crop	Nematode	Scientific name	Reduce nematode populations
beets	sugar beet cyst nematode	*Heterodera schachtii*	X
chard	sugar beet cyst nematode	*Heterodera schachtii*	X
cole crops	sugar beet cyst nematode	*Heterodera schachtii*	X
	cabbage cyst nematode	*Heterodera cruciferae*	X
spinach	sugar beet cyst nematode	*Heterodera schachtii*	X
sugar beets	sugar beet cyst nematode	*Heterodera schachtii*	X
various broadleaf vegetable and field crops	root knot nematodes	*Meloidogyne* spp.	X
	root knot nematodes, warm-climate species	*Meloidogyne incognita, M. javanica, M. arenaria*	X
	Northern root-knot nematode	*Meloidogyne hapla*	X
various tree and vine crops	root-knot nematodes	*Meloidogyne* spp.	X
	lesion nematode	*Pratylenchus vulnus*	X
	ring nematode	*Criconemella xenoplax*	X

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SMALL GRAIN PRODUCTION MANUAL PART 13

Harvesting and Storage

TOM KEARNEY, University of California Cooperative Extension Farm Advisor Emeritus, Yolo-Solano Counties; **SERGIO GARCIA,** University of California Cooperative Extension Farm Advisor, San Benito County; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

UNIVERSITY OF CALIFORNIA
Division of Agriculture and Natural Resources
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HARVESTING

Direct Combining

Most small grain crops in California are harvested when the moisture content of the grain is 8 to 12 percent. Grain is fully developed when its moisture content drops below 35 percent, but it cannot be stored safely until the moisture is below 14 percent. A simple test to determine whether grain is dry enough for harvest is to rub a grain head between the palms of your hands. If the kernels do not separate readily from the chaff or if the kernels separate but are easily dented with your thumbnail, the grain is too moist to harvest. Grain can be harvested at higher moisture content and artificially dried to below 14 percent before storage, but this is usually not cost-effective. Harvesting early and drying the grain may be justified in some cases by the time gained for planting a high-value crop that follows the small grain crop. If green weeds are present when the crop is ready for harvest, herbicides are available to desiccate the weeds so that normal combining can proceed.

Follow the manufacturer's recommendations for adjusting the combine when you prepare for harvest. Attachments can be added to measure the amount of grain

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being lost as unthreshed seed or as free seed over the shoe and straw walkers at the rear of the machine. Frequent adjustments are necessary during harvest as conditions change. Use a slower cylinder speed and less air as grain becomes drier; very dry grain kernels crack easily.

Windrowing

Windrowing (swathing) instead of direct combining is sometimes done to hasten drying, to dry out late-spring or summer weed growth, or to avoid grain yield losses by cultivars susceptible to grain shattering at maturity. Shattering is the loss of grain when kernels are knocked from the spikes (or panicles in oat) as the spikes move against each other or are whipped about by wind. Losses can vary greatly between cultivars. Cultivars of wheat with the tight glume characteristic do not shatter much but are more difficult to combine than those with loose glumes. Swathing should be done after the grain moisture level is less than about 35 percent (late dough stage) to avoid losses in grain yield due to underdeveloped (immature) kernels. Windrows can be combined after sufficient drying time (1 to 3 days).

STORAGE

Since prehistoric times grain has been stored to save seed, provide food between harvest seasons, and supply feed for livestock. Today, grain is harvested over a relatively short period of time during the year and is stored for a variable period (from a few weeks or less to several years) before being distributed to the final destinations as food, feed, seed, or other uses. An extensive system of grain handling and storage has been developed.

Handling and Storage Facilities

Today, much of the grain supply is stored in farm silos. Grain is also stored in bulk bins, bagged and stored in warehouses, and in commercial grain elevators.

- Farm silos store grain grown on the farm.
- Country silos store grain from surrounding farms for distribution to local mills and for transfer to larger regional silos.
- Regional or inland silos are located in heavy grain-growing and high-population areas and receive grain from country silos and import terminals.
- Export silos store grain in preparation for loading onto oceangoing vessels.
- Import silos store grain discharged from oceangoing vessels.

Grain Quality in Storage

Storage conditions should maintain the quality of the grain. The value of grain depends not only on the market situation but also on the condition of the grain. Grain quality is judged on characteristics including grain cleanness, shininess, plumpness, color, odor, and test weight; insect-damaged kernels; presence of live insects and foreign material; and proportion of germinated and broken kernels.

Length of time in storage and seed viability

The length of time that seed grain can be stored without loss of viability depends on the storage environment. The main factors are the moisture content of the seed while in storage and the storage temperature. Grain that contains 11 to 13 percent moisture or less can be stored in weatherproof bins or silos for many years in most climates without deterioration, provided it is protected from insects, rodents, external moisture, and high humidity. The composition of sound dry grain remains almost unchanged except for some increase in fatty acids and a slight loss of energy con-

tent from respiration. At average air temperatures weight loss in dry matter is about 1 percent over 20 years of storage. Prolonged storage results in a slight loss in protein. Under proper storage conditions, seed germination after 20-year storage is about 45 to 50 percent.

Grain moisture

Most small grain crops in California have a relatively low moisture content at harvest (8 to 12 percent). In other parts of the United States, the average moisture content at harvest ranges from 18 to 26 percent. Grain can be stored safely at a moisture content of below 14 percent; grain with a higher moisture content should be dried. The most economical method to dry grain is delay harvest until the grain reaches the desired moisture content. Low humidity, solar radiation, and windy conditions decrease grain moisture content. Forced unheated air can lower grain moisture if relative humidity is below 70 percent after the grain has dried to 15 to 17 percent moisture. The drying of grain requires airflow of 1 to 6 cubic feet per minute per bushel of grain (0.8 to 4.8 liters of air per minute per liter of grain). Using heated air to dry grain is costly, but it is rapid and dependable. Drying should start promptly after harvest and proceed continuously at a rate fast enough to avoid heat damage. For grain intended for seed, 110°F (43°C) is generally the upper temperature limit; for grain intended for milling, temperatures should not exceed 130°F (54°C); for grain intended for feed, temperatures from 145° to 160°F (62° to 71°C) are permissible.

Insect pests

Insects destroy as much as 30 percent of the world's supply of stored grain each year; however, in developed countries, losses are usually about 10 percent. More than 50 species of insects are found in stored grain and grain products in the United States. The most common and destructive stored-grain insect pests include

- granary weevil *(Sitophilus granarius)*
- rice weevil *(Sitophilus oryzae)*
- maize weevil *(Sitophilus zeamais)*
- saw-toothed grain beetle *(Oryzaephilus surinamensis)*
- red flour beetle *(Tribolium castaneum)*
- lesser grain borer *(Rhyzopertha dominica)*
- rusty grain beetle *(Cryptolestes ferrugineus)*

These insects are widely distributed in all grains, cereal products, and animal feeds, and are very common where grain is stored (silos, warehouses, storage bins, barns, and houses). Because most insect infestations originate after grain is placed in storage, sanitation offers the most practical means of preventing insect infestations. Grain should be free of infestation before being placed in storage. New grain should not be placed on top of old grain; bins should be completely emptied and cleaned before they are refilled. Extra care should be given to areas of potential insect contamination such as broken sacks and small piles of grain around machinery, grain bins, warehouses, and silos.

The temperature and moisture of the storage environment can be manipulated to prevent insect problems. As temperature and moisture become lower, the rates of insect activity, feeding, development, and reproduction are reduced. Grain temperature can be lowered by aeration with ambient air or refrigerated air. The goal is to reduce grain temperature to about 58° to 65°F (14° to 18°C), a level at which most insects either cannot complete development or grow very slowly. Simple temperature aeration controllers can be used to lower air temperatures to cool the grain at night. Insects

such as weevils are long-lived at a temperature of about 58°F (14°C), and only prolonged exposure to temperatures below 50°F (10°C) significantly increases mortality; cooling with refrigerated air is an option in such cases. Secondary benefits of aeration include control of moisture migration, preservation of grain quality, and distribution of volatile toxicants.

The lower the moisture content of grain, the less susceptible it is to spoilage by insects and mites, as well as by fungi (see below). Mites and fungi are a problem only at moisture contents above 14 percent, and insects cannot reproduce in grain of moisture content below about 9 percent. To help prevent losses to insects, mites, and fungi, grain with a high moisture content must be dried either in the field or in storage after it is received using either ambient or heated air.

Corrective treatments are required when grain becomes infested; these treatments can include fumigation and heated air. The role of chemical grain protectants for insect control is in question because of the decreasing tolerances of chemical residues in grain and food products and the increasing incidence of insecticide resistance. Consult with your local UCCE Farm Advisor or pest control adviser for correct application materials and rates.

Monitoring is essential for protecting stored grain. Infestations can be detected in bulk grain by taking grain samples, usually with a spatial sampling program, at regular intervals of between 2 and 4 weeks. An alternative is the use of trapping procedures, such as probe traps and sex pheromone–baited flight traps, to detect insects in bulk grain and empty storage structures.

Fungal (mold) pests

Various fungi (molds) are an important part of the natural microflora of grain, both in field crops and in stored grain. The term "field fungi" is used to describe fungi growing on grains before harvest. Common field fungi include *Alternaria alternata, Cladosporium cladosporiodes, C. herbarum, Epicoccum nigrum, Fusarium* spp., and others. The term "storage fungi" is used to describe fungi involved in the deterioration of grains during storage. *Aspergillus* and *Penicillium* are the most important genera in this group, which includes *Aspergillus candidus, A. fumigatus, A. nidulans, A. repens, Penicillium brevicompactum, P. verrucosum, P. hordei, P. roquefortii,* and others.

The original source of both groups of fungi is the field. Invasion by fungi before harvest is governed primarily by the interaction between the plant host and the fungus, while growth by fungi after harvest is governed by crop nutrients, temperature and moisture, and competition by insects. Field fungi generally do not grow in grain with a moisture content less than 20 percent, and their growth is severely inhibited by low oxygen and high carbon dioxide concentrations. Clean and dry storage conditions combined with low storage temperatures are the best line of defense against fungi (and bacteria) that cause moldy grain. The best ways to prevent mold damage are to avoid storing grain with high moisture content and to cool the grain with aeration (temperatures that limit insect growth also reduce mold growth).

Fungal growth and mycotoxin production can be important causes of loss of quality in stored grain, especially in grain held at a high moisture content. Mycotoxins are produced by both field fungi and storage fungi. There are four basic types of toxigenic fungi:

- plant pathogens such as *Fusarium graminearum*, which causes scab, an important disease in the northern plains states but not currently in California
- fungi such as *Fusarium moniliforme* and *Aspergillus flavus* that grow and produce mycotoxins on senescent or stressed plants

- fungi that initially colonize the plant and predispose the grain to mycotoxin contamination after harvest, such as by *A. flavus*
- fungi that occur in the soil or in decaying plant material on the developing kernels in the field and later proliferate in storage, such as *Penicillium verrucosum* and *Aspergillus ochraceous*

The five agriculturally important fungal toxins include deoxynivalenol, zearalenone, ochratoxin A, fumonisin, and aflatoxin. Worldwide, aflatoxins produced by storage fungi have caused the most severe mycotoxicoses. Factors that affect mycotoxin formation in storage include moisture, temperature, time, mechanical damage to grain, oxygen and carbon dioxide levels, composition of substrate, fungal abundance, prevalence of toxigenic strains, spore load, microbiological interactions, and invertebrate vectors. *Eurotium* spp. (*Penicillium* spp.) xerophilic fungi are often the primary invaders of stored grains; once established, their metabolic activity raises the moisture content of the grain, allowing establishment and growth of fungi such as *Aspergillus flavus* and *A. parasiticus*. Mycotoxin production is maximized from about 77º to 96°F (25º to 35ºC).

Vertebrate pests

Rodents, birds, and other wildlife can infest or damage stored grain. Rodent-proofing buildings and other storage areas is the best method of managing these pests. Secure any opening larger than ¼ inch (6 mm) in foundations, walls, floors, roofs, and eaves. Inspect grain storage facilities frequently for new infestations.

Safety of Grain Storage

Storage structures such as warehouses, storage bins, barns, silos, and granaries present significant hazards because the majority of time these facilities are enclosed and develop a toxic or oxygen-depleted atmosphere. Human exposure to reduced oxygen levels causes anoxia, which affects judgment, causes rapid fatigue or nausea, and can be fatal. Other toxic gases in grain storages include nitric oxide, nitrogen dioxide, nitrogen tetroxide, ammonia, and hydrogen sulfide. These gases can cause symptoms ranging from mild respiratory irritation to death, depending on the exposure. Respiratory hazards associated with grain storage structures include dust, mold, fungal toxins, and residual fumigants. Exposure to these hazards presents both long- and short-term health risks.

When working in grain storage facilities, always use the correct respiratory equipment and never enter a confined space alone. Falls from grain storage structures are a leading cause of injury. Safety cages should be installed around permanent ladders 20 feet (6 m) high or higher. When handling grain always remember the potential for grain dust explosion or fire. Be aware of potential ignition sources, such as electric shorts, hot engines, and open flames. Moving grain puts a large amount of highly flammable dust in the air. Proper safety procedures must be followed when operating grain handling equipment such as augers, sweepers, conveyers, and elevators. The grain itself can pose a serious safety threat. Moving grain cannot support the weight of a person; someone can sink very rapidly and become trapped or buried and suffocated by falling grain.

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PART 14

Troubleshooting Small Grain Production

An Identification Guide to Field Problems in Small Grains

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MICK CANEVARI, University of California Cooperative Extension Farm Advisor, San Joaquin County; **RON VARGAS,** University of California Cooperative Extension Farm Advisor, Madera County; **STEVE WRIGHT,** University of California Cooperative Extension Farm Advisor, Tulare County; and **LEE JACKSON,** Extension Specialist, Small Grains, Department of Plant Sciences, University of California, Davis

This publication, *Troubleshooting Small Grain Production,* is the last in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual.* The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
- *Part 3: Seedbed Preparation, Sowing, and Residue Management*, Publication 8166
- *Part 4: Fertilization*, Publication 8167
- *Part 5: Irrigation and Water Relations*, Publication 8168
- *Part 6: Pest Management—Diseases*, Publication 8169
- *Part 8: Pest Management—Vertebrates*, Publication 8171
- *Part 9: Pest Management—Weeds*, Publication 8172
- *Part 10: Small Grain Forages*, Publication 8173
- *Part 11: Small Grain Cover Crops*, Publication 8174
- *Part 12: Small Grains in Crop Rotations*, Publication 8175
- *Part 13: Harvesting and Storage*, Publication 8176

It can be difficult to diagnose nutrient deficiencies and toxicities, disease symptoms, insect damage, and herbicide injury in small grains. Symptoms of damage from herbicides, fertilizers, or environmental conditions may develop rapidly or be delayed until later in the growing season. Deficiency symptoms of one nutrient may be masked by the levels (excess or deficiency) of other nutrients, and soil pH affects the availability of some nutrients and influences deficiency and toxicity symptoms. Herbicide injury may cause plant symptoms that mimic nutritional or pathological disorders. Foliar symptoms of disease range in size, color, and configuration and may appear simultaneously with symptoms of pesticide injury, leading one to overlook the real cause of the problem. In order to accurately troubleshoot field problems, you should have a sound knowledge of how small grain growth and development affects plant nutrient uptake and needs and susceptibility to diseases and pests (see part 2, *Growth and Development*).

UC PEER REVIEWED

This publication provides descriptions and photographs of abiotic (environmental) and biotic (pest- or disease-related) disorders of small grains and includes a troubleshooting guide to assist you in correctly identifying the cause or causes of problems in the field.

TROUBLESHOOTING CROP PROBLEMS

- Determine the variety and plant growth stage.
- Check all parts of the plant for symptoms, including the leaves, stems, and roots, as well as the inside of stems and roots.
- Estimate the percentage of plants damaged in the affected part of the field.
- Determine whether the problem in the field matches the pattern of irrigation, mechanical or equipment operations, spray or fertilizer applications, insect or disease outbreaks, or soil characteristics.
- Evaluate whether weeds in or adjacent to the field share similar symptoms in order to eliminate or confirm factors such as diseases and pests, herbicide drift, or nutrients as possible causes.
- Determine the history of the problem, which can often provide the foundation for accurate diagnosis.
- Identify recent environmental events, field operations, previous crop history, and cultural practices.

NUTRIENT DEFICIENCIES

Many of the following brief descriptions of symptoms of various nutrient deficiencies, toxicities, and other common disorders of small grains have been adapted from the publication Nutrient Deficiencies and Toxicities in Wheat: A Guide to Field Identification (Snowball and Robson 1991), which contains a wealth of other information on the topic.

Nitrogen

Symptoms of nitrogen deficiency (see figs. 7 and 8) appear first on older leaves. The older leaves appear pale, with chlorosis beginning at the leaf tip and gradually merging into light green further down the leaf blade, while new leaves remain relatively green. As chlorosis spreads to other leaves, older leaves become totally chlorotic, changing from yellow to nearly white.

Phosphorus

Early symptoms include reduced growth and vigor. Leaves become dull dark green with slight mottling of the oldest leaves. Leaves coil to a greater extent than normal, and old leaves sometimes encase younger leaves. On older leaves chlorosis begins at the leaf tip and moves down the leaf blade. Necrosis of chlorotic areas is fairly rapid; the leaf tip becomes orange to dark brown and shrivels while the remainder of the leaf turns yellow. The base of the leaf remains dark green.

Potassium

Severe deficiency symptoms appear on the oldest leaves, although growth of the whole plant can be affected. Leaves have an unthrifty and spindly appearance. Necrosis on oldest leaves begins as necrotic speckling along the length of the leaf and spreads rapidly to the tip and margins. An arrow of green tissue can remain pointing upward from the base. Chlorotic tissue, generally seen as a mottling, rapidly turns necrotic. Complete death of old leaves is common, and plants in the field may appear to have dried prematurely due to drought stress.

Sulfur

Symptoms of sulfur deficiency are similar to those of nitrogen deficiency except that the whole plant is pale, with greater chlorosis of young leaves. The pattern of chlorosis of new leaves may show gradation in intensity from tip to base, but leaves rapidly become totally chlorotic with a light yellow color. Leaf tip necrosis can appear, but it may indicate nitrate accumulation rather than a direct result of sulfur deficiency.

Magnesium

Young leaves are pale (in contrast to old leaves, which remain dark) and soon become chlorotic and remain unopened, resulting in a twisted appearance similar to that of drought-stressed plants. If the deficiency is severe, the entire length of the leaf remains folded or rolled. Chlorosis of new leaves becomes mottled and finally necrotic; older leaves may develop a mottled chlorosis and in some cases a reddish coloration along the margins.

Iron

Symptoms of iron deficiency are similar to those of magnesium deficiency in that new leaves are affected first and become chlorotic. Iron deficiency differs in that there is a more marked contrast between the green of old leaves and the chlorosis of new growth. Also, leaves show longitudinal interveinal chlorosis, resulting in a pattern of alternate green and yellow striping. Under severe deficiency new growth appears completely devoid of chlorophyll and turns white.

Manganese

Symptoms appear first in new leaves, which become pale and limp in contrast to old leaves. Light gray flecking and striping then appear at the base of the newest fully opened leaf, and, under severe deficiency, flecking and striping appears over the entire length of the leaf.

Copper

Initial symptoms are a general wilting of the plant at early tillering. Plants are light green in color. Withertip, a sudden dying and withering (curling) of the tip end of the blade, appears on young leaves and may extend up to half the length of the leaf. The base of the blade can remain green.

Zinc

Initial symptoms generally appear on middle-aged leaves that show a change in color from green to muddy gray-green in the central regions. These leaf regions appear drought-stressed, and necrotic areas soon develop and extend to leaf margins. Leaves may take on an oily appearance, and necrotic patches become larger and surrounded by mottled yellow-green areas.

NUTRIENT TOXICITIES

Aluminum

Aluminum toxicity may occur on soils with low pH. Retarded root growth is the most characteristic symptom. Plants also have reduced growth above ground and appear unthrifty with thinner than normal leaves. Yellowing occurs along the margin near the tip of the oldest leaf. Brown lesions form in chlorotic regions and work in from the margins, resulting in the formation of indentations. Old leaves become drought-stressed and withered and collapse in the center.

Boron

Initial symptoms, a mottled chlorosis just behind the tip of the oldest leaf and along the margin, are indistinguishable from those of phosphorus toxicity. Eventually, the chlorosis associated

with boron toxicity is less yellow. Mottled chlorotic areas have a dehydrated appearance, and the necrosis of the leaf tip leads down the margins in a fine necrotic edging. Chlorotic spots appear in from the margins and well down the leaf; necrotic areas form within the chlorotic spots and join together, giving much of the leaf a shriveled and dead appearance.

Phosphorus

The initial symptom of phosphorus toxicity is a mottled chlorosis just behind the tip of the oldest leaf and along the margin. The leaf tip becomes necrotic. The chlorosis progresses to a bright yellow along the margins, leaving a green arrow effect and increased necrosis at the tip. The base of the blade remains green.

Manganese

Symptoms appear first on oldest leaves and progress to younger leaves and include chlorosis with little necrosis, chlorosis progressing to necrosis, and in some cases, reddening combined with necrosis and chlorosis. Symptoms first appear on the oldest leaf tips and progress along the leaf with the leaf margins being more affected. A brown blotch or gray flecks of necrotic tissue can appear over the entire leaf.

OTHER COMMON ABIOTIC DISORDERS

Low Temperature and Frost Injury

When frost occurs from emergence through seedling development, cells at the growing point may be killed. This causes bands of yellow or tan on early leaves and can cause leaves to develop without chlorophyll (see figs 2 and 32). These leaves remain white while later leaves usually develop normally. Frost can also damage floral tissues. Frost injury to the developing head tissues can occur before heading, anytime after stem elongation (6- to 7-leaf stage) begins; this may occur as early as late January for early fall-sown small grains. The immature spike becomes increasingly vulnerable to frost and wind chill injury as it grows upward away from the protection of the densely tillered and leafy canopy at the soil surface. Injury generally is associated with minimum temperatures in the 29º to 35ºF (–1.7º to 1.7ºC) range. Often only one frost is involved, and the duration usually does not exceed a few hours.

Injury that occurs at flowering usually is nonuniform because flowering time can vary widely in a field due to topography, nutrition, and plant density differences. Flowering usually takes place over a three- to five-day period on an individual spike (or panicle in the case of oat), while flowering within a field may extend over a period of 15 to 20 days due to nonuniform emergence and fertility. During flowering, when the pollen tube is extending, growth may be stopped by unfavorable temperature. At temperatures near 32ºF (0ºC) there is no killing of glumes, but the male flower parts can be sterilized.

Symptoms of frost injury are most apparent after heading (see fig. 31). The grain spikes may appear tan in color (somewhat like a mature, dry spike ready for harvest), but the grain will not develop into kernels; instead, spikes will be blank because flower development and pollination were disrupted. Spikes that have been frozen and then subjected to wind may shatter, leaving a spike that appears only as a stem (rachis). The risk of frost injury to fall-sown small grains in the Central Valley and surrounding areas can be reduced by delaying sowing until at least mid-November. Late-heading cultivars are recommended for early-fall sowing. Thickly planted stands are more vulnerable to frost damage than are thinner stands since thick stands are not as capable of generating new tillers as thinner stands.

Waterlogging

Small grain plants have a relatively low water demand during early stages of development. Excess water or waterlogging displaces soil oxygen, stunts plants, and turns leaves yellow or reddish. Symptoms usually occur first in low spots within a field where water can collect (see fig. 29).

Salt Damage and Salinity

Affected plants are stunted and dark blue green in color, with tip burn and firing of the leaf margins (see fig. 4). Since soil salinity is rarely uniform within a field, variability in crop growth is one of the first symptoms. Bare spots within a field are common. Wheat is less tolerant of salinity than is barley, but it is more tolerant than rice, field corn, or beans. However, wheat often yields higher under alkaline soil conditions (and the accompanying reduced soil permeability to water) because of its ability to withstand waterlogged conditions better than barley and because of its higher grain yield potential. Wheat yield is reduced when the electrical conductivity (EC) of the soil (saturated extract) exceeds a threshold of about 6.0 mmhos/cm. Yield reduction is proportional to salinity, with a yield decrease of about 3 to 5 percent for each 1 mmhos/cm (the measurement unit of salinity) increase in salinity above the threshold (Maas and Poss 1989).

Herbicide Injury

Contact herbicides

Leaf tissue damage can occur from herbicides used for weed control in cereals or from herbicides used in other crops that may drift long distances. Leaf burn from herbicides (see figs. 3, 5, and 6) is usually prompted by unfavorable environmental conditions such as freezing, long periods of fog, or dry, windy periods that increase susceptibility of the plant to injury. Symptoms on foliage begin with small spots or patches of brown to white bleached tissue. Affected areas eventually darken and dry up. Leaf damage also can occur from herbicide applications as a result of surfactants or fertilizer solutions in the spray mixture.

Phenoxy herbicides

The phenoxy herbicides MCPA and 2,4-D are mainstay herbicides used for broadleaf weed control in small grain production. Proper timing of application based on crop growth stage is critical for maintaining crop safety. If 2,4-D is applied too early (2- to 3-leaf stage) or too late (boot stage) it may cause abnormal kernel development or prevent spikes or awns from freely emerging from the leaf collar. It causes twisted spikes or elongated rachis at heading as well as kernel blanking (see figs. 34, 35, and 36). Dicamba, also a growth regulator herbicide, causes prostrate vegetative growth (fig. 33) and lodging when applied too late (tillering stage and later). It also causes distortion or twisting of grain spikes.

Soil residual herbicides

Soil residual (or soil active) herbicides are used on many crops that are grown prior to small grain crops. Some have a long soil half-life and remain at a high enough concentration in the soil to adversely affect the development of the small grain crop. The extent of injury and symptoms depend on herbicide type, the concentration of herbicide remaining in the soil, and, to some degree, on the variety or type of small grain crop: wheat, barley, and oat have different levels of herbicide susceptibility. Damage may be observable at germination and may inhibit seedling emergence, or damage may appear later when roots reach the herbicide zone, resulting in stunting, growth suppression, and foliage discoloration. Following dinitroanalin herbicides, seedlings germinate but develop short, stubby roots and stunted plants. Residues from acetolactate synthase (ALS) herbicides (rimsulfuron, imazamox) can kill germinating seedlings or cause stunting or yellowing.

DAMAGE BY DISEASES AND INSECT PESTS

Comprehensive descriptions of key disease and pest problems of small grains can be found in part 6, *Pest Management—Diseases*, and in part 7, *Pest Management—Insects*.

Figure 1. Wireworm damage to barley field. Photo by John Prato.

Figure 2. Leaf banding from frost damage. Photo by Jack Kelly Clark.

Figure 3. Leaf burn from herbicide injury. Photo by Ron Vargas.

Figure 4. Leaf tip burn from salinity. Photo by Steve Wright.

TROUBLESHOOTING GUIDE

Once you have a basic understanding of small grain development and can recognize normal plant growth at all stages and identify visual abnormalities, use the following troubleshooting guide to match up many common symptoms and problems with their causes. The guide is organized by plant parts affected, primary symptoms, and causes, and includes photographs of symptoms taken in affected fields.

Troubleshooting Guide for Small Grains

SEEDLINGS (CROP EMERGENCE)

Primary symptoms	Cause
Delayed emergence and nonuniform stand; yellow stems and leaves below soil surface; elongated subcrown.	Deep planting (below 2 in, or 5 cm) in heavy-textured soil; soil crusting.
Dead seedlings; roots of emerging plants are pruned, killing the seedlings and reducing the stand. As surviving plants mature, stems may be girdled, resulting in white heads.	Wireworms (fig. 1).

LEAVES

Primary symptoms	Cause
Leaf banding (narrow white stripes across leaf blade).	Freezing temperature as leaf emerges (fig. 2).
Leaf tip burn. Brown necrotic tissue beginning at leaf tip, usually ½ to 1 inch (12 to 25 mm) long.	Drying wind, moisture stress; contact herbicides; foliar fertilizer burn; soil salinity (figs. 3, 4).
White or tan speckled upper leaves, bleached circular areas to ¼ inch (6 mm) in size.	Herbicide drift (paraquat); or other herbicides/ adjuvants or foliar fertilizer sprays (figs. 5, 6).
Leaf surfaces skeletonized. Plants may senesce early and produce few tillers.	Cereal leaf beetle.
Light to intense yellowing of lower leaves or of entire plant.	Nitrogen deficiency; denitrification from saturated soil (figs. 7, 8).

(continued)

Figure 5. Paraquat spray drift injury. Photo by Jack Kelly Clark.

Figure 7. Nitrogen deficiency from denitrification. Photo by Steve Wright.

Figure 6. Shark herbicide injury. Photo by Ron Vargas.

Figure 8. Nitrogen deficiency. Photo by Steve Wright

Figure 9. Leaf yellowing of barley from barley yellows dwarf virus. Photo by Lee Jackson.

Figure 10. Leaf yellowing of wheat from barley yellows dwarf virus. Photo by Lee Jackson.

Figure 11. Leaf reddening of oat from barley yellows dwarf virus. Photo by Jack Kelly Clark.

Figure 12. Barley yellow dwarf virus infected area. Photo by Steve Wright.

Figure 13. Oat bird cherry aphid. Photo by Jack Kelly Clark.

Figure 14. Silvering of leaves due to mite feeding. Photo by Jack Kelly Clark.

Figure 16. "Hooked spike" from Russian wheat aphid. Photo by Jack Kelly Clark.

Primary symptoms	Cause
Lower leaves pale green; upper leaves yellow to white.	Sulfur deficiency.
Yellow, red, or purple leaves; uneven, blotchy leaf discoloration progressing from leaf tip to base and margin to midrib. Wheat and barley leaves usually become yellow, while oat leaves usually become red. Plants also can be stunted. Oat panicles can be blasted (florets become sterile). Aphids may be present.	Barley yellow dwarf virus (figs. 9, 10, 11, 12, 13).
Leaves first appear silvery and later take on a scorched appearance; leaves may appear yellowish and plants stunted, similar to cold temperature injury; webbing may be present.	Mites (fig. 14).
Leaves curled like a soda straw (tubelike); white, yellow, or purple vertical leaf stripes. Plants can be stunted and sometimes prostrate; awns may be trapped in the curled flag leaf, distorting the spike which assumes a fish-hook appearance; aphids may be found inside the curled leaves.	Russian wheat aphid (figs. 15, 16).
Irregularly shaped necrotic leaf spots, reddish-brown with gray-brown ashen centers and small black (pepper-size) specks (wheat).	Septoria tritici leaf blotch fungus (fig. 17).

(continued)

Figure 15. Leaf curling and streaking from Russian wheat aphid. Photo by Jack Kelly Clark.

Figure 17. Septoria tritici blotch lesions. Photo by Jack Kelly Clark.

Figure 18. Barley net blotch lesions. Photo by Jack Kelly Clark.

Figure 19. Early symptoms of leaf scald of barley. Photo by Jack Kelly Clark.

Figure 20. Late symptoms of leaf scald of barley. Photo by Jack Kelly Clark.

Figure 21. Wheat leaf rust pustules. Photo by Jack Kelly Clark.

Figure 22. Wheat leaf rust uredial and telial pustules. Photo by Jack Kelly Clark.

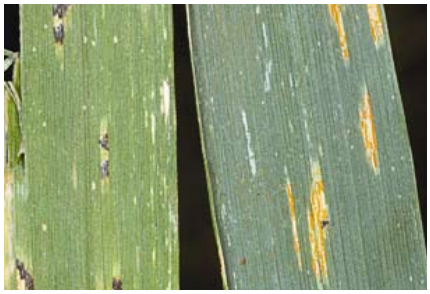

Figure 23. Oat crown rust pustules. Photo by Jack Kelly Clark.

Figure 24. Wheat stripe rust symptoms. Photo by Jack Kelly Clark.

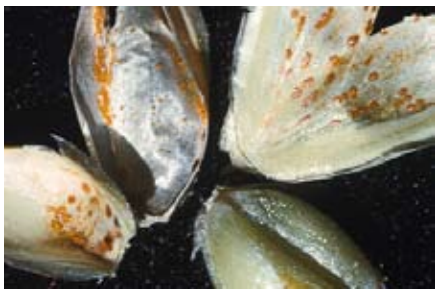

Figure 25. Stripe rust symptoms on wheat kernels. Photo by Milton D. Miller.

Figure 26. Patches of powdery mildew. Photo by Jack Kelly Clark.

Primary symptoms	Cause
Small brown spots to narrow brown blotches with a netted or cross-hatched appearance; surrounding tissue becomes yellow. Lesions can expand, spread over the entire leaf (barley).	Barley net blotch fungus (fig. 18).
Irregularly shaped to oval leaf spots with bluish gray centers and dark brown margins; spots can coalesce, giving the appearance of rapid scalding (barley).	Barley scald fungus (figs. 19, 20).
Yellow-brown (barley) to reddish-orange (wheat) pustules on leaves and sheaths. Pustules on barley are small and round; pustules on wheat are scattered or clustered on upper leaf surface. As the plants mature, the pustules turn dark and shiny as teliospores are formed.	Leaf rust fungi (figs. 21, 22).
Oblong, orange-colored pustules primarily on leaves and sheaths (oat). As the plant matures, the pustules turn dark and shiny as teliospores are formed.	Oat crown rust fungus (fig. 23).
Yellow-orange pustules form conspicuous stripes primarily on leaves (wheat and barley). As plant matures, the pustules turn dark and shiny as teliospores are formed.	Stripe rust fungi (figs. 24, 25).
Patches of white cottony growth (mycelium and spores) develop opposite chlorotic spots on leaf surfaces. These patches later turn dull gray-brown. Small dark-brown structures (cleistothecia) develop among the cottony patches.	Powdery mildew fungus (figs. 26, 27).

Figure 27. Patches of powdery mildew with cleistothecia. Photo by Jack Kelly Clark.

Figure 28. Plants dying due to lagoon water. Photo by Steve Wright.

Figure 29. Plant death due to waterlogged soil. Photo by Steve Wright.

Figure 30. Stunted wheat roots from compacted soil. Photo by Ron Vargas.

WHOLE PLANT

Primary symptoms	Cause
Areas of dying, yellow to reddish brown plants usually at ends of fields or in low spots in field.	Saturated soils; lagoon water with high organic matter content (figs. 28, 29).
Stunted plants, poor tiller development; leaves purple; delayed heading.	Cold soils; low phosphorus availability.
Uneven, shallow, horizontal root growth; stunted plants in rows or strips; visible traffic patterns.	Compacted soil (fig. 30).
Leaves appear water soaked and dark green; bleached white spikelets appear later. Absence of kernels at different positions in the spike; injury may vary through field.	Freezing temperatures during heading, at pollination, or during grain fill (figs. 31, 32).
Prostrate growth, sharp bends at stem nodes; kinked heads and curled awns.	Dicamba herbicide injury (fig. 33).

Figure 31. Freezing injury to wheat spike. Photo by Jack Kelly Clark.

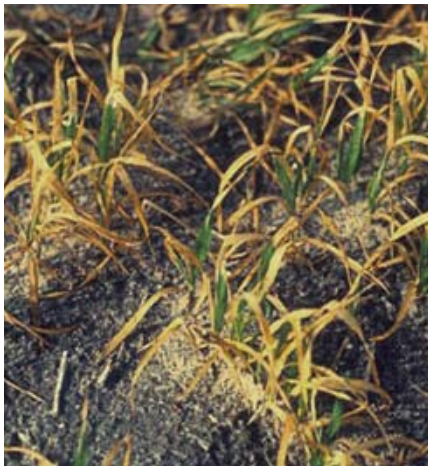

Figure 32. Frost injury to barley seedlings. Photo by Ron Vargas

Figure 33. Prostrate growth from Dicamba herbicide injury. Photo by Mick Canevari.

Figure 34. Distorted spikes from phenoxy herbicide injury. Photo by Jack Kelly Clark.

Figure 35. Distorted spike and kinked leaf from phenoxy herbicide injury. Photo by Mick Canevari.

Figure 36. Leaf twisting from phenoxy herbicide injury. Photo by Mick Canevari.

HEAD TISSUES AND/OR SEEDS

Primary symptoms	Cause
Bulging, malformed spikes and curled awns; nonuniform grain symmetry; leaf twisting.	Misapplication (timing or rate) of phenoxy herbicides; frost injury (figs. 34, 35, 36).
Blanking and bleaching of spikes (white heads). Lower leaf sheaths, culms, crowns, subcrown internodes, and roots are discolored (brown or black) and rotted.	Root and foot rot fungi (figs. 37, 38, 39).

(continued)

Figure 37. White heads caused by common root rot. Photo by Jack Kelly Clark.

Figure 38. Root rot of wheat. Photo by Milton D. Miller.

Figure 39. Browning of wheat crown and roots. Photo by Lee Jackson.

Figure 40. Blackening of stems caused by take-all. Photo by Jack Kelly Clark.

Figure 41. Wheat stem maggot inside stem. Photo by Jack Kelly Clark.

Primary symptoms	Cause
Blanking and bleaching of spikes (white heads); blackening of roots, crown, and under lower leaf sheaths. The presence of a layer of dark brown or black fungal mycelium underneath the lower leaf sheaths distinguishes take-all from common root rot.	Take-all root rot fungus (fig. 40).
Blanking and bleaching of spikes (white heads). The spike turns white and is easily pulled free from the stem where it has been chewed through; legless maggots may be found inside the stem.	Wheat stem maggot (fig. 41).
Normal spike tissue is replaced by olive-black masses of spores enclosed in fragile membranes that rupture near flowering time, releasing the spores and leaving only a bare rachis at maturity (barley, wheat).	Loose smut fungi (fig. 42).
Kernels are replaced by round, seedlike bodies that contain masses of dark spores. Glumes on infected spikes spread apart. The spore masses have a distinctive odor, similar to that of decaying fish, when they are crushed.	Covered smut (barley, oat) and stinking smut or bunt (wheat) fungi (fig. 43).

Figure 42. Loose smut of wheat, spike infection. Photo by Jack Kelly Clark.

Figure 43. Covered smut of barley. Photo by Marsha Feyler.

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