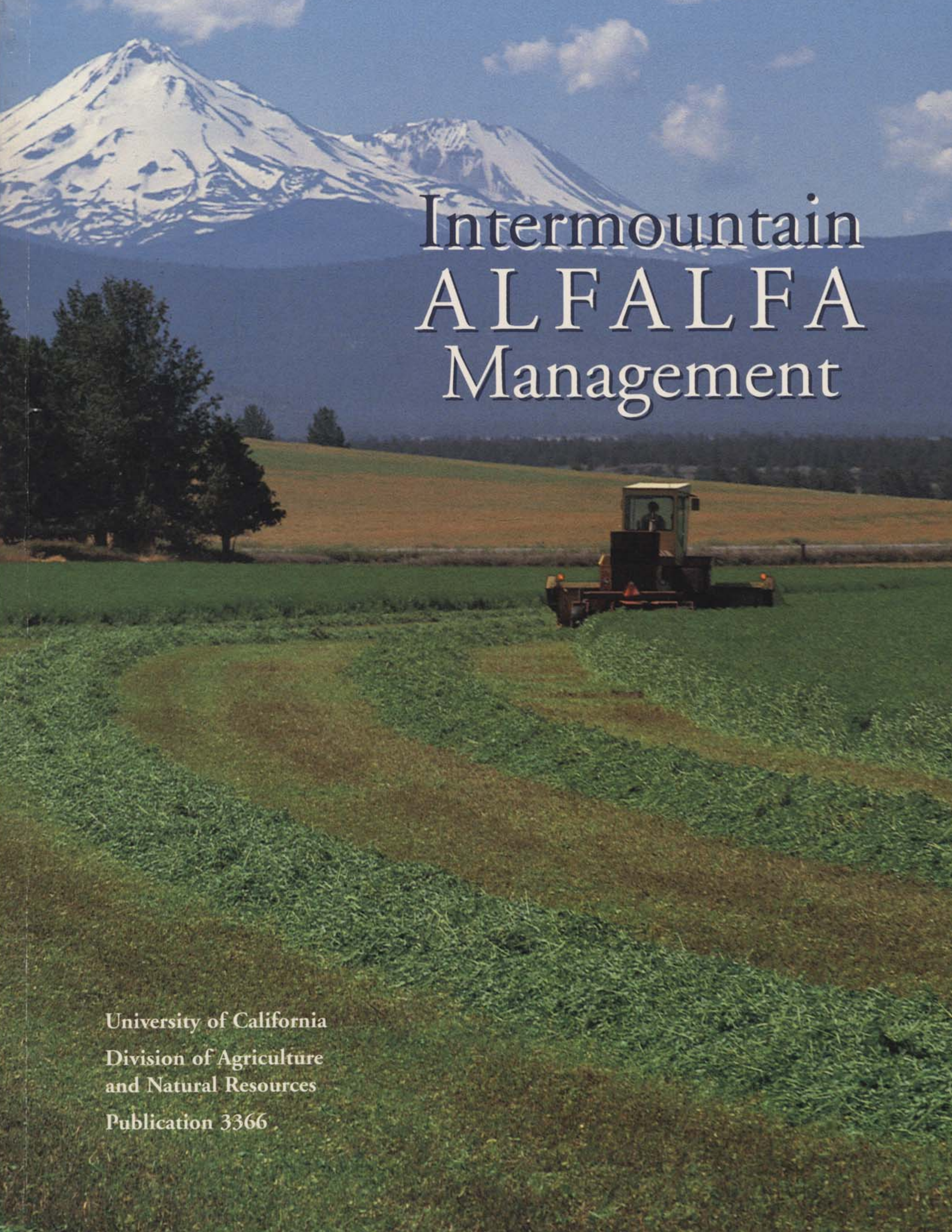

Intermountain ALFALFA Management

University of California
Division of Agriculture and Natural Resources
Publication 3366

INTERMOUNTAIN ALFALFA MANAGEMENT

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Technical Editors
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On the front cover: Pictured is the second cutting of a center-pivot-irrigated alfalfa field at the Prather Ranch in Butte Valley, California. Majestic Mount Shasta appears in the background. The photograph was taken in July 1993.

On the back cover: At the Prather Ranch alfalfa shows its adaptability to a wide range of soil and climatic conditions and serves for both off-farm sales and on-farm use.

PHOTOS BY STEVE ORLOFF

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Confine chemicals to the property being treated. Avoid drift onto neighboring properties, especially gardens containing fruits and/or vegetables ready to be picked.

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INTRODUCTION

Steve B. Orloff

Alfalfa (*Medicago sativa* L.) is called the Queen of Forages. There is little wonder why this crop has acquired such a prestigious reputation. Not only is it the oldest cultivated forage crop, but it is also one of the most palatable and nutritious: Alfalfa is rich in protein, vitamins, and minerals. When cut prior to bloom, it is low in fiber and high in energy. Because of its superior nutritional quality, alfalfa is the primary component in the dietary ration of dairy cattle and is an important feed for horses, beef cattle, sheep, and milking goats. Alfalfa has a very high yield potential compared with that of other forage crops. It is an integral component of many crop rotations because of its ability to fix nitrogen, improve soil structure and tilth, and control weeds in subsequent crops.

Alfalfa is the most popular and important forage crop grown in California. It is produced on approximately 1 million acres, or about 1 out of 8 eight irrigated acres in the state. The intermountain counties of Siskiyou, Shasta, Modoc, Lassen, Plumas, Sierra, Inyo, and Mono account for about 15 percent of the state's acreage and produce approximately 10 percent of the total crop. Alfalfa assumes a more prominent role in the Intermountain Region than in other alfalfa-production areas of California because there are few rotation crops in the area. Alfalfa is the most extensively grown crop in the Intermountain Region, as well as the crop with the highest gross receipts.

The intermountain portion of Northern California has unique environmental conditions that set it apart

from other alfalfa-production areas of the state. Actually, the intermountain area has more in common with neighboring states than with the rest of California. Alfalfa is produced in high-elevation valleys (from 2,500 to 5,000 feet) scattered throughout the intermountain area. Each valley has distinct physical and climatic characteristics due to differences in elevation and topography. Most soils of the region were formed from alluvium derived primarily from volcanic rock. Despite having a similar origin, great differences in soil properties exist between production valleys, within individual valleys, and even within fields. Soils range in texture from loamy sands to heavy clay loams. Organic matter content varies from less than 1 percent to more than 12 percent in the Tulelake Basin. Irrigation water is supplied from lakes, rivers, and wells. Most alfalfa is sprinkler-irrigated (primarily by wheel lines and center pivots); however, flood irrigation is used in some of the more level valleys with heavier soils.

Alfalfa is produced under dryland conditions in some valleys, but these areas represent a minor portion of intermountain production acreage. The most distinctive characteristic common to all intermountain areas is the short growing season (90 to 160 days). Coupled with the short growing season are large fluctuations in temperature, both from day to night and from summer to winter. Weather during the growing season is generally warm during the day and cool at night. However, below-freezing temperatures can occur any night of the year in many of these production areas.

Climate has a profound effect on alfalfa production. Because of the climate in the Intermountain Region, dormant varieties of alfalfa (those with a fall dormancy rating from 2 to 4) prevail there. Growers can obtain two to four alfalfa cuttings between May and September (three is the most common number). Annual hay production averages 5 tons, though yields of 8 tons per acre or higher have been obtained on more productive soils under good management. Total seasonal production is relatively low, but individual cuttings of 2 to 3 tons per acre are common. Stand life is long—typically 6 to 8 years.

The Intermountain Region is known for high-quality alfalfa hay, which is sometimes called mountain hay. Its quality is commonly attributed to the short growing season and cool night temperatures. For most of the year, intermountain alfalfa grows more slowly than that in warmer areas; therefore, it generally has a higher leaf-to-stem ratio and a lower fiber content. It is used locally as cattle feed and trucked to dairies throughout much of California and western Oregon. Nearly all alfalfa is produced as hay, with very little green chop or silage production.

Although the intermountain environment is advantageous for some aspects of alfalfa production, it creates some serious challenges. Because of the short and relatively cool growing season and cold winters, diseases and insects are not as great a problem as in other areas. Because of fewer cuttings per season, summer annual grasses are not as serious as in the Central Valley and low desert areas of California. However, because of the long stand life and limited rotation crop options, perennial weeds are particularly troublesome. Rodent pests are frequently a severe problem for the same reasons. Climatic conditions are conducive to production of high-quality hay, but late- and early-season frosts are a constant threat. Rain damage is common during any cutting.

Successful alfalfa production in the Intermountain Region requires a thorough understanding of all aspects of crop management. The intent of this manual is to provide growers, advisors, and consultants involved in the alfalfa industry with a comprehensive guide to alfalfa production and management in the Intermountain Region. Contributors were University of California Farm Advisors and Specialists. We have attempted to assemble into one publication the most current information and recommendations on all areas of alfalfa management, including stand establishment, fertilizer use, irrigation, pest management, harvesting, forage quality, grazing, and management of depleted stands.

CHAPTER ONE

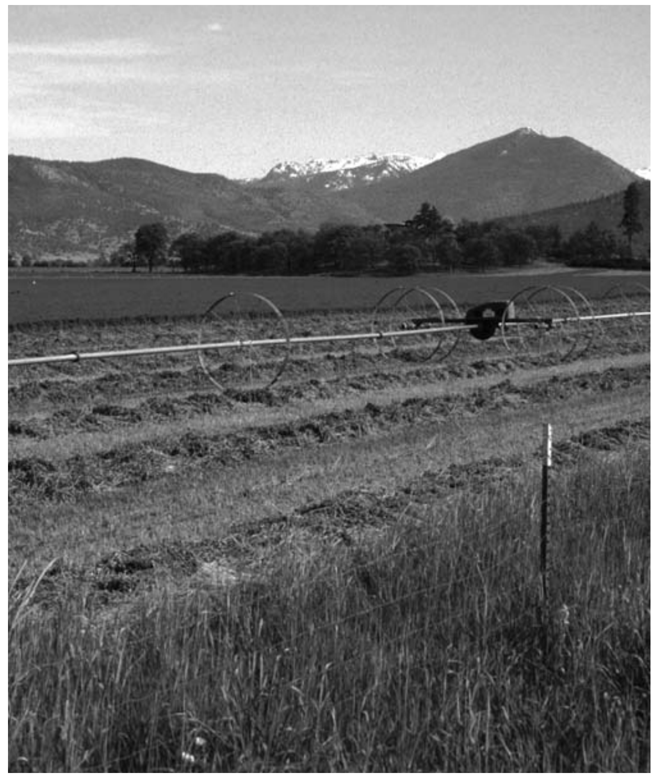
SITE SELECTION

Donald L. Lancaster and Steve B. Orloff

Alfalfa can be grown on a variety of sites in the Intermountain Region of California. Since site conditions often limit both yield and profit potential, a grower should pay particular attention to site selection. Some site limitations can be overcome or reduced, but the cost may be high, affecting future profitability. If site conditions are poor, alfalfa production may be unprofitable even under optimum management.

When selecting a site for alfalfa production, consider the physical and chemical properties of the soil, the likelihood of waterlogging, the topography, and the quantity and quality of available irrigation water (Table 1.1).

When alfalfa is grown on sites that provide adequate rooting depth, nutrition, aeration, and water, and do not present excess salts or alkali problems, growers using good management practices can produce hay yields of 6 to 8 tons per acre. However, greater management skill is required to achieve profitable alfalfa production on marginal or undesirable sites. Remember, the better the site, the higher the potential yield.



SOIL FACTORS

The geologic history of intermountain California is complex. Consequently, within a single 40-acre field may be several different soil types. As the first step in determining the suitability of a site for alfalfa production, learn the soil types found there by consulting soil surveys. Published by the United States Department of Agriculture Natural Resources Conservation Service, these surveys contain soil maps to assist growers in identifying soil units, and include information on texture, water-holding capacity, depth, drainage, and infiltration rate. If the survey indicates that the site may have promise, have the soil and water analyzed. Do this before planting alfalfa on the site. Information on soil sampling methods is presented in chapter 5.

Physical Properties

Soil texture

The term *soil texture* refers to the relative proportion of sand, silt, and clay in soil. Soil texture affects the water-holding capacity and infiltration rate (the rate

Table 1.1. Characteristics of ideal, marginal, and undesirable sites for alfalfa production.

CHARACTERISTIC	UNIT OF MEASURE	IDEAL	MARGINAL	UNDESIRABLE[1]
Soil texture		Sandy loam–clay loam	Loamy sand, silty clay	Sand, clay
Soil depth	ft	>6	3–6	<3
Soil chemistry[2]				
pH		6.3–7.5	5.8–6.3 and 7.5–8.2	<5.8 or >8.2
EC_e	mmho/cm	0-2	2–5	>5
ESP	%	<7	7–15	>15
Boron	mg/L	0.5–2.0	2–6	>6
Frequency of waterlogging or high water table		Never	Only during dormant period	Sometimes during periods of active growth
Slope		Nearly level	Slightly sloping to 12% slope	>12% slope
Water supply	gpm/acre	>8	5.5–8	<5.5
Water quality				
EC_w	mmoh/cm	<1.3	1.3–3.0	>3.0
SAR		<6.0	6.0–9.0	>9.0
Boron	mg/L	<0.5	0.5–2.0	2.0–6.0

Note: These categories are approximate and should be modified when warranted by experience, local practices, special conditions, or irrigation method.
1. These sites are considered unsuitable for profitable alfalfa production unless reclaimed or specialized management is employed.
2. Values are based on saturated paste pH and saturated paste extract concentrations.

at which irrigation water will enter the soil profile). Clay holds the most water; sand allows the fastest water infiltration.

Alfalfa can be successfully produced on a wide range of soil textures, but sandy loam to clay-loam soils are preferred. These soil types provide the best combination of water holding and water infiltration for alfalfa. Sands and loamy sands have such low water-holding capacities that fields must be irrigated every few days, a task that is difficult with most irrigation systems (except center pivot or linear move systems). Alfalfa production on fine-textured clay soils can be equally difficult. In these soils, water infiltration and drainage are extremely slow. Aeration may be poor because the small pore spaces associated with fine soils limit the diffusion of oxygen to plant roots, impairing root growth.

Rocky soils are common in the Intermountain Region. Soils with numerous rocks near the surface are not well suited to cultivation and often damage harvest equipment. Avoid them whenever possible.

Depth and profile

The soil provides a rooting medium through which the alfalfa draws water and nutrients. The deeper the soil, the more water and nutrient storage capacity the site provides. To find soil profile problems, use a backhoe to dig several evaluation pits in a potential field (Figure 1.1). Each pit should be at least 4 feet deep.

A site should provide a minimum of 3 feet of unrestricted rooting depth.

An ideal site has deep, uniformly textured soil with no drainage or salt problems. Under ideal conditions, alfalfa roots will extend 6 to 12 feet deep or more. Unfortunately, because of the geology of the Intermountain Region, many soils are not that deep. To be suitable for alfalfa production, a site should provide a minimum of 3 feet of unrestricted rooting depth.

Like shallow soils, restrictive subsurface layers limit alfalfa production. The most common problems in the Intermountain Region are hardpans, claypans, sand and gravel lenses, and stratified or layered soils. These reduce alfalfa yields because they present a barrier to root penetration or inhibit water infiltration and drainage.

DON LANCASTER

Figure 1.1. Use a backhoe to dig several evaluation pits in a potential field to determine the soil depth and to detect soil profile problems.

Soil profile problems are not limited to compacted layers—abrupt changes in texture within the soil profile can have a similar effect. A clay layer within a sandy loam soil or a layer of sand within a loam or clay-loam soil can prevent root penetration and soil water movement. An abrupt change in soil texture impedes the downward movement of water even when water is moving from a clay soil into a sandy layer. Water movement into a different textural class does not occur to any appreciable degree until the layer above is saturated. Consequently, a zone of poor aeration often occurs at the interface between different layers and can even result in a temporarily perched water table. The greater the change in textural class and the more abrupt the change, the greater the effect.

Deep tillage can help reduce, but usually can not eliminate problems associated with hardpans, claypans, and layered soils. Deep ripping is effective to resolve hardpan problems, since a fractured hardpan will not re-cement itself. However, ripping alone is not enough to solve a claypan or layered-soil problem. These problems are only solved by mixing soils to a depth below the restrictive layer. This is usually accomplished with a moldboard or slip plow. Major physical modification of soils is expensive (often in excess of $200 per acre), and alfalfa production seldom justifies the cost. When possible select an alternative site, free of restrictive subsurface layers.

Waterlogging and Fluctuating Water Tables

Some areas of the Intermountain Region are former swamps or lakes and are subject to fluctuating water tables and intermittent flooding. During years of above-average precipitation, the water table level may be well within the root zone of alfalfa. Alfalfa does not tolerate wet soil conditions during periods of active growth: perched or fluctuating water tables in the root zone can severely reduce yields and stand life. Oxygen depletion in the root zone and diseases of the root and crown (such as Phytophthora root rot) often occur under excessively wet conditions.

An intermittent, or fluctuating, high water table is usually more damaging than a stable high water table. With a stable high water table, the alfalfa roots are restricted to the well-aerated soil above the high water table. However, with a fluctuating water table, roots may grow below the high water table level when conditions are favorable, only to become damaged when the water table rises. The damage that occurs from waterlogging depends on the time of year when waterlogging occurs and its duration. Waterlogging is far more serious when it occurs during the growing season than when alfalfa is dormant. Furthermore, the longer waterlogging persists and the warmer the temperature, the greater the injury to the crop.

Deep tillage can improve internal drainage in some soils. Precise field leveling and drainage tile may also help correct waterlogging problems, but the resulting increase in alfalfa production may be insufficient to recover the costs. Avoid sites with waterlogging or a fluctuating high water table.

Alfalfa does not tolerate wet soil conditions during periods of active growth.

Chemical Properties

Fertility

The parent material of a soil largely determines its mineral content and fertility. Most areas of the Intermountain Region are naturally deficient in sulfur and phosphorus. Potassium, boron, and molybdenum are also deficient in some sites. These nutrient deficiencies are easily corrected through proper diagnosis and fertilizer application (see chapter 5); they do not limit site selection.

pH

Soil pH affects nutrient availability and can indicate problems with soil structure. Maximum nutrient availability for most crops occurs when pH values are between 6.0 and 7.0. However, higher pH values (6.3 to 7.5) are recommended for alfalfa production because they favor activity of nitrogen-fixing *Rhizobium* bacteria. Soils with pH values below 6.0 are unsuitable; lime them before planting, particularly if pH decreases with increasing soil depth. On the other hand, soil pH values above 8.2 indicate excess sodium. High-pH sites are relatively unproductive unless reclaimed (Figure 1.2).

Salinity and Sodicity

Problems with excess soil salt (saline soils) and sodium (sodic soils) occasionally occur in the Intermountain Region. Soils formed in enclosed basins under low-rainfall or desert conditions are often saline. Also conducive to high salt concentrations are high water tables in which salts rise because of the upward (capillary) movement of water. Similarly, irrigation water high in soluble salts contributes to soil salinity.

Alfalfa is moderately sensitive to salt. High salt may be toxic and reduce water availability. Visual indicators of excess salt include slick spots, white or black crusts on the soil surface; marginal leaf burn; and the presence of salt-tolerant weeds. Laboratory analysis of soils is required to confirm visual symptoms and to determine the type and degree of salinity. Carefully sample fields at different depths throughout the root zone when salinity is suspected.

Soil salinity is measured by determining the electrical conductivity of the soil extract (EC_e). Salts conduct electricity; therefore, the higher the electrical conductivity of the soil extract, the greater the salinity of the soil. EC_e values above 2.0 millimhos per centimeter (mmho/cm) can suppress alfalfa yields, depending upon the specific ions in the soil-water

Figure 1.2. Soil reclamation requirements.

Before it is possible to reclaim any saline or sodic soil, a grower must have

1. **an ample supply of quality water**
   Reclamation requires a supply of irrigation water sufficient to leach excess salts below the root zone. Until the soil is reclaimed, apply more water than is necessary to satisfy the needs of alfalfa. The extra water carries harmful salts below the root zone, where they are less likely to injure the crop.
2. **good drainage**
   Both surface and internal drainage must be adequate. Water must pass into and through the soil to carry away salts present in the soil or released during reclamation. Salts are not washed *off* the soil surface, but *through* the soil below the root zone. Therefore, soil reclamation cannot occur without adequate drainage to at least the depth of the root zone. Deep ripping or installation of drainage tiles may be required to provide acceptable internal drainage in some sites.
3. **a source of calcium**
   Reclamation of sodic (not saline) soils requires that calcium replace the sodium that is leached off soil particles. If calcium carbonate is present in the soil, sulfur-containing soil amendments can be used to free up the calcium. To soils low in calcium apply a calcium source, such as gypsum.
4. **adequate financing to complete the job**
   Reclamation requires a considerable investment. Unless you have adequate finances to complete the job, reclaiming salt-affected soils may not be a profitable venture.
5. **patience**
   Complete reclamation may take many years. Initially, growers must be content with improved land rather than an actual cash return from crop production.

Adapted from Mueller. 1992. Site Selection. In: *Central San Joaquin Valley Alfalfa Establishment and Production.*

A water supply of at least 7 to 8 gallons per minute is needed for each acre of alfalfa.

solution. Alfalfa suffers a 10 percent yield reduction when soil salinity levels reach approximately 3.4 mmho/cm. In general, soils with EC_e values above 5.0 should be avoided or reclaimed prior to planting alfalfa. If drainage is adequate, saline soils can be reclaimed by deep leaching. Water in excess of crop needs must be applied for deep leaching to occur. This is most easily accomplished by reclaiming the soil prior to planting alfalfa or by applying water during the dormant season, when alfalfa is not actively growing.

Excess sodium can be a significant yield-limiting factor. High sodium levels cause clay particles to disperse. This degrades soil structure; the soil surface seals and water infiltration slows. Soils with an exchangeable sodium percentage above 15 are considered sodic. This means that more than 15 percent of the exchange sites (negatively charged positions on soil particles that hold onto positively charged elements and compounds) are occupied with sodium rather than beneficial elements such as calcium, magnesium, and potassium. When this condition occurs, a laboratory analysis can determine the gypsum requirement of the soil. *Gypsum requirement* refers to the amount of calcium required to displace sodium on the exchange sites. Sulfur can be used instead of gypsum to reclaim soils that are high in calcium carbonate. After an amendment has been applied and sodium replaced with calcium, the displaced sodium must be leached below the alfalfa root zone.

Avoid sites that are adversely affected with excess salts or sodium. The reclamation process usually requires several years and, in the case of sodic soils, a substantial investment in soil amendments. Subsurface drainage systems may also be required to effectively reclaim a site for sustainable economical alfalfa production.

Boron

Some sites present growers with boron problems. In the Intermountain Region boron deficiency is much more common than boron toxicity. Fertilizers can correct boron deficiency (see chapter 5). Because alfalfa is highly tolerant of boron, boron toxicity is rarely a problem in alfalfa fields in the Intermountain Region. When it occurs, however, it can be difficult to resolve. Boron is far more difficult to leach than sodium or other salts. Boron toxicity is usually associated with high concentrations of boron in the irrigation water. Changing the water supply may help correct the problem. High boron levels in soil are difficult to lower; doing so takes large quantities of water and many years. Fortunately, boron toxicity problems are not observed in alfalfa until soil boron levels exceed 6 milligrams per liter in saturated paste extract.

TOPOGRAPHY

Level or nearly level land facilitates irrigation and water penetration. Water accumulation in low spots can "drown out" alfalfa. Uneven or undulating fields may require extensive land leveling. This results in major cut and fill areas, which often create additional problems. Areas where major cuts have been made are usually less productive because much of the topsoil has been removed and the soil may be shallower than in surrounding areas. The productivity of cut areas may not match that of the rest of the field until they have been farmed for several years. Also, significant settling may occur in fill areas, making additional leveling necessary. To alleviate some of these problems, as well as the salinity problems that commonly occur in new fields, produce an annual crop such as small grains before planting alfalfa.

Both topography and soil texture should determine the type of irrigation used. Use sprinkler irrigation on coarse-textured soils or moderately sloping land. Even with sprinkler irrigation systems, the amount of slope that can be tolerated is limited, depending on the soil-water infiltration rate. In most cases, avoid slopes in excess of 12 to 15 percent.

IRRIGATION WATER

When selecting a potential site for alfalfa production, be sure that there is an adequate supply of quality water available for season-long irrigation. Both quantity and quality of irrigation water can limit alfalfa yields.

Quantity

Insufficient irrigation water is perhaps the most common site limitation in the Intermountain Region. Many fields have been planted with inadequate irrigation systems, pump capacity, or water supply. Peak water use of alfalfa, approximately 0.30 inches per day, occurs during July (see chapter 4). To meet peak water needs and compensate for inefficiencies in the irrigation system, a water supply of at least 7 to 8 gallons per minute is needed for each acre of alfalfa. The precise amount depends on the climate of the area and the uniformity of water application. Failure to meet peak water needs results in reduced seasonal yields and profits.

Quality

Poor water quality is occasionally a problem in the Intermountain Region. Water from underground wells may contain excess salt. Excess boron is a problem in some geothermal wells in the region. Some surface water sources contain excess colloidal clays, salts, or weed seeds that can present management and stand-life problems. See Table 1.1 for guidelines about water quality. Toxicities due to foliar absorption of sodium and chlorides can occur with sprinkler irrigation. This is most common during periods of very low humidity and high winds.

Little can be done to improve irrigation water quality. In fact, soil reclamation efforts are unproductive if irrigation water quality is poor. The only cost-effective method of dealing with poor irrigation water is to find an alternative water source or blend the existing water with higher-quality water.

ADDITIONAL READING

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CHAPTER TWO

STAND ESTABLISHMENT

Jerry L. Schmierer, Steve B. Orloff, and Roger W. Benton

Profitable alfalfa production is contingent upon establishment of a dense vigorous stand. Proper stand establishment is especially important in the Intermountain Region, where alfalfa fields may remain productive for 5 to 8 years or longer. Poor stand establishment can reduce the profitability of alfalfa by lowering yields, diminishing stand life, and reducing the nutritional quality of the hay. Mistakes made during stand establishment cannot usually be offset later.

SEEDBED PREPARATION

Inadequate seedbed preparation is a common cause of stand establishment failure. The objectives of seedbed preparation are to loosen the soil to remove any impediment to root growth, to level the field for drainage and ease of harvest, and to firm and smooth the soil surface for optimum crop emergence. This is accomplished through primary tillage (deep plowing or ripping); land leveling; and secondary tillage, which breaks up clods and firms the soil.

Primary Tillage

Alfalfa requires well-drained, relatively deep soil (a minimum of 3 to 4 feet) for maximum production. Physical or chemical limitations caused by hardpans, stratified soils, or salts can restrict rooting depth, which leads to decreased productivity and lower yield. Soil compaction occurs from equipment traffic, especially when it takes place on wet soils and when the crops transported are heavy, as are potatoes or sugar beets. Deep tillage can reduce compaction.

Several deep-tillage implements are used in alfalfa seedbed preparation: a ripper, or subsoiler; a moldboard plow; and a slip plow. A ripper is the most commonly used implement to alleviate compaction. For best results, work when the soil is dry and rip below the depth of the compacted layer. Ripping wet soils does not fracture compacted layers. Space the shanks no more than 3 feet apart. Ripping in one direction at half the spacing results in more of the soil being fractured than cross ripping—that is, using 20-inch centers in one direction is more effective than using 40-inch centers in two directions. The duration of the beneficial effects of ripping varies depending on the soil type and the nature of the compaction problem, but fields should ordinarily be ripped prior to each alfalfa planting. In some cases ripping can be done well in advance of alfalfa seeding. For example, prior to a spring planting, rip fields in the fall. Rip fields in a cereals-alfalfa rotation prior to planting the grain crop. Ripping shatters compacted layers but does not mix the soil, so the beneficial effects of ripping may be short-lived in layered soils (soils with distinct changes in soil texture with depth).

A moldboard plow can also be used to alleviate compaction problems. It is particularly beneficial in layered soils, because plowing inverts and mixes the soil. Plowing can be a useful way to remove old alfalfa stands, bury weed seeds and plant debris, and incorporate fertilizer deep into the soil. However, plowing can sometimes bring less-desirable soil to the surface and is especially problematic in rocky fields. Any soil requires extra tillage or time to firm up or settle after plowing. In most Intermountain Region soils, an excellent seedbed can be prepared without plowing.

The proper type and degree of deep tillage can be difficult to ascertain. No single "recipe" is appropriate for all locations. An understanding of the soils and a knowledge of crop history are great aids in evaluating the need for deep tillage. Prior to removing a stand use a backhoe to determine the distribution of roots in the soil profile; root distribution indicates soil stratification or impermeable layers. The economics of deep tillage can be difficult to predict. Deep-tillage implements have high horsepower requirements, so deep tillage can be very expensive—in excess of $200 per acre. Fortunately, deep tillage is not necessary for most fields in the Intermountain Region. However, ripping to moderate depths, 20 to 32 inches, is usually cost-effective and recommended to reduce compaction from preceding crops.

Land Leveling

Leveling the field is important. The degree of leveling necessary depends on the irrigation system and soil type. With sprinkler irrigation, low spots need to be filled and leveled so that water does not pond and drown the alfalfa. More extensive leveling is required for fields with flood-irrigation systems.

Before the advent of laser leveling, correct cut and fill as well as the proper field slope were difficult to attain. Laser leveling is expensive, but it is by far the preferred method when flood irrigation is used. Laser leveling may be done in two stages. The rough leveling may be done after primary tillage. After irrigation borders are formed, the area between borders can be laser-leveled to attain a precise level and slope. Laser leveling between borders is also a common practice in older, previously leveled fields that are being planted to alfalfa.

Secondary Tillage

The field should be disced, harrowed, floated, and packed to form a firm, clod-free seedbed that is neither powdery nor fluffy (Figure 2.1). It should be firm enough so that a heel print in the prepared soil is not more than ½ inch deep. Poor establishment is likely if the surface is not well compacted prior to seeding. A relatively clod-free seedbed prevents excess air space, permits good seed-soil contact, allows uniform planting depth, and improves moisture availability to the seed. Take care not to overwork heavy soils: Overworking will increase their undesirable tendency for surface crusting.

COURTESY FORD NEW HOLLAND

Figure 2.1. The ideal seedbed should be firm, not powdery or fluffy, and clod-free.

PREIRRIGATION

Alfalfa can be seeded into moist soils or seeded into dry soils and then irrigated. Planting into moisture can be accomplished by either preirrigating before planting or by preparing the seedbed in the fall and taking advantage of winter precipitation to provide moisture. The advantages of planting into moist soils are that the moisture has usually melted the clods and, if the moisture is uniform, alfalfa seeds can germinate uniformly and quickly. Also, keeping up with irrigation is easier when starting with a full soil-water reservoir. Contact-type herbicides or shallow cultivation can be used to control weeds that emerge prior to planting.

Despite these advantages, the time required for seedbed preparation, irrigation, surface drying, spraying for weed control, and then planting deters many growers from preirrigation. Preparing the seedbed, planting, and irrigating is much simpler. However, a dry planting system can be less forgiving. The grower must take great care to meet the water requirements of the young crop. Weed populations are usually higher in fields that have not been preirrigated, making postemergence weed control more difficult.

SEEDING

Seeding Depth

Seed placement is critical. More stand establishment failures probably relate to seeding too deep than to any other single factor. Seeding depth should not exceed ⅜ inch, except for sandy soils, where ⅝ inch is acceptable. Seeding deeper than this can reduce seedling emergence considerably (Table 2.1).

Table 2.1. Emergence from different seeding depths.

DEPTH (IN.)	% EMERGENCE[1]
¼–½	60
1	48
2–2½	2

Source: R. Sheesley

1. Emergence from different depths can vary with soil type—that is, poorer emergence results from deeper depths with a heavy soil, in contrast to a sandy soil.

Seeding Methods

Various implements are used to plant alfalfa, but all basically involve either broadcasting or banding (drilling) the seed. Each method presents advantages and disadvantages. Factors to consider when selecting a seeding method include cost, time, equipment available, and uniformity of seed distribution. Adequate alfalfa stands can be established using either method. Firming the seedbed after planting is an important part of seeding. It ensures the seed-soil contact necessary to prevent desiccation of the emerging alfalfa seedling. Cultipacking or ring rolling once after seeding is usually sufficient in broadcast seedings; cultipacking twice can be beneficial on coarse-textured soils. Press wheels or a cultipacker works well in drilled seedings.

Broadcasting

Compared to banding, broadcast seeding is generally faster and distributes seed more uniformly. A disadvantage of broadcast seeding is that uncovered seed remains on the soil surface. However, the amount of uncovered seed is considered insignificant. Several systems are used to broadcast alfalfa seed. A cultipacker seeder such as a Brillion seeder has been used with excellent results (Figure 2.2). A Brillion seeder drops seed between double corrugated rollers. The leading roller breaks clods and firms the soil prior to seeding. The trailing roller splits the ridges made by the first roller, covering and packing the seed. Seed can also be successfully broadcast by using an air-flow ground

VERN MARBLE

Figure 2.2. A Brillion seeder is often used with excellent results to broadcast alfalfa seed.

applicator, fluid or suspension seeding techniques, aerial application, or the small seed attachment of a grain drill, which allows seed to fall out of the seed tubes and scatter on the ground. Aerial seeding is uncommon in the Intermountain Region. When used, increase the seeding rate by 2 to 4 pounds per acre to compensate for losses and nonuniformity.

Banding

A standard grain drill is typically used to band, or drill, alfalfa. Nearly all the seed is incorporated and covered when alfalfa seed is drilled. Phosphorus fertilizer can be banded with the seed at the time of seeding, another advantage of this seeding method. In addition, drilling disturbs soil less than does broadcasting, so drilling conserves soil moisture. This is particularly important when growers rely on rainfall for crop emergence. The primary disadvantage of drilling alfalfa seed relates to distribution. The distance between alfalfa seed rows is typically 6 to 7 inches. This is a particular problem when there is a planter skip, doubling the distance between rows to 12 to 14 inches. Some growers drill in two directions to overcome this problem.

Seeding Rates

A wide range of seeding rates can be acceptable provided the seedbed was properly prepared. Twenty alfalfa seedlings per square foot constitutes an adequate stand. One pound of alfalfa seed spread evenly over an acre equates to approximately 5 seeds per square foot (4 pounds per acre equals 20 seeds per square foot). Although these figures suggest extremely low seeding rates are feasible, this is not the case. Typically, only 60 percent of the seeds germinate and emerge; 60 percent of emerged seedlings may die during the first year. Under ideal conditions, adequate stands have been established with seeding rates as low as 12 to 15 pounds per acre. To compensate for less-than-ideal conditions and unforeseen weather, the seeding rate recommended for irrigated fields is 15 to 20 pounds per acre when drilling and 20 to 25 pounds per acre when broadcasting. An extra few pounds of seed is generally not too costly and is cheap insurance against less-than-optimum seedbed and weather conditions. Seeding rates higher than these are excessive. Because of self-thinning, a 1-year-old alfalfa stand seeded at an excessive rate would not likely be any different than a 1-year-old stand seeded at the recommended rate.

Seed dryland alfalfa at 8 to 10 pounds per acre. Higher seeding rates waste seed because dryland conditions cannot support as many plants per square foot as can irrigated fields.

More stand establishment failures probably relate to seeding too deep than to any other single factor.

PLANTING DATE

Factors to be considered when determining planting date include weather (primarily temperature and the likelihood of rainfall), cropping pattern, harvest date of the preceding crop, water availability, irrigation method, weed pressure, and the time of year when environmental conditions are optimum for crop emergence and seedling development. No single planting date satisfies all the criteria. Advantages and disadvantages of each time period must be weighed to decide the most appropriate date (Table 2.2). Actual seeding dates vary depending on the intermountain production area (Figure 2.3).

Spring

Spring planting dates vary considerably within the Intermountain Region. Planting can begin as early as the last week in February in areas such as Shasta Valley; they can be as late as the end of May in higher-elevation areas. The likelihood of a damaging frost delays the starting date for spring planting. Alfalfa is extremely cold tolerant at emergence. However, plants are frost sensitive when they have two trifoliolate leaves, and may be killed by 4 or more hours exposure, at 26°F (–3°C) (Figure 2.4). After plants reach the three-leaf stage, they can again withstand lower tem-

Table 2.2. Considerations in selecting a planting date.

	ADVANTAGES	DISADVANTAGES
Spring	• Rainfall may be sufficient for crop emergence. (This is especially important for flood-irrigated alfalfa fields.) • Higher yield the seeding year than that from summer planting.	• Reduced yields in seeding year (compared to fall seeding). • Chance of damaging spring frosts. • Weed competition. (Summer weeds may persist beyond first cutting and contaminate subsequent cuttings.) • Irrigation may be difficult during summer of first year (due to limited root system).
Midsummer	• Low probability of killing frost. • Rapid uniform emergence. • Improved effectiveness of some broadleaf herbicides (such as 2,4-DB).	• Frequent light irrigations required; many irrigation systems are inadequate. • Income lost from rotation crop or shorter production season for alfalfa. • Competition from summer annual weeds.
Late summer	• Nearly full production the year after seeding. • Less weed competition: Many fall-germinating annual weeds are killed by winter frosts; surviving winter annual weeds will be removed in the first cutting. • Alfalfa root and crown development over fall and spring facilitate irrigation management the first year.	• Sprinkler irrigation needed for crop emergence. • Likelihood of frost or heaving injury if planted too late. • In higher-elevation areas climate may preclude harvesting grain early enough to allow for timely alfalfa seeding.

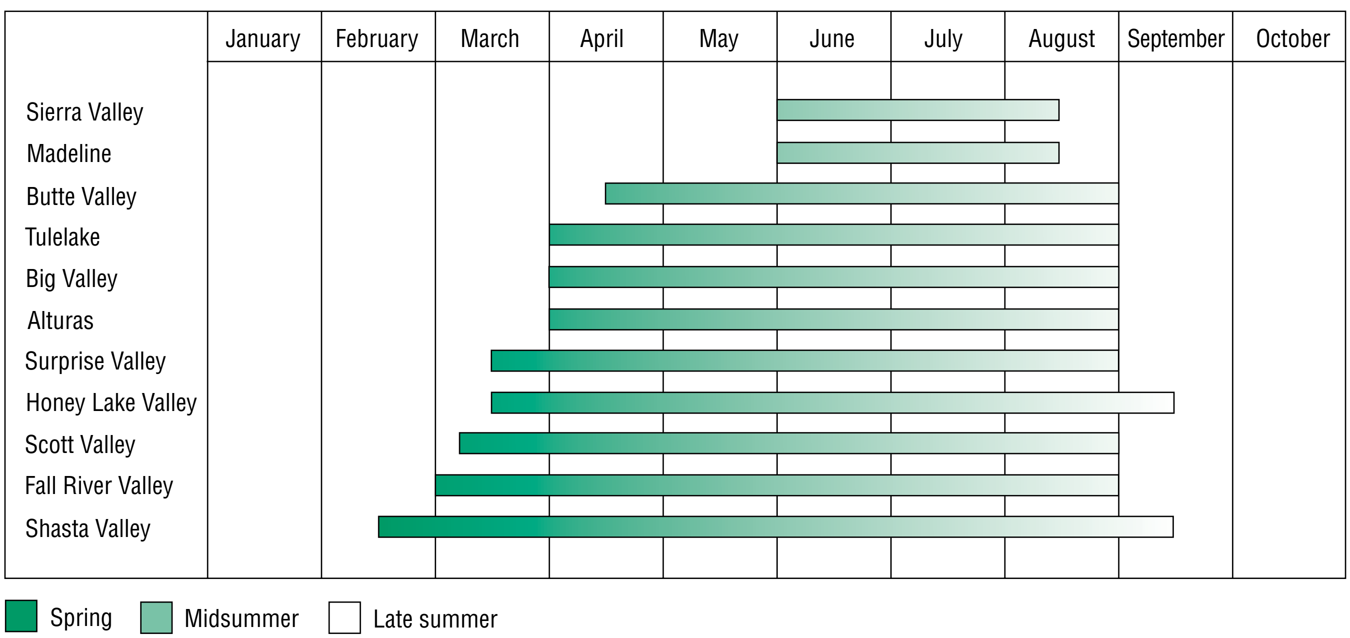

Figure 2.3. Alfalfa planting dates for areas in the Intermountain Region.

peratures. The main advantage of spring planting is that spring rains may provide sufficient moisture for crop emergence and reduce subsequent irrigation requirements. This is particularly advantageous in flood-irrigated fields. It is difficult to flood-irrigate during alfalfa establishment without causing soil erosion and washouts. (A washout is when irrigation water tears a seedling out of the soil.) The primary disadvantages of spring planting are competition from summer annual weeds and first-harvest yields lower than those from fall plantings.

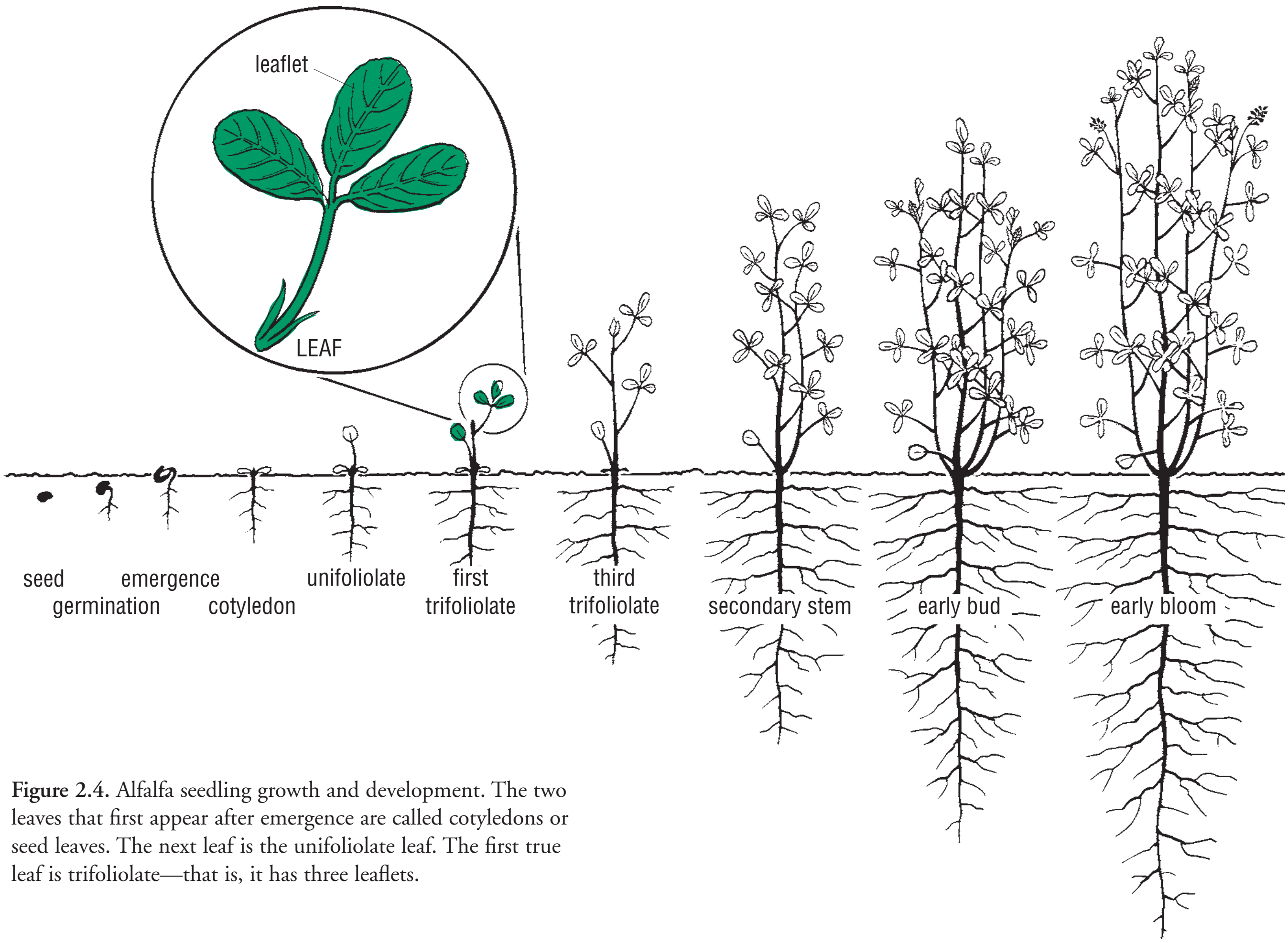

Figure 2.4. Alfalfa seedling growth and development. The two leaves that first appear after emergence are called cotyledons or seed leaves. The next leaf is the unifoliolate leaf. The first true leaf is trifoliolate—that is, it has three leaflets.

Midsummer

Summer plantings are the norm for elevations around 5,000 feet. Even in the lower valleys, planting during the warm summer months offers advantages. Warm temperatures promote rapid and uniform emergence and development of the young seedlings, and the danger of a killing frost is very low. The broadleaf herbicide 2,4-DB works well under these conditions. The major disadvantage of summer planting is that hot dry weather in midsummer can make maintaining adequate soil moisture extremely difficult, and make frequent irrigation necessary. An inadequate irrigation system or insufficient labor is an insurmountable obstacle to summer planting.

Fall

Fall planting in the Intermountain Region is more appropriately called late-summer planting. Depending on elevation, early to late August is the best time for a late-summer planting. Seeding at this time offers significant advantages. Moderate temperatures favor rapid emergence and development of alfalfa seedlings. Alfalfa plants seeded in late summer continue to grow and develop over the fall and spring. By mid-spring, alfalfa plants are well established and the result is a first-year yield similar to that from an older stand and much greater than that from a spring seeding. This is a major economic advantage. The yield advantage is not limited to the first production season; it continues for several yeears after planting.

Also, compared to spring-seeded alfalfa, alfalfa plants seeded in late summer have a much better-developed root system come summer. Consequently, it is easier to avoid moisture stress between irrigations during the hot summer months.

The risk of late-summer planting occurs when fields are planted too late (September or later in most areas). Planting should be completed at least 30 to 45 days before the first killing frost (approximately 26°F, or –3°C). Harsh winter conditions can take a toll on immature alfalfa seedlings. Freezing and ice formation causes soil heaving in fine-textured soils, uprooting and killing alfalfa seedlings that have not developed an adequate root system. Larger, more-established plants are better able to withstand these conditions.

The ability to seed alfalfa in late summer depends on the crop rotation sequence and weather. If alfalfa follows a late-harvested crop such as sugar beets or potatoes, a late summer planting is not possible. However, late-summer alfalfa plantings following a winter or spring cereal crop are feasible. Winter cereals or cereals grown for hay work best because they are harvested early enough to allow sufficient time to prepare fields for an August alfalfa planting. An August planting is also feasible following spring cereals produced for grain. Success depends on the harvest date of the grain, and the harvest date relates to the production area and weather conditions.

SEEDING STRATEGIES

Several strategies have been developed to seed alfalfa in the Intermountain Region. The best approach depends on the area, soil type, and planting date.

Tillage Prior to Seeding

The most common technique for both spring and fall plantings is to perform tillage and seedbed preparation operations just prior to planting. A technique that works well for spring plantings is to do primary tillage in the fall and final seedbed preparation in the spring. Soils are usually drier in fall than they are in spring, so ripping in the fall is more effective. An early spring planting date is possible because growers are not delayed waiting for spring soils to dry sufficiently to rip them.

Fall Tillage with Spring No-till Seeding

In spring, heavy soils are nearly impossible to prepare. An alternative in some areas is to prepare the land in fall and let winter rains and freezing create a clod-free surface (this has been done successfully in the Shasta Valley). Emerged weeds can be sprayed with Roundup (glyphosate) herbicide prior to seeding. The seedbed will generally be weed-free and the surface smooth and firm. In warmer areas growers use no-till methods to plant alfalfa in late February. These growers prefer no-till drilled seeding because tillage dries out the surface, removing needed moisture in the surface layer. This technique relies on soil moisture and spring rains for crop emergence and early seedling development. The field does not usually require irrigation until the alfalfa is a few inches tall and the threat of washouts from flood irrigation has diminished.

Stubble Seeding

Seeding into stubble is a practice used by many growers who have a crusting or wind erosion problem. It works well for late-summer seedings when there is insufficient time to cultivate the soil. Alfalfa seed is sown directly into the cereal stubble. Seedbed preparation, fertilizer application, and leveling all occur prior to cereal planting. After the grain crop is harvested, the straw is burned or it is cut, raked, and baled. For stubble seeding, oat hay may be preferable because its stubble is short—growers have no excess straw to remove. Also, volunteer grain is not usually a problem following an oat hay crop. But beware: If too much straw or stubble is left in the field, providing winter cover for meadow mice, a severe pest problem can develop (see chapter 10). When necessary, weeds can be controlled with a foliar herbicide prior to alfalfa emergence. A suitable seedbed is prepared by using a harrow or other tillage implement (such as a Rotera tiller) to loosen soil and allow seed incorporation. For stubble seeding, alfalfa seed can be broadcast or drilled.

FERTILIZER USE

Adequately fertile soil is fundamental to successful stand establishment. Soil fertility contributes to seedling vigor, which helps alfalfa compete with weeds. Analyze soil fertility prior to planting (see chapter 5). Phosphorus is commonly deficient and is particularly important when establishing alfalfa. If soil is deficient in phosphorus, apply a 1- to 2-year supply at planting. The fertilizer can be broadcast and then disced or harrowed. Banding phosphorus with or below the seed has worked well for drilled seedings. This method places the element where it is readily available to the alfalfa, not the weeds. Furthermore, banded fertilizer is less likely to be bound in soil reactions than is broadcast fertilizer.

> ***Plant roots grow in the presence of water, not in search of it.***

The merit of applying nitrogen to alfalfa has been debated for years. Although applying small amounts of nitrogen at planting may increase seedling growth and vigor, it is not economical in most cases. As a general guideline, when soil nitrate levels are greater than 15 parts per million (ppm) and conditions favor effective nodulation (soil pH of 6.2 to 7.5 and presence of sufficient *Rhizobium* bacteria), nitrogen application does not result in economical yield increases. However, a yield increase may be expected when conditions for nodulation are poor, when soil nitrate levels are below 15 ppm, or when organic matter content is below 1.5 percent. A response to nitrogen fertilizer is more likely when soil temperatures are less than 60ºF (16ºC) for several weeks after planting. Under these circumstances, a small amount (10 to 50 pounds per acre) of nitrogen fertilizer is beneficial. A greater amount inhibits nodulation and delays crop development. Growers must be aware that applying nitrogen fertilizer may promote weed growth. For this and other reasons, preplanting nitrogen applications should not exceed 20 pounds per acre.

IRRIGATION

Proper irrigation of a new seeding is essential to achieving a dense healthy stand. The soil must remain moist while alfalfa is germinating and during initial seedling development. Seedling alfalfa plants are not as resilient as established plants; seedlings should not be stressed, either with too much or too little water. Some growers let seedling alfalfa fields become dry, trying to force roots to grow deeper. This is not a recommended practice; plant roots grow in the presence of water, not in search of it. Plant roots will not grow in dry soil.

The irrigation requirements of a seedling field obviously depend on planting date. Rain may suffice for an early spring seeding, but seeding after March is risky without the ability to irrigate. Growers that have to irrigate a new seeding should apply approximately 1 inch of water per irrigation (a 3- to 4-hour set for most wheeline irrigation systems). Assuming a ¼ inch per day moisture loss due to soil evaporation and crop water use, sprinkle every 4 to 5 days (for detail on irrigation scheduling, see chapter 4). Do not overirrigate; damping-off diseases (chapter 9) that attack young seedlings are greatly enhanced by excessively moist conditions.

WEED CONTROL

The consequences of inadequate weed control in the seedling year can be devastating to the alfalfa stand and the profitability of alfalfa production. Weeds compete with alfalfa for light, water, and nutrients and can reduce the vigor of seedling alfalfa. In cases of severe competition, weeds can reduce alfalfa plant density to such a degree that the field has to be replanted. Some weeds can be toxic or unpalatable to animals and make the first cutting unsalable.

Controlling weeds in the seedling year can get the alfalfa off to a fast, healthy start and reduce weed pressure in subsequent years. Deal with perennial weeds several seasons before planting alfalfa. Proper weed control in previous crops can reduce weed problems in alfalfa. The topic of weed control in a new alfalfa seeding is covered at length in chapter 6.

COMPANION CROPS

Small grains, primarily oats, are sometimes planted with alfalfa as a companion crop (also called a nurse crop). The proported benefits of a companion crop are weed control, increased forage yields the first cutting of the seeding year, and wind and frost protection for tender alfalfa seedlings. However, the risk associated with companion crops is excessive plant competition, which can reduce alfalfa stand, vigor, and yield of subsequent alfalfa cuttings. Trials conducted several years ago in Butte Valley demonstrated that competition from a companion crop reduced alfalfa seedling root length by 3 to 4 inches. Alfalfa seedings are often stressed for lack of water during harvest of the companion crop. This reduces root growth and possibly the future productivity of the alfalfa stand.

The advisability of planting an oat companion crop depends on several factors, including planting date of the alfalfa, oat seeding rate, weed species present and their population level, cost of weed control, expected severity of wind or frost, and the hay market. If a companion crop is used, the key to success is managing the field to the advantage of the alfalfa rather than the companion crop. Oat seeding rates should not exceed 20 pounds per acre or excessive competition will occur. The field should be cut based on the maturity of the alfalfa and not the oats. However, if the companion crop is overtopping alfalfa seedlings and restricting light penetration, cut the field early; this will allow more sunlight to reach the alfalfa seedlings. The greatest damage from companion crops generally occurs when the grain crop lodges, or falls. Therefore, manage the field to avoid lodging: use a low oat-seeding rate, apply little or no nitrogen fertilizer, and choose short oat varieties that are not prone to lodging.

Cereals other than oats have been used as companion crops. Many newer varieties of wheat and barley have very large leaves that can cut off light to alfalfa seedlings. These varieties, therefore, are undesirable companion crops.

The best advice to most growers is, Do not use a companion crop. However, for cases where a companion crop is needed—where soil crusting is a problem or where blowing sand can cut off young seedlings, do not exceed a seeding rate of 20 pounds per acre. In such cases, minimize competition from the companion crop by seeding the cereal on a 12-inch row spacing perpendicular to prevailing winds. (The normal spacing would be 6 to 7 inches.) Another alternative is to use an herbicide such as Poast to control the companion crop when it is young, before it competes with the alfalfa. Whether a companion crop is used or not, remember that the primary goal when seeding alfalfa is to establish a long-lived productive stand of alfalfa. The short-term benefits of a companion crop can be nullified if the alfalfa stand and vigor suffer from excessive competition.

Benefits of a companion crop can be nullified if alfalfa stand and vigor suffer from excessive competition.

SEED INOCULATION

Nitrogen-fixing *Rhizobium* bacteria, which are found in alfalfa root nodules, usually supply the plant with nitrogen needed for growth. Existing populations of nitrogen-fixing bacteria ordinarily provide adequate nodulation in fields with a history of alfalfa production. However, there are rare fields with a history of alfalfa production that benefit from seed inoculation.

Inoculate soils without a recent history of alfalfa production. Commercial inoculum is available for seed treatment. Be sure to use fresh inoculant and do not expose it to hot, dry conditons prior to planting. If you are unsure of the history of a field, inoculum is cheap insurance.

FUNGICIDAL SEED COATINGS

There are years and field situations in which fungicide-treated seed would reduce stand loss during establishment, but these cases are believed to be rare. Seedling diseases are uncommon in the Intermountain Region.

At a given seeding rate in pounds per acre, approximately one-third fewer seeds are planted if the seeds are coated, due to the weight of the coating. Unless seedling diseases are known to be a problem, plant raw seed.

TIMING OF THE FIRST HARVEST

The last step in alfalfa stand establishment is deciding when to make the first cutting. Carbohydrates produced during photosynthesis are stored in roots. Stored carbohydrates provide the energy for regrowth after cutting. Premature cutting does not allow sufficient time for root reserves to accumulate, so it reduces alfalfa vigor and possibly the yield of subsequent cuttings. Alfalfa should be "established" prior to the first cutting. The appearance of bloom has been used as an indicator of whether the stand is established, but several factors can cause alfalfa to bloom prematurely. The number of stems per plant is a far better indicator of when to cut. Do not cut seedling alfalfa until it has developed at least three stems (Figure 2.4). Some experts recommend that the roots of alfalfa grown in sandy or sandy loam soil be at least 14 inches deep prior to the first harvest. Such roots are deep enough to avoid impedance from traffic-induced compaction layers. If you are forced to cut alfalfa prematurely, whether to remove weeds or for any other reason, lengthen the interval between the first and second cuttings. This will allow the young alfalfa plants sufficient time to recover and replenish depleted root reserves.

ADDITIONAL READING

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CHAPTER THREE

VARIETY SELECTION

Harry L. Carlson

Alfalfa growers in the Intermountain Region, like growers elsewhere, need to select alfalfa varieties based on yield and quality performance in their specific region. The varieties best suited for the high-elevation intermountain valleys of northeastern California are different from the varieties adapted to the warmer, longer-season production areas in the remainder of the state.

After choosing varieties with growth characteristics and pest and disease resistances suitable for your area, plant test strips to check their performance under specific field and management conditions. Time and money spent on selecting the most suitable variety will be rewarded with higher yields and a net increase in profits.

Harvesting alfalfa in variety trial, Tulelake, California.

YIELD

Economics force growers to be concerned about the yield potential of selected varieties. Many costs associated with crop production are fixed costs, such as those relating to stand establishment, land rent or ownership, and equipment ownership. The increased yield afforded by the selection of an improved variety spreads these costs over greater amounts of hay, which lowers the cost of production per ton of hay produced. Restated, it simply costs less per ton to produce high-yielding alfalfa, particularly if the increased yields are the result of a simple change to an improved variety.

STAND PERSISTENCE

Annual yields are important, but it is the yield of the crop over the total years of production, or life of the stand, that determines the actual profitability of the crop. The cost of alfalfa stand establishment is relatively fixed for a given farm operation. The effect of stand establishment costs on overall profitability depends largely on the number of years that the crop is in production. The longer the stand life, the greater the number of years in which to recover the cost of establishment. Generally, growers in the Intermountain Region would like to maintain stands for 5 years or more, with a stand life of 7 years being typical. Failure to meet this goal means that establishment costs will be spread over fewer growing seasons; the total cost of production per year will be higher.

Stand life refers to the need to maintain minimum average plant populations greater than five or six plants per square foot. Fields with stands below this level will have reduced yields (see chapter 15). Also, sparse stands usually produce thick-stemmed, "low-test" hay that may be quite weedy. With the high cost of producing and making hay, growers cannot afford to farm fields when poor stands result in low yields or low-quality hay.

The most important varietal factor in maintaining adequate stands in the Intermountain Region is winter hardiness. The intermountain area is subjected to months of subfreezing winter temperatures. To make things worse, these cold temperatures often occur without the benefit of an insulating blanket of snow. Accordingly, varieties without winter hardiness suffer winterkill and stands may be reduced to subeconomic levels after only one or two seasons. Of course, plant populations can be reduced by other factors, such as disease or cultural mismanagement; but if a variety is not sufficiently winter hardy, optimum management of other production factors will not prevent winter stand loss.

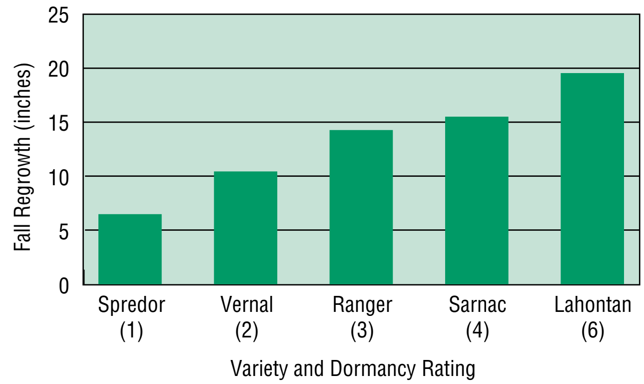


Figure 3.1. Observed fall regrowth of standard varieties for fall dormancy rankings. (Data were gathered in a 1986 variety trial, Tulelake, California.)

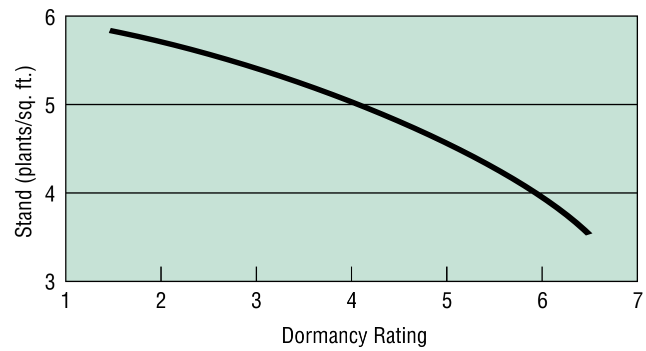


Figure 3.2. Fall dormant varieties are less susceptible to stand loss from winterkill. (Data were gathered in fifth-year stands in a variety trial planted in 1981, Tulelake, California.)

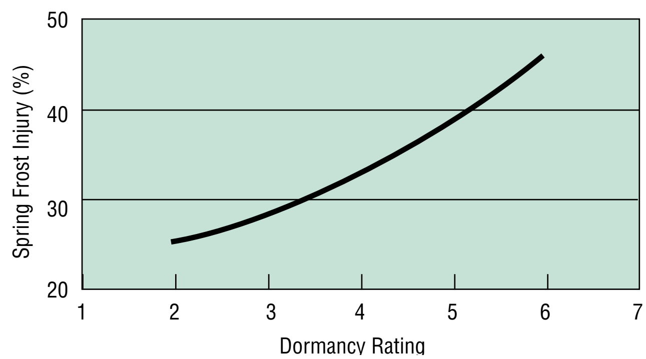


Figure 3.3. Spring frost injury is more likely with less-dormant varieties. (Data were gathered in a 1985 variety trial, Tulelake, California.)

FALL DORMANCY

A major component of winter hardiness is fall dormancy. *Dormancy* refers to a variety's tendency to cease growth in the fall as days shorten and temperatures drop. Dormant varieties begin growing again in the spring as soil temperatures warm. The fall dormancy of a variety can be classified based on industry standards for fall regrowth. On this scale, the dormant variety Vernal is rated as a 2, less dormant varieties similar to Ranger receive the rating of 3, and semidormant varieties similar to Saranac are grouped in class 4 (Table 3.1 and Figure 3.1).

Plants that are winter dormant are much less susceptible to cold temperatures and winterkill (Figure 3.2). Less-dormant varieties that begin growth early in the spring may be hit by early spring frosts that can damage both yield and quality of the first cutting (Figure 3.3; see color photo 3.1). In contrast, the yield of third or fourth alfalfa cuttings may be reduced in dormant varieties that go dormant early in the fall.

Thus, the selection of a variety with the proper dormancy is a compromise. Select varieties that are sufficiently dormant to assure winter survival and to prevent premature spring growth, but do not select those varieties that are so dormant that valuable growing days are lost in spring and fall. In studies conducted in Tulelake, California, the varieties that produced the highest yields with adequate winter survival tended to be in fall dormancy class 3 (Figure 3.4). In intermountain areas with warmer, longer growing seasons, dormancy class 4 varieties may be better performers. Dormancy class 2 varieties would perform better in

Table 3.1. Alfalfa varieties categorized by fall dormancy class, which are based on fall growth.

FALL DORMANCY CLASS	STANDARD VARIETY	EXAMPLE VARIETIES
1 (very dormant)	Norseman	Spredor 3
2 (dormant I)	Vernal	DK 122, Avalanche +Z
3 (dormant II)	Ranger	Blazer XL, Centurion
4 (moderately dormant I)	Saranac	Agressor, Webfoot MPR
5 (moderately dormant II)	DuPuits	Archer, Robust
6 (semidormant)	Lahontan	
7 (moderately nondormant)	Mesilla	
8 (nondormant)	Moapa 69	
9 (very nondormant)	CUF 101	

Table 3.2. General guidelines for varietal pest and disease resistance needed in the Intermountain Region.

PEST OR DISEASE	RESISTANCE CLASS
Bacterial wilt	Resistance (R)
Verticillium wilt	Resistance (R)
Fusarium wilt	High resistance (HR)
Southern anthracnose	Resistance (R)
Phytophthora root rot	Resistance (R)
Spotted alfalfa aphid	Susceptible (S)
Pea aphid	Resistance (R)
Blue alfalfa aphid	Moderate resistance (MR)
Stem nematode	Resistance (R)
Root-knot nematode	Resistance (R)

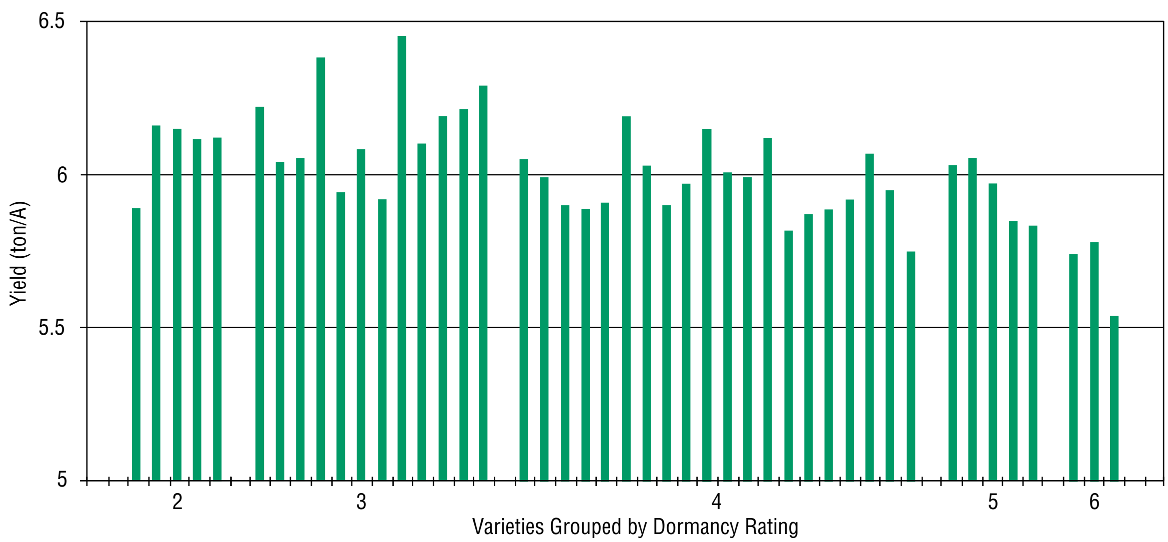


Figure 3.4. In Tulelake, California, varieties with a dormancy ranking of 3 provide the best average yield performance. Some varieties in dormancy rankings 2 and 4 perform well also. (Data reflect 6-year average yields from 45 varieties, 1981–86.)

intermountain areas with seasons that are cooler and shorter than those typical of the Tulelake region. These distinctions are not absolute. Growers should consider varieties with dormancy ratings one above and one below the rating generally recommended for your region.

PEST AND DISEASE RESISTANCE

The yield performance and stand life of an alfalfa variety are assumed to be related to the pest and disease resistance of the cultivar. Cultivar resistance may be less important in the Intermountain Region than in other areas, however. Many areas in the Intermountain Region are not plagued by several of the serious disease and pest problems that significantly limit alfalfa production in other regions. A variety with little pest or disease resistance may perform very well there. This does not mean that pest and disease resistance are not important—it only indicates that a review of yield results from one area may not show the whole picture.

In specific fields, varietal pest and disease resistance may be critical. For example, high resistance to Phytophthora root rot may not be needed in the very well drained soils common in areas such as Tulelake,

Table 3.3 Fall dormancy and pest resistance ratings for alfalfa varieties

		PEST RESISTANCE**									
	FALL DORMANCY*	BACTERIAL WILT	VERTICILLIUM WILT	FUSARIUM WILT	ANTHRACNOSE RACE 1	PHYTOPHTHORA ROOT ROT	SPOTTED ALFALFA APHID	PEA APHID	BLUE ALFALFA APHID	STEM NEMATODE	NORTHERN ROOT-KNOT NEMATODE
Spredor 3	1	HR	MR	HR	R	MR	S	MR	—	MR	—
5262	2	HR	LR	MR	—	R	R	R	—	MR	—
Agate	2	HR	—	HR	MR	R	—	—	—	—	—
Alfagraze	2	MR	—	R	MR	LR	—	R	—	R	—
Avalanche + Z	2	HR	HR	HR	HR	HR	—	R	—	MR	—
DK122	2	HR	R	R	HR	HR	MR	R	—	—	—
Pacesetter	2	HR	R	R	HR	HR	—	—	—	—	—
Sterling	2	HR	R	HR	HR	HR	R	R	—	—	—
Vernal	2	R	—	MR	—	—	—	—	—	—	MR
WL 252 HQ	2	HR	R	HR	HR	HR	MR	R	LR	R	—
120	3	HR	—	LR	LR	R	—	R	—	—	—
5246	3	HR	R	HR	HR	HR	R	R	—	MR	—
5396	3	R	R	R	HR	R	R	R	—	HR	MR
Achieva	3	R	R	HR	HR	HR	R	R	—	MR	—
Arrow	3	HR	R	HR	MR	HR	—	R	—	MR	—
Blazer XL	3	R	R	HR	HR	HR	HR	R	—	R	—
Centurion	3	HR	R	R	R	R	MR	R	—	—	—
Class	3	HR	R	R	HR	HR	R	R	—	MR	—
Columbo	3	R	HR	HR	R	R	R	HR	—	MR	MR
Guardian	3	HR	HR	HR	HR	HR	—	HR	—	R	R
Innovato+Z	3	HR	HR	HR	HR	HR	MR	R	S	R	—
MultiKing 1	3	HR	R	HR	R	R	MR	MR	—	MR	—
Oneida VR	3	R	HR	HR	MR	MR	—	—	—	—	—
Treasure	3	HR	R	HR	HR	R	MR	R	—	MR	—
Ultra	3	R	R	HR	HR	R	LR	R	—	R	—
Victory	3	HR	R	HR	HR	MR	—	—	—	—	—
Webfoot	3	R	—	MR	—	R	—	—	—	—	—
5364	4	R	MR	R	MR	MR	HR	HR	—	R	—
5472	4	HR	MR	HR	MR	MR	R	HR	—	R	—
Affinity +Z	4	HR	HR	HR	HR	HR	—	R	—	R	—
Agressor	4	HR	R	HR	HR	HR	MR	HR	MR	MR	—
Allstar	4	HR	R	HR	HR	HR	LR	R	—	R	MR
Apollo Supreme	4	HR	R	HR	HR	R	—	HR	—	—	—
Aspen	4	HR	R	HR	HR	HR	—	HR	—	R	R
Cimarron VR	4	HR	R	HR	HR	R	HR	HR	MR	R	—
Crystal	4	HR	R	HR	R	HR	LR	R	MR	MR	—
DK133	4	HR	R	HR	HR	HR	R	R	—	MR	—
Extend	4	HR	R	R	HR	HR	—	HR	—	R	—
Fortress	4	R	R	R	—	HR	HR	R	—	HR	—
Laser	4	HR	R	HR	R	HR	MR	—	MR	—	MR
Magnum III	4	R	MR	R	MR	R	MR	R	MR	MR	—
MagnumIV	4	HR	R	HR	R	HR	MR	—	MR	R	MR
Webfoot MPR	4	HR	HR	HR	HR	HR	—	R	—	—	—
WL 322 HQ	4	HR	R	HR	MR	R	HR	HR	R	LR	LR
WL 323	4	HR	R	HR	HR	HR	MR	R	—	HR	—
Archer	5	MR	MR	HR	R	R	HR	HR	R	R	R
Robust	5	R	R	HR	R	R	R	R	MR	R	MR
Lahontan	6	MR	—	LR	—	LR	MR	LR	—	R	—

***Fall Dormancy Ratings**
1 = Very dormant
2 = Dormant I
3 = Dormant II
4 = Moderately dormant I
5 = Moderately dormant II
6 = Semidormant

**** Pest-Resistance Ratings**
S = Susceptible
LR = Low Resistance
MR = Moderate Resistance
R = Resistance
HR = High Resistance

Source: Association of Official

but high resistance to this disease is clearly required in wet, poorly drained fields in other intermountain production areas. Likewise, stem nematode resistance may not be important in the region as a whole, but it is critical in fields that have stem nematode infestations.

Although the minimum resistance levels required will vary for different fields and production areas, the guidelines in Table 3.2 are helpful when considering resistance needs for a field about which little is known. As more is learned about the problems in a specific field or area, the grower can select varieties with more or less resistance than suggested; the important thing is to counter a problem with a variety with resistance to it. Pest and disease resistances that may be critical in specific fields include resistance to bacterial wilt, Phytophthora root rot, Fusarium wilt, anthracnose, pea aphid, stem nematode, and root knot nematode.

The serious crop-threatening disease Verticillium wilt has recently been identified in a few isolated fields in the Intermountain Region. Because of the potential seriousness of Verticillium wilt, intermountain producers may wish to select varieties with resistance to this disease.

For information on relative resistance of varieties, refer to Table 3.3 or obtain a current copy of *Fall Dormancy and Pest Resistance Ratings for Alfalfa Varieties* produced by the Certified Seed Council (Davis, California). Note that resistance in a variety is not absolute. Alfalfa varieties have diverse genetic backgrounds, so a portion of the plants of resistant or even highly resistant varieties may be susceptible to the rated pest or disease. Table 9.1 (chapter 9) explains the resistance rating system and describes the percentage of resistant plants in each rating category.

HAY QUALITY

Quality is critical to the sale price of alfalfa hay. Growers need to match the quality of the hay produced with the demands of the market in which they choose to sell. For example, dairy hay demands a premium price but must also meet exacting quality test standards. Ideally, growers should select varieties to meet such criteria. Unfortunately, it is not that simple. Many factors other than variety selection affect hay quality. Factors such as stand density and cutting schedule have a great effect on quality. As mentioned, hay quality will decline as plant stands thin. Generally, alfalfa cut at an early stage of maturity is of higher quality than more mature alfalfa (see chapter 11). Management of irrigation, fertilizer, weeds, insects, and disease can have major impacts on hay quality. Because of the confounding effects of all these factors, measuring small differences in quality among different varieties is extremely difficult. One variety may produce the highest-quality hay under one set of conditions, but it may not perform as well as other varieties when grown under different management.

Never use yield results from a single cutting or even a single year to make a variety selection

This is not to say that quality differences among varieties do not exist—only that such differences are generally small and difficult to measure. Accordingly, very little unbiased information is currently available to help growers distinguish one variety from another on the basis of quality. Improved hay quality is a major emphasis in the current breeding programs of major alfalfa seed companies, and new varieties with measurable improvement in quality characteristics may be forthcoming in the near future. For now, the best available recommendations in regard to quality are to maintain healthy plant stands and to match the cultural and cutting management of a field to the growth characteristics of the variety selected (see chapter 11).

SOURCES OF INFORMATION

This chapter has already mentioned the information available from the Certified Alfalfa Seed Council. In addition, seed company representatives are a ready source of information about specific alfalfa varieties. Do not hesitate to ask pointed questions about variety dormancy groups, pest and disease ratings, and relative yield and quality performance in your area. The University of California (UC) is another source of information. For years UC has conducted large alfalfa variety trials at the Intermountain Research and Extension Center in Tulelake, and UC Farm Advisors have conducted many variety tests in the major alfalfa-producing valleys throughout the intermountain area. Farm Advisors can provide growers and seed handlers with the performance results from these studies.

INTERPRETING YIELD TRIAL RESULTS

Performance information can be gleaned from reports of university-conducted research, provided that the tests were conducted under representative climatic conditions and management. Remember, the closer the test was to home, the greater the likelihood that research information will apply to a specific set of local conditions. Also, where possible, select varieties that have been in trials for multiple years at more than one location. A variety will be exposed to a range of cutting and weather conditions in different fields and over the life of the stand. The greater the number of years and locations tested, the greater the likelihood that the test data will reflect the various conditions a variety may encounter. Never use yield results from a single cutting or even a single year to make a variety selection.

In reviewing test results, avoid the temptation to automatically select the top-yielding variety. Typically, varieties yielding near the top of a given trial have measured yields only a small fraction of a ton less than those of the top-yielding variety. Such small differences may be the result of very small errors in the experimental technique. It is prudent to look at all the varieties in the top-yielding group and make final variety selections based upon factors in addition to yield. Such factors include relative pest and disease resistance, quality, experience with or information about the varieties, and seed price.

Once a new variety is selected, consider planting small test strips, 1 to 5 acres in size, of the new variety to check performance under your specific field and management conditions. Do not plant test strips on the edge of a field or in isolated or poor areas of the field. In a fair test the new variety receives management typical for the field. Count bales from the test strips to estimate yield and collect separate samples from the bales to determine quality.

VARIETIES, BRANDS, AND BLENDS

This chapter refers primarily to alfalfa varieties recognized by the Association of Official Seed Certifying Agencies. Alfalfa seed can also be purchased as trade name brands or as blends of various brands and varieties. Like recognized varieties, some blends and brands perform well and some perform poorly. The dilemma in dealing with blends and brands is that you cannot be sure that the material tested and discussed in reports of experimental trials is the same as will be sold under that specific name in the future. The varieties that make up a blend often vary from year to year, depending on seed availability. When you purchase a blend or brand because you used it successfully in the past, make sure that what you buy actually has the same components as the combination you bought before.

SEED PRICE

Paying extra money for seed of a variety that does not outperform seed of a less expensive cultivar is certainly foolish. On the other hand, it takes only a small difference in yield or stand life to justify a large difference in seed cost. For example, a grower who pays an extra dollar per pound for seed of a new variety that provides as little as a 5 percent improvement in yield (about 0.33 ton per acre per year, for a 6-year period) is money ahead. At planting the seed costs an extra $20 per acre, but over the life of the stand it provides an average increase in net profits of $200 per acre. As a rule, money used to purchase high-quality, certified seed of a locally adapted variety is money well spent.

ADDITIONAL READING

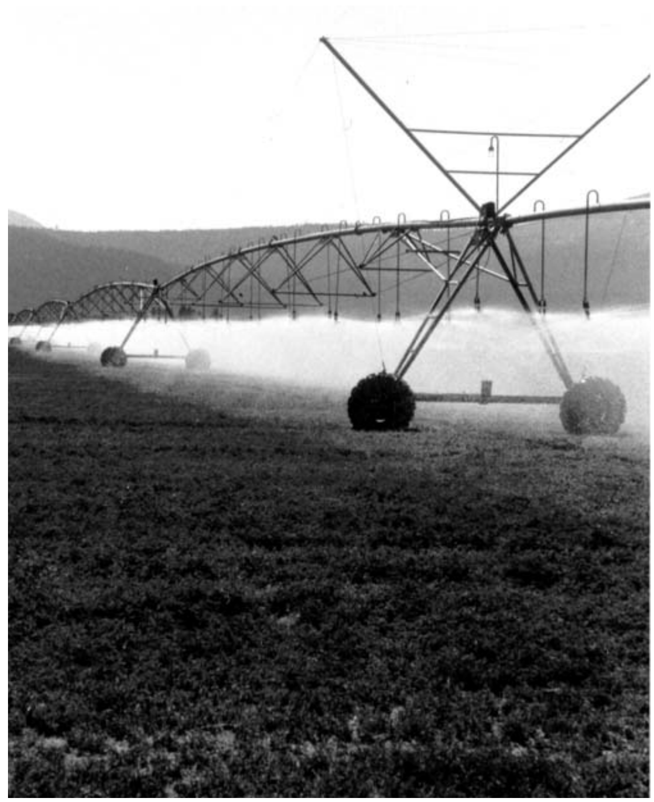
Certified Alfalfa Seed Council. 1994. *Fall dormancy and pest resistance ratings for alfalfa varieties.* Davis, CA: 1994/95 edition.

Hill, R. R., Jr., J. S. Shenk, and R. F. Barnes. 1988. Breeding for yield and quality. In A. A. Hanson, D. K. Barnes, and R. R. Hill, Jr. (eds.), *Alfalfa and alfalfa improvement,* 809–25. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. Number 29.

CHAPTER FOUR

IRRIGATION

Steve B. Orloff, Harry L. Carlson, and Blaine R. Hanson



The Intermountain Region has a high-desert climate where irrigation must provide the majority of water needed for alfalfa growth. Improper irrigation management limits alfalfa yields in the Intermountain Region more often and to a greater extent than does any other aspect of alfalfa production. The return from other inputs (i.e., variety improvement, fertilizer, and pest control) will be significantly reduced or eliminated if a lack of water limits crop development. Therefore, properly applied and timed irrigations are critical for maximum yield and profit.

Figure 4.1 shows the typical alfalfa yield response to applied irrigation in the Intermountain Region. As irrigation increases, so do alfalfa yields—but only to the point where crop water needs have been met. Applying water over and above crop requirements does not improve yield and only adds to the cost of production. What is more, excess water may increase pest and disease problems and shorten alfalfa stand life.

The actual shape of the yield response curve varies from location to location and from year to year. The minimum yield without irrigation, the optimum irrigation level, and the maximum potential yield vary based on soil type, rainfall, and seasonal temperatures. Still, most alfalfa grown in the region follows the trend illustrated in Figure 4.1.

Proper irrigation management leads to increased yields, improved stand health, and a reduction in unnecessary water use. This chapter will discuss the basics of alfalfa irrigation scheduling and water application techniques. Sound irrigation practices are based on an understanding of how water is stored in the soil, crop water requirements, and irrigation system design and operation.

WATER STORAGE

Soil is the storage reservoir from which plants extract water (Figure 4.2). If too much water is applied, the storage reservoir will overflow and water will run off or percolate below the root zone of the crop. If the storage reservoir gets too low, plants will be stressed and yield reduced. The key to irrigation management is to keep the soil-water reservoir full enough to avoid plant stress but not overfill the reservoir.

Soil type determines the capacity of the soil reservoir. Soil is composed of soil particles of varying sizes,

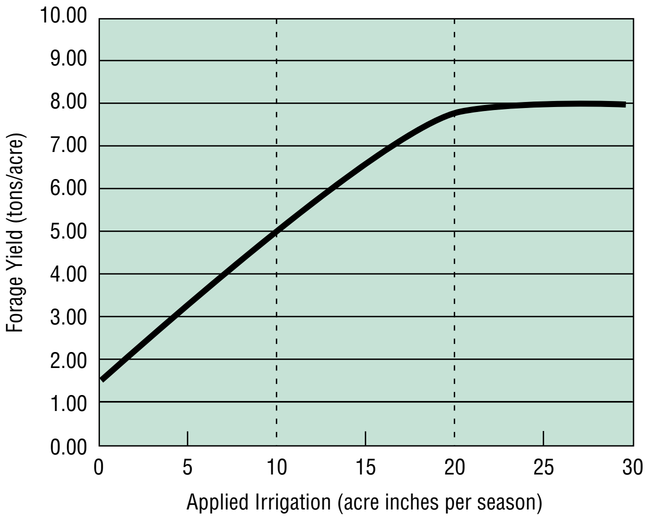


Figure 4.1. Typical yield response of alfalfa to applied irrigation in the Intermountain Region.

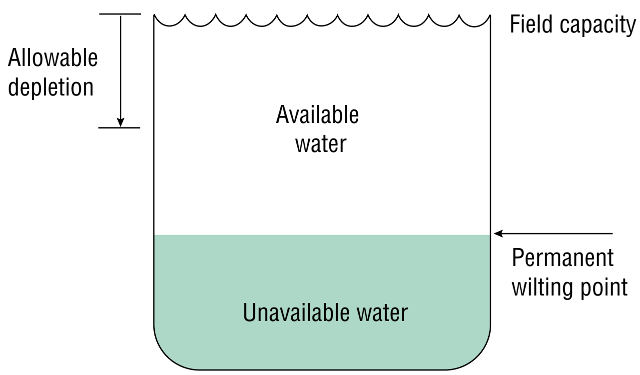


Figure 4.2. Think of the soil-water reservoir as a storage tank. Only a portion of the water in the tank is available to plants. To avoid yield reductions, keep the storage tank filled to a level between field capacity and the allowable soil depletion level.

organic matter, and voids, or pore spaces. Water occupies some of the pore spaces and is held as a film around soil particles. The more pore spaces, the greater the water-holding capacity. Sandy soils (coarse-textured soils) have large pores, but fewer total pores than clay (fine-textured) soils. Therefore, the water-holding capacity of sandy soils is far less than that of clay soils.

Available Water

After an irrigation or heavy rainfall, water fills the pore spaces; the soil is saturated. Under the influence of gravity, water drains from the larger pore spaces and gradually moves deeper into the soil profile. Downward movement of water slows considerably within 1 to 3 days after irrigation. The water that remains in the soil after this initial drainage is considered stored. When the soil has stored all the water it is capable of holding, the soil profile is full, or at field capacity.

Not all the water held in soil is available to plants. A portion is held so tightly by soil particles that it is unavailable. The amount of water plants can extract from the soil is called available water. If plants extract all the available water, the soil dries to the permanent wilting point. When this happens, plants wilt and die. Table 4.1 shows the available water content for different soil types. Note that the available water content of coarse sand is very small (less than 1 inch available water per foot of soil) compared to that of the clay soils (which have more than 2 inches available water per foot of soil). Table 4.1 cites values for general soil types. To find values for your soils consult Soil Surveys available from the Natural Resources Conservation Service, or study University of California (UC) Leaflet 21463, *Water-Holding Characteristics of California Soils.*

Water Storage Capacity

To determine the total water storage capacity of a soil, a grower must consider the rooting depth of the crop. Although alfalfa roots may penetrate as deep as 12 feet in some soils, the effective rooting depth for irrigation purposes is generally assumed to be 4 feet. The assumption is based on the fact that most of the water is extracted from the upper portion of the root system (Figure 4.3). Approximately 70 percent of the water is extracted by the upper half of the root system. To calculate the total storage capacity of the soil, multiply the available water content of the soil in inches per foot of soil by the rooting depth of the crop. For example, the calculation to determine the available water storage capacity of a sandy loam soil follows.

1.5	in. available water/ft.
x 4	ft. of rooting depth
6	in. total storage capacity

If you are calculating the water storage capacity of a field of young alfalfa or a field with a restricted root zone, dig a hole to see how deep the roots actually go. If you used the standard 4-foot rooting depth in your calculation, the result will be inaccurate.

Table 4.1. Estimates of available water content and allowable depletion for different soil types.

SOIL TYPE	AVAILABLE WATER (IN./FT.)	ALLOWABLE DEPLETION (IN./FT.)	4 FT ROOT ZONE[1] AVAILABLE WATER (IN.)	4 FT ROOT ZONE[1] ALLOWABLE DEPLETION (IN.)
Coarse sand	0.5	0.25	2.0	1.0
Fine sand, loamy sand	1.0	0.50	4.0	2.0
Sandy loam	1.5	0.75	6.0	3.0
Fine sandy loam, loam, silt loam	2.0	1.00	8.0	4.0
Clay-loam, silty clay	2.2	1.10	8.8	4.4
Clay	2.3	1.15	9.2	4.6
Organic clay loams	4.0	2.00	16.0	8.0

1. A 4-foot root zone is a typical effective rooting depth for alfalfa.

Allowable Depletion

As soil dries, soil particles hold stored water more tightly. Extracting water becomes increasingly difficult for plants. Extraction may become so difficult that plants cannot meet their water needs. If this occurs, growth slows and yields decline. The amount of water loss that can occur before water extraction becomes too difficult is termed the allowable depletion (Table 4.1). For alfalfa, allowable depletion is 50 percent. To avoid yield reductions, irrigate the field before 50 percent of the available water has been depleted. Keep in mind, however, that 50 percent allowable depletion is a maximum value. Fields can be irrigated before 50 percent of the available water has been depleted without reducing yield.

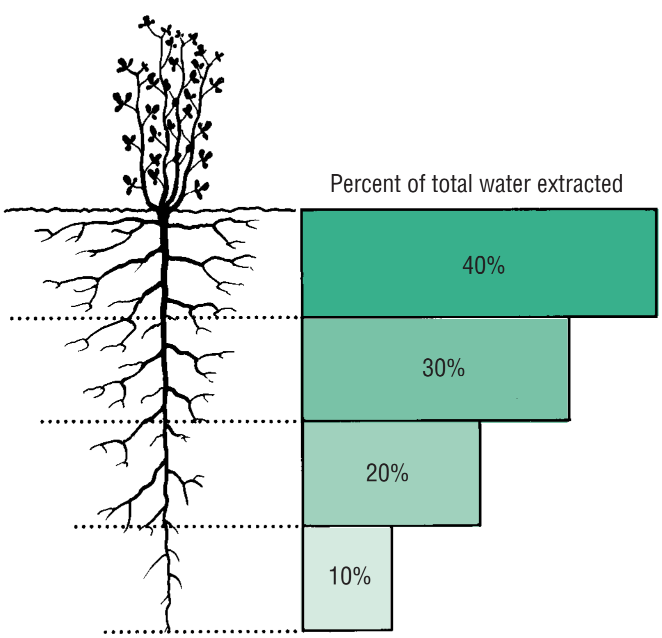


Figure 4.3. Typical water extraction pattern of alfalfa roots.

As you can see, an understanding of soil properties allows you to answer the two questions paramount to irrigation: When to irrigate? and How much to apply? Irrigate the field when 50 percent or less of the available water in the soil has been depleted. The amount of water to apply is the amount required to fill the soil reservoir to field capacity.

IRRIGATION SCHEDULING

Two principle methods are used to schedule irrigations in alfalfa fields. One method relies on soil-based measurements; the other is called the water budget method; and it involves weather monitoring. Both methods can be equally effective. The best approach, however, is to use both. Throughout the season, verify recommendations based on the water budget method by using soil-based measurements.

The Soil Moisture Method

Measuring soil moisture

The moisture status of soil can be monitored in various ways. Each of the moisture measurement techniques described below can help to schedule irrigations.

THE LOOK-AND-FEEL METHOD Enough experience with a given soil type allows a grower to estimate soil moisture conditions by simply feeling the texture and dampness of a soil sample. For example, samples from clay or clay-loam soils that can be made into a firm round ball with light hand pressure are considered to be adequately moist, but samples that crumble into powder when crushed in hand are considered to be too dry. The look-and-feel method works well for many experienced growers, but it is fairly imprecise. Its major disadvantages are that proper feel and texture vary among soil types and the ability to schedule irrigations based on feel alone requires skill and years of experience. The major advantages of this method are that it is quick and samples can be easily taken from many areas of the field. The ability to check fields often is important because the look-and-feel method does not indicate when the soil is becoming too dry. In other words, some water stress might occur before the look-and-feel method indicated the need to irrigate.

Improper irrigation . . . limits alfalfa yields . . . more often and to a greater extent than any other aspect of alfalfa production.

TENSIOMETERS Soil moisture tensiometers measure how strongly soil particles hold water. Wet soil holds water more loosely than dry soil.

A tensiometer is usually a 1-inch tube made of plastic. It is filled with water and sealed on the top with a mounted vacuum gauge. On the bottom, the tube is fitted with a porous ceramic tip. The tube is installed in soil, with the tip at the desired monitoring depth. As soil dries, water moves out of the tube, through the porous tip, and into the drying soil. The movement out of the tube creates a suction (negative pressure) that the gauge measures. The drier the soil, the greater the negative pressure measured on the gauge.

Researchers have determined the allowable soil depletion, in terms of tensiometer pressure readings, for many crops. Yield loss does not occur with alfalfa until negative pressures rise above 70 to 80 centibars—the pressure depends on the soil type. Plant stress occurs at lower tension readings in sandy soil than in heavy clay soil.

Reading a tensiometer is quick and convenient. By placing several tensiometers at different depths, you can quickly determine soil moistures at various locations in the root zone. The major advantage of tensiometers is that pressure readings can be correlated with plant yield responses.

The biggest disadvantage of tensiometers is that they need to be permanently installed. In some installations the gauge and top portion of the tensiometer is above ground. This makes haying difficult and haying equipment often damages the meters. However, more elaborate installations can be made that place the whole instrument below ground. Frequent replacement is expensive because of the cost of parts and labor.

Tensiometers must be properly installed to work correctly. Take extra care to seat the instrument's tip into the soil and to avoid gaps between the tube and soil that allow irrigation water to run down the side of the tube. Tensiometers also require frequent servicing to replace the water lost from the tube. They must be removed in the winter to prevent damage from freezing.

MOISTURE BLOCKS Although many models of moisture blocks are available, they all do the same thing. They electronically monitor the relative moisture content of a buried ceramic or gypsum block. As the soil dries, the relative moisture content of the buried block also declines. Some models measure the moisture content of the buried block by measuring the resistance between internal electrodes in the block; others measure heat dissipation between a heat source and a thermistor. Regardless of how the block works, meters are available that read in centibars, and the readings are approximately equivalent to those from a tensiometer: Allowable depletion occurs between 70 and 80 centibars, depending on soil type.

Like tensiometers, moisture blocks are easy to read at any time. They can be installed at several depths at a given monitoring site, and the readings correlate well with plant moisture needs. In addition, the blocks may be fitted with long underground wires that lead to a central reading station. Such a configuration greatly minimizes the risk of equipment damage to the block, and it certainly makes reading the blocks more convenient.

Disadvantages of the blocks are the high purchase cost, the care and time needed to install the blocks in the soil, and the problem of tearing out wire leads if the wires are not set underground or if reading stations are not well placed. With moisture-sensitive crops such as many vegetables, soil moisture blocks have the additional disadvantage of not being as sensitive as tensiometers under high soil moisture conditions. Fortunately, deep rooted alfalfa can tolerate lower soil moisture readings so the drier operational range of moisture blocks is adequate for irrigation scheduling in alfalfa.

NEUTRON PROBES The most technologically advanced method of measuring soil-water content is the neutron probe. This instrument contains a radioactive source and measures soil-water content by emitting fast neutrons into the soil and then measuring the return of slow neutrons back to the instrument. The number of neutrons returned is directly proportional to the number of hydrogen atoms the initial emission encountered. Most of the hydrogen atoms in the soil are components of water, so the number of returning neutrons reflects water content.

Because of cost, technical complexity, and health and safety regulations regarding the use of radioactive material, leave neutron probes to professional irrigation consultants who have the training and permits required to use the instrument.

Using soil moisture data

The best way to apply soil-moisture measurements to irrigation scheduling is to plot the measurements on a graph. The plotted data present a picture of how fast the soil is drying (Figure 4.4). For example, following a full irrigation that completely fills the soil profile, the tensiometer reading is low (point A in Figure 4.4). As alfalfa grows, it draws on the soil-water and the tensiometer readings begin to rise. After a few points have been plotted, you can estimate approximately how many days it will take for the soil to dry to the allowable depletion (80 centibars in this example). By day 10, in this example, three points have been plotted, so you can estimate that the soil will be dry enough to warrant irrigation on about day 20. The next reading, on day 14, confirms this estimate; water is applied on day 20. By that time the soil had indeed dried to the point of allowable depletion and irrigation was necessary. The graph indicates that the irrigation did not completely refill the soil profile—that is, on the day following irrigation, the tensiometer dropped to only about 40 centibars (point C). As explained earlier, the amount of water to apply in a given irrigation is determined by the soil type and the percentage depletion. The soil in this example is a fine sandy loam, so the allowable depletion is about 4 inches (1 in. x 4 ft of rooting depth). The irrigation applied at point B was less than 4 inches, so another irrigation was needed 10 days later. The second irrigation was a 4-inch irrigation, which filled the soil profile and returned the tensiometer reading to near 0 (point D).

In scheduling irrigations or in monitoring irrigation effectiveness, it is important to sample soil moisture at more than one depth. In the case of a mature alfalfa crop, place tensiometers or moisture blocks at 18 inches and 36 inches in the soil. Use readings taken at 18 inches to schedule irrigations; use the readings at 36 inches to determine if the crop is using deep water and if irrigations are completely filling the soil profile.

The Water Budget Method

UNDERSTANDING THE WATER BUDGET CONCEPT As the term budget implies, the water budget method involves tracking additions and losses

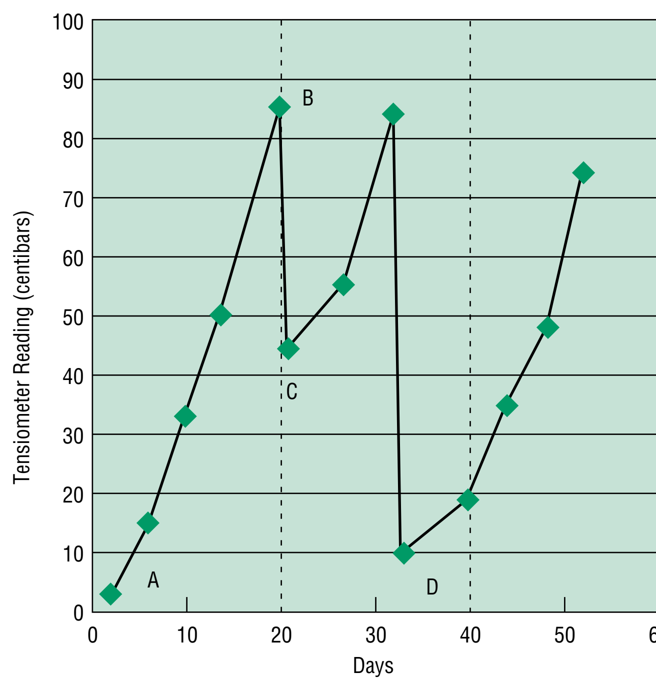


Figure 4.4. Plot of tensiometer readings following irrigation and drying cycles. A = initial low tensiometer reading following a full irrigation; B = reading indicating high pressure following several days of crop water use, just prior to an irrigation; C = reading after partial irrigation that did not fill the soil profile; D = reading after a full irrigation.

and balancing them. The losses are due to crop water use and inefficiencies in the irrigation system. The additions are due to irrigation and rainfall. The objective of the water budget method is to maintain soil moisture near the optimum level by keeping track of crop water use and then irrigating to replace the water used. Knowledge of crop water use is essential to using the water budget approach.

Crop water use is also called evapotranspiration (ET). The term *evapotranspiration* refers to the combined loss of water through evaporation from the soil and from water taken up and evaporated from the plant (transpiration). The rate at which plants use water is determined by the growth stage of the plant and by weather. Small plants use less water than large plants, for example, and all plants use more water when it is hot than when it is cool. Plants use more water on sunny days than cloudy days, and on days with high winds. For these reasons, plants use much less water in the spring and fall than during the long hot days in the middle of the summer. Figure 4.5 shows how daily water use of alfalfa near Tulelake, California, fluctuates throughout the growing season.

Over the years, irrigation scientists have quantified the effects of weather on plant water use. By using weather data you can predict with reasonable accuracy the water use of alfalfa in a specific region. The data needed include measurements of relative humidity, wind velocity, air temperature, and light intensity. Irrigation science has progressed to a point where such predictions are sufficiently accurate to be used for irrigation scheduling.

Crop water use values for irrigation scheduling may be obtained from several sources. Some local newspapers publish current values. Reference ET values for Tulelake, McArthur, and Alturas are calculated daily by the California Department of Water Resources (DWR) and can be obtained through DWR's California Irrigation Management Information System (CIMIS). You can use these ET values for other locations in the Intermountain Region by selecting the location with weather conditions most similar to those

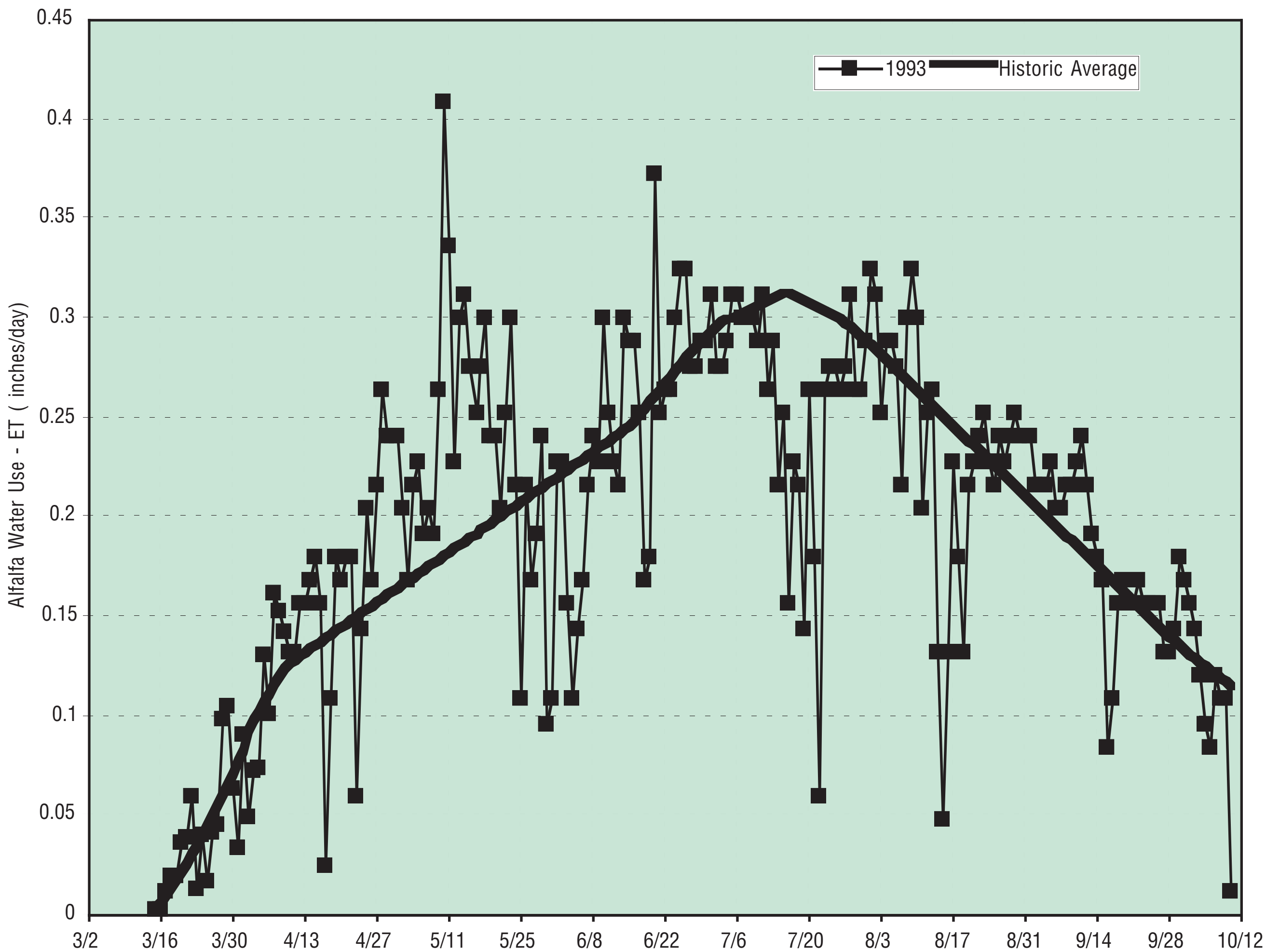


Figure 4.5. Comparison of daily water use by alfalfa: 1993 season and long-term average.

in your area. The reference values are based on pasture use, however. You must modify them to estimate alfalfa water use before using the values for irrigation scheduling. UC Farm Advisors can assist you with the conversion. In most situations, historical long-term averages of water use by alfalfa suffice for irrigation-scheduling purposes. Table 4.2 shows average long-term water use values for Tulelake. Adjust long-term averages to reflect current weather conditions, since weather can vary significantly from year to year and there is no such thing as an "average" year. For example, contrast the daily water use shown in Figure 4.5 with the long-term average daily use.

When to Irrigate

At the start of the production season, the soil profile is filled with water from rainfall or irrigation. From that point on, the grower tracks daily crop water use and keeps a running total of it. Once total crop water use, or total soil water depletion, equals or approaches the allowable depletion, the field should be irrigated (Figure 4.6). After irrigating and refilling the soil-water reservoir, daily crop water use is again calculated and added to the total water use to date. Another irrigation is scheduled when soil-water depletion since the last irrigation approaches the allowable depletion. Figure 4.7 summarizes the steps of the water budget method.

Water requirements of alfalfa are based on weather conditions and do not change because of soil type. Many believe that alfalfa grown on sandy soil needs more water than that grown on another type of soil. The fact is that alfalfa grown on sandy soil does not need more total water; it does, however, need irrigation more frequently and at lower volume (for a shorter set time or with smaller nozzles). This is so because sandy soil has less water storage capacity than do other soil types. Table 4.3 shows minimum recommended irrigation frequencies for different soil types in the Intermountain Region. The recommendations are based on historical data on crop-water use. Looking at Table 4.3, compare the irrigation frequency for a sandy soil to that for a clay soil. During July for example, a

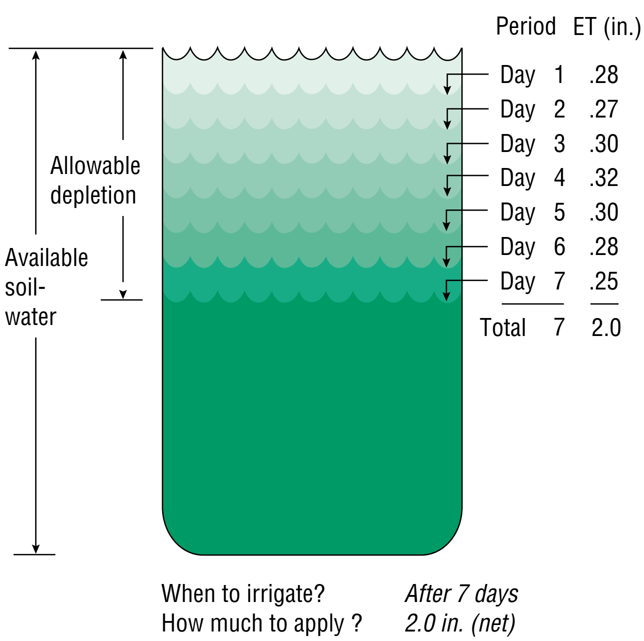


Figure 4.6. The water budget method. Daily ET is accumulated until the allowable depletion is reached. The field is then irrigated to refill the soil-water reservoir.

Table 4.2. Average weekly and daily water use by alfalfa in the Tulelake Basin.[1]

WEEK BEGINNING (MO. AND DAY)	WEEKLY TOTAL (IN.)	DAILY AVERAGE (IN.)
3/15	0.10	0.01
3/22	0.32	0.05
3/29	0.59	0.08
4/5	0.83	0.12
4/12	0.95	0.14
4/19	1.04	0.15
4/26	1.13	0.16
5/3	1.22	0.17
5/10	1.30	0.19
5/17	1.39	0.20
5/24	1.48	0.21
5/31	1.57	0.22
6/7	1.66	0.24
6/14	1.76	0.25
6/21	1.91	0.27
6/28	2.05	0.29
7/5	2.13	0.30
7/12	2.18	0.31
7/19	2.14	0.30
7/26	2.05	0.29
8/2	1.93	0.28
8/9	1.81	0.26
8/16	1.69	0.24
8/23	1.56	0.22
8/30	1.44	0.21
9/6	1.33	0.19
9/13	1.19	0.17
9/20	1.07	0.15
9/27	0.95	0.14
10/4	0.85	0.12

1. Based on long-term average weather data

Table 4.3. Recommended irrigation frequencies for alfalfa produced on different soil types in the Intermountain Region. (see notes below.)

		Irrigation frequency[1] (days between irrigations)					
Soil type	Irrigation amount[2]	Apr.	May	June	July	Aug.	Sept.
Coarse sand	1.00	7	5	4	3	4	6
Fine sand, loamy sand	2.00	14	10	8	7	8	12
Sandy loam	3.00	21	15	13	10	12	18
Fine sandy loam, loam, silt loam	4.00	29	20	17	13	15	24
Clay-loam, silty clay	4.40	–	22	18	15	17	26
Clay	4.60	–	23	19	15	18	27
Organic clay loams	8.00	–	–	33	27	31	–
Daily crop water use (in.)		**.14**	**.20**	**.24**	**.30**	**.26**	**.17**

1. Irrigation frequency is calculated by dividing the irrigation amount, or allowable depletion, by daily crop water use.
2. Irrigation amount is the net amount of water to apply (the allowable depletion for that soil type from Table 4.1 multiplied by 4 ft of rooting depth). The actual amount that should be applied is the net amount in the table divided by the irrigation efficiency. (This accounts for inefficiencies in the irrigation system and is explained in detail later.)

Notes:

a. The values in the table are based on irrigations occurring when 50% of the available soil moisture is depleted (50% allowable depletion).

b. For the months where no values are listed, irrigation scheduling should be based on soil moisture monitoring. Dashes mean that the soil-water-holding capacity is so great that irrigation frequency is significantly less than once per month.

c. For the early part of the year, use soil moisture monitoring to determine the first irrigation. The values in this table can then be used to determine the time of subsequent irrigations.

Figure 4.7. The steps of irrigation scheduling according to the water budget method.

Water Budget Irrigation Scheduling

1. Estimate daily crop water use by using published daily estimates, data from CIMIS, or tables of long-term average crop water use (see Table 4.2 for an example).
2. Add the daily water use to the running total of water use to date. The result is the soil water depletion to date.
3. Subtract any water additions—irrigations or rainfall—from soil-water depletion to date.
4. Schedule irrigation to replace the accumulated water use by the crop.

The goal: Keep soil-water depletion above the allowable depletion, without adding water in excess of the water-holding capacity of the soil. Remember that letting the soil dry beyond the allowable depletion results in lost yield and that applying more water than the soil can hold leaches nutrients and wastes energy and water.

fine sand or loamy sand must be irrigated every 7 days, while a clay soil must be irrigated every 15 days.

Compensating for production practices and limitations

The water budget theory of irrigation scheduling is relatively straightforward, but alfalfa production practices complicate putting the theory into practice. For example, cutting affects water use by alfalfa. Generally, water use is near zero immediately after cutting and rises slowly after a few days, as the crop begins to grow. After about 10 days, alfalfa regrowth fully covers the ground and full crop water use resumes. A grower must compensate for this reduction in water use after cutting or he or she will overirrigate. Sophisticated methods for calculating the reduction are available, but a practical method is to consider alfalfa water use to be zero for 5 days after cutting. After 5 days switch to full-use estimates until alfalfa is cut again. (See Studying a Practical Example, later in this chapter, to understand how this rule of thumb is applied.)

Harvesting and curing operations also complicate irrigation scheduling. Water cannot be applied too close to a cutting because irrigation wets the soil. On wet ground, harvest equipment may get stuck and is more likely to cause wheel ruts and compaction. Also, alfalfa that is cut and laid on moist soil to dry will cure very slowly. The preferred interval between irrigation and cutting depends on soil type. It may be as short as 2 days for sandy soils and as long as 10 to 15 days for fine-textured clay soils. Furthermore, fields obviously cannot be irrigated while alfalfa is curing, which typically requires from 5 to 8 days.

Because cutting delays irrigation, fields usually need water as soon after cutting as possible. Alfalfa is most sensitive to water stress when regrowth begins after cutting. When irrigation is postponed after cutting, dramatic yield reductions can result.

So, to summarize: (1) Fields should not be irrigated too close to cutting, and (2) fields should be irrigated as soon as possible after the hay has cured and been removed from the field. (The practical example later in this chapter shows how irrigation scheduling can be adjusted to allow for harvesting and curing.)

To account for seasonal differences in water requirements, growers must either change irrigation frequency or change set times to adjust the amount of water applied per irrigation (or both). Two 12-hour sets per day prevail in wheel-line- and hand-line-irrigated alfalfa fields in the Intermountain Region. (Though each set is described as 12 hours long, actual irrigation time is shortened by the amount of time workers take, between sets, to move the lines.) Longer or shorter set times are unusual because of labor constraints and the difficulty of moving irrigation lines at night. Set times for flood-irrigated fields are also inflexible; they are determined by the length of time required for the water to travel from the head to tail end of the field. Therefore, the most convenient method for scheduling alfalfa irrigations is to vary the irrigation frequency or the number of days between irrigations (see Table 4.3).

However, sometimes the number of days between irrigations is fixed because of delivery or irrigation system limitations. Under these conditions, record the accumulated crop water use between irrigation dates. Adjust irrigation set times to deliver the amount of water that has been depleted since the last irrigation.

Whenever using the water budget method to schedule irrigations, monitor soil moisture regularly to "ground-truth" the accuracy of the water budget method.

Studying a practical example

An example should help clarify the preceding discussion on practical irrigation scheduling. To follow along with this example, refer to the accompanying water use table, Table 4.4, and to the graph of soil-water depletion, Figure 4.8. This example relates to a healthy, well-established alfalfa field on sandy loam soil in the Tulelake region.

On May 12, the field was given a 12-hour irrigation that supplied 2.4 inches of water (net). This irrigation completely refilled the soil profile, so the soil-water depletion on this date was 0.00 (see point A on the table and graph). For 6 days, the crop was assumed to use water in amounts typical for the region (Table 4.2 supplies this information). The average crop water use was added each day to the soil depletion balance. On May 18 the field received 0.50 inch of rain, so 0.50 inch of water was subtracted from 0.96, the soil depletion balance. The daily crop water use, 0.20 inch, was then added. So, soil-water depletion on May 18 (point B) was calculated to be 0.66 inch (0.96 – 0.50 + 0.20 = 0.66).

The objective of the water budget is to maintain soil moisture near the optimum level by keeping track of crop water use and then irrigating to replace the water used.

After May 18, average crop water use figures were again added each day to the soil-water depletion balance. On May 26 (point C) the accumulated depletion totaled 2.29 inches. Because this soil depletion approximated the net amount applied in a 12-hour irrigation, the field was irrigated the next day, May 27. On that day, the 2.4-inch application of water was subtracted from 2.29, the soil depletion balance; 0.21 inch of average crop water use was added, resulting in a net soil-water depletion of 0.10 inch (point D). Important note: The 2.29 inches of soil-water depletion that occurred before the May 27 irrigation was less than the 3 inches of allowable depletion for this sample sandy loam soil (Table 4.1). Therefore, no yield reduction occurred due to moisture stress prior to this irrigation. The irrigation

Table 4.4. Water use table for a sample alfalfa field, Tulelake area.

	DATE	CROP WATER USE (IN.)	RAIN OR IRRIGATION (IN.)	SOIL WATER DEPLETION (IN.)	EVENT
A	5/12	0.19	2.4	0.00	12-hour irrigation
	5/13	0.19		0.19	
	5/14	0.19		0.38	
	5/15	0.19		0.57	
	5/16	0.19		0.76	
	5/17	0.20		0.96	
B	5/18	0.20	0.5	0.66	0.5 in. rain
	5/19	0.20		0.86	
	5/20	0.20		1.06	
	5/21	0.20		1.26	
	5/22	0.20		1.46	
	5/23	0.20		1.66	
	5/24	0.21		1.87	
	5/25	0.21		2.08	
C	5/26	0.21		2.29	
D	5/27	0.21	2.4	0.10	12-hour irrigation
	5/28	0.21		0.31	
	5/29	0.21		0.52	
	5/30	0.21		0.73	
	5/31	0.22		0.95	
	6/1	0.22		1.17	
	6/2	0.22		1.39	
	6/3	0.22		1.61	First cutting
E	6/4	0.00		1.61	
	6/5	0.00		1.61	
	6/6	0.00		1.61	
	6/7	0.00		1.61	
	6/8	0.00		1.61	
	6/9	0.24		1.85	
	6/10	0.24		2.09	
F	6/11	0.24		2.33	
G	6/12	0.24	2.4	0.17	12-hour irrigation
	6/13	0.24		0.41	
	6/14	0.25		0.66	
	6/15	0.25		0.91	
	6/16	0.25		1.16	
	6/17	0.25		1.41	
	6/18	0.25		1.66	
	6/19	0.25		1.91	
	6/20	0.25		2.16	
H	6/21	0.27	2.4	0.03	12-hour irrigation
	6/22	0.27		0.33	
	6/23	0.27		0.60	
	6/24	0.27		0.87	
	6/25	0.27		1.14	
	6/26	0.27		1.41	
	6/27	0.27		1.68	
	6/28	0.29		1.97	
	6/29	0.29		2.26	
I	6/30	0.29	2.4	0.15	12-hour irrigation
	7/1	0.29		0.44	
	7/2	0.29		0.73	
	7/3	0.29		1.02	
	7/4	0.29		1.31	
	7/5	0.30		1.61	
	7/6	0.30		1.91	
	7/7	0.30		2.21	
J	7/8	0.30	2.4	0.11	12-hour irrigation
	7/9	0.30		0.41	
	7/10	0.30		0.71	
	7/11	0.30		1.01	
	7/12	0.31		1.32	
K	7/13	0.31	1.2	0.43	6-hour irrigation
	7/14	0.31		0.74	
	7/15	0.31		1.05	
	7/16	0.31		1.36	
	7/17	0.31		1.67	Second cutting
L	7/18	0.00		1.67	
	7/19	0.00		1.67	
	7/20	0.00		1.67	
	7/21	0.00		1.67	
	7/22	0.00		1.67	
	7/23	0.30		1.97	
	7/24	0.30		2.27	
M	7/25	0.30	2.4	0.17	12-hour irrigation
	7/26	0.29		0.46	
	7/27	0.29		0.75	
	7/28	0.29		1.04	
	7/29	0.29		1.33	
	7/30	0.29		1.62	
	7/31	0.29		1.91	
	8/1	0.29		2.20	

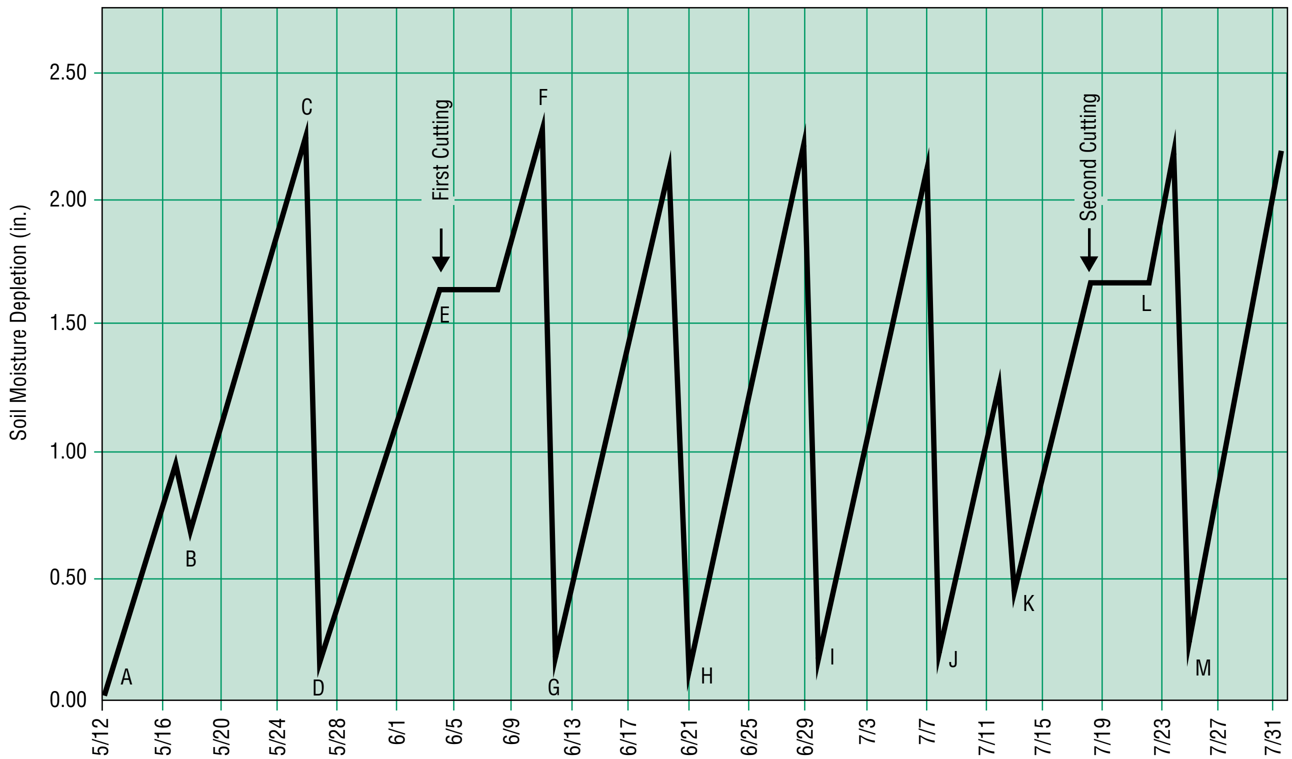


Figure 4.8. Soil-water depletion in sample alfalfa field, Tulelake area.

occurred 7 days before the first cutting, on June 3, allowing ample time for the soil to dry for harvest.

As explained earlier, it is acceptable to assume that for 5 days after cutting, crop water use is zero. After that time switch to using full-use estimates. In this example crop water use was estimated as zero from June 4 through June 8 (period E). On the sixth day following cutting, June 9, the use of full-use estimates resumed.

After soil-water depletions totaled 2.33 inches on June 11 (point F), irrigation was applied on June 12 (point G). This allowed ample time for the hay to cure after cutting on June 3. In a similar manner, normal irrigations were scheduled for June 21 and 30 and July 8 (points H, I, andJ). Irrigations were more frequent during this period because of the increased water demand of midsummer.

On July 13 (point K), an early irrigation consisting of 1.2 inches, half the normal amount of water, was applied. If this irrigation had been delayed until 2.4 inches of water had been depleted, the irrigation would have been too close to the second cutting, on July 17. The early, partial irrigation was scheduled to carry the alfalfa through the postharvest period without a water deficit. Again allowing for zero crop water use for 5 days after cutting (period L), the next irrigation was scheduled for July 25 (point M).

ADJUSTMENTS TO ACHIEVE UNIFORMITY AND EFFICIENCY

Information on crop water use (Table 4.2) indicates the net water requirement of alfalfa, not the actual amount that should be applied. The amount of water in an irrigation must supply crop water requirements as well as compensate for inefficiencies in the irrigation system. Irrigation water can be lost from runoff; deep percolation (movement of water below the root zone of the crop); and, in the case of sprinklers, spray evaporation and drift. Most irrigation water losses are attributable to nonuniformity of water application. If every part of the field received the same amount of water, uniformity would be 100 percent. However, no irrigation is perfectly uniform—some parts of the field receive more water than do others. To compensate for nonuniformity, some parts of the field must be overirrigated so that others will be adequately irrigated. To avoid underirrigation of large areas of the field, use the equation that follows to calculate the gross irrigation requirement—that is, the amount of water needed to meet plant needs (crop water needs) and compensate for irrigation inefficiency.

$$\text{Gross irrigation requirement} = \frac{\text{Net irrigation requirement}}{\text{Irrigation system efficiency}}$$

Irrigation system efficiency

For example, if the alfalfa uses 4 inches of water (that is, if the net irrigation requirement is 4 inches) and the system efficiency is 80 percent, the application required to meet plant needs is 5 inches (4 inches ÷ 0.8 = 5 inches).

The efficiency of an irrigation system is difficult to measure. Numerous field studies show however, that an irrigation efficiency of 75 percent can be used to calculate gross irrigation requirement when irrigating with wheel-line or hand-move sprinkler systems. Use 85 percent when irrigating with center-pivot machines (Table 4.5). The irrigation efficiency of flood systems varies from 65 to 80 percent, depending on soil type, slope, border length, and other factors. Select a value within this range based on knowledge of your irrigation system.

APPLICATION RATE

Knowing how much water the crop needs is of little benefit if you do not know how much water is being applied in an irrigation. Knowledge of the application rate is a prerequisite to using the water budget method.

The application rate can be calculated from the irrigation system flow rate. Several methods are available to ascertain the flow rate of an irrigation system. On a whole-field basis, a flow meter is the most precise and convenient means where the water supply is delivered in pipes. The drawback to flow meters is their cost (approximately $800 or higher, depending on pipe diameter). Flow rates can also be estimated by using the pump capacity or with data collected from a pump test (often performed by utility companies). Flumes and weirs are used to determine the flow rate for systems where ditches deliver water. (Flow rates and water volumes are often expressed in different units, but each can be easily converted—see Table 4.6.)

After you know the flow rate, you are ready to calculate application rate. The calculation you use depends on the type of irrigation system you have.

Table 4.5. Typical application efficiencies for different irrigation systems.

SYSTEM	APPLICATION EFFICIENCY
Sprinkler	
Wheel line	65–80
Hand line	70–80
Center pivot	75–90
Flood	
Border strip	65–80

Table 4.6. Conversions useful when scheduling irrigation.

1 acre-inch	=	27,154 gallons
1 acre-foot	=	325,848 gallons
1 cubic ft per second (CFS)	=	449 gpm
1 CFS	=	approx. 2 acre-feet per day
1 CFS	=	approx. 1 acre-inch per hour

Wheel-Line and Hand-Move Sprinkler Systems

To calculate the application rate for one of these systems, use the following equation:

$$\text{Application rate (in./hr.)} = \frac{96.3 \times Q}{Sm \times Sl}$$

where

Q = average sprinkler discharge, expressed in gallons per minute (gpm)

Sm = spacing along the main line (that is, the distance between moves) expressed in feet

Sl = spacing along lateral (that is, the distance between sprinklers) expressed in feet

Figure 4.9 presents an example that uses the equation.

To determine sprinkler discharge, divide the system flow rate by the number of sprinklers or slip a hose over a nozzle and measure the volume of water collected in a given time period. Or, as an alternative to using the equation above, you can estimate application rate for a sprinkler system from irrigation tables provided you know the nozzle size, pressure and sprinkler spacing. (Table 4.7).

The average depth of water applied during an irrigation is estimated by multiplying the application rate, in inches per hour, by the set time in hours.

Center-Pivot Systems

The equation that follows will allow you to calculate the average depth of water applied per revolution of a center-pivot irrigation system:

$$\text{Depth applied (in.)} = \frac{Q \times H}{449 \times A}$$

where

Q = flow rate, expressed in gpm

H = hours per complete revolution

A = area irrigated with pivot, expressed in acres

Figure 4.10 is an example that employs the equation.

Border-Strip Flood Systems

The average depth of water applied per set with a flood-irrigation system is calculated as follows.

$$\text{Depth applied (in.)} = \frac{Q \times T}{449 \times A}$$

where

Q = flow rate, expressed in gpm

T = irrigation set time, in hours

A = area, in acres

Figure 4.11 shows how to apply the equation.

Table 4.7. Sprinkler application rate (in./hr.) for 40- by 60-ft spacing.

NOZZLE SIZE (IN)	APPLICATION RATE (IN/HR) 40 PSI	50 PSI	60 PSI
3/32	.06	.07	.08
7/64	.09	.10	.11
1/8	.11	.13	.14
9/64	.15	.16	.18
5/32	.18	.20	.22
11/64	.22	.25	.27
3/16	.26	.29	.32
13/64	.31	.34	.38
7/32	.36	.40	.44

Figure 4.9. Sample calculation to determine the application rate of a wheel-line or hand-move sprinkler system.

Pump capacity = 675 gpm
Number of sprinklers = 96
Main line spacing = 60 ft
Lateral spacing = 40 ft
Set time = 12 hr

Average application rate:

$$Q = \frac{675 \text{ gpm}}{96 \text{ sprinklers}} = 7 \text{ gpm/sprinkler}$$

$$\text{in./hr} = \frac{96.3 \times 7 \text{ gpm}}{40 \text{ ft} \times 60 \text{ ft}} = 0.28 \text{ in./hr.}$$

Average depth applied:

$$D = 0.28 \text{ in./hr} \times 12 \text{ hr} = 3.36 \text{ in. total}$$

Figure 4.10. Sample calculation to determine average depth of water applied by a center-pivot system.

Flow rate = 900 gpm
Hr/revolution = 70 hr
Area irrigated = 125 acres

Average depth applied per revolution:

$$D = \frac{900 \text{ gpm} \times 70 \text{ hr}}{449 \times 125 \text{ acres}} = 1.12 \text{ in./revolution}$$

Note: Acreage under pivot is equal to

$$\frac{(r)^2 \times 3.14}{43{,}560}$$

where: r = radius of the pivot (ft)

Figure 4.11. Sample calculation to determine the average depth of water applied by a flood-irrigation system.

Flow rate = 1,120 gpm
Set time = 8 hr
Area irrigated = 3.6 acres

Average depth applied:

$$D = \frac{1{,}120 \text{ gpm} \times 8 \text{ hr}}{449 \times 3.6 \text{ acres}} = 5.54 \text{ in.}$$

SYSTEM DESIGN REQUIREMENTS

The key to efficient irrigation management begins with the irrigation system and its flow rate. The system flow rate of many irrigation systems in the Intermountain Region is inadequate. To fully meet crop needs, the system flow rate must be sufficient to irrigate the field adequately during the period of peak evapotranspiration (typically July) without exceeding the allowable soil moisture depletion. The following equation can be used to calculate the necessary flow rate:

$$Q = \frac{449 \times A \times D}{T}$$

where

Q = flow rate, expressed in gpm

A = area irrigated in acres

D = gross depth of water to be applied, in inches

T = actual irrigation time, in hours

The interval between irrigations is determined by dividing the allowable soil moisture depletion by the daily peak ET rate (from Table 4.2). The gross depth of water to be applied is the allowable soil moisture depletion divided by the irrigation efficiency of the system (discussed in previous section). The hours of irrigation is the time required to irrigate the field. The fewer the hours of irrigation, the higher the flow rate needs to be.

Figure 4.12 presents a system flow rate calculation typical of the Intermountain Region. A grower needs 326 gallons per minute to irrigate a 40-acre alfalfa field. This equates to 8 gallons per minute per acre of wheel-line-irrigated alfalfa. The required flow rate would be slightly less (approximately 7.5 gpm) for irrigation systems that do not involve downtime during which the lines are moved.

IRRIGATION SYSTEM IMPROVEMENTS

Sprinkler Systems

System design factors that affect irrigation efficiency include sprinkler spacing, operating pressure, pressure differences throughout the system, and nozzle type and size. Several changes in system design improve uniformity and performance of sprinklers (Figure 4.13).

The most common sprinkler spacing in intermountain alfalfa fields is 40 by 60 feet (in other words, 40 feet between sprinkler heads and 60 foot moves). Numerous field evaluations show that this spacing results in good uniformity when large ($\frac{11}{64}$ or larger) sprinkler nozzles are used under low to moderate wind conditions.

Sprinkler pressure should be above 35 pounds per square inch (psi). Minimize pressure losses due to friction in the lateral lines by using appropriate pipe diameters. The most common lateral pipe diameter is 4 inches. However, pressure losses can be greatly reduced —and energy saved—by using 5-inch diameter pipe for laterals. Analyze pressure losses due to friction in the main line as well; change the pipe size if necessary.

Knowing how much water the crop needs is of little benefit if you do not know how much water is applied in an irrigation.

Select the proper nozzle type. Types of nozzles include standard circular orifices, low-pressure nozzles, and flow-control nozzles. Field evaluations reveal that standard nozzles are adequate for systems with pressures of 35 psi or greater. Use flow-control nozzles for systems with pressure losses exceeding 20 percent of the design pressure.

Wind lowers the uniformity of sprinkler systems by distorting the spray pattern of sprinkler nozzles. Its impact can be significant, especially when wind velocity is high. Changes, such as closer spacing or lower pressure, can lessen the effects of wind, but its impact cannot be completely eliminated. Sprinkler systems that move continuously (that is, center-pivot or linear-move systems) are not as affected by wind as are wheel-line or hand-move systems.

Figure 4.12. Sample calculation to determine the system flow rate for a 40-acre alfalfa field.

Type of irrigation system = wheel-line sprinkler
Allowable soil moisture depletion = 3.0 in.
Peak ET = 0.3 in./day
Irrigation efficiency = 75 percent

1. Interval between irrigations

$$= \frac{\text{Allowable soil moisture depletion}}{\text{Peak ET}}$$

$$\frac{3.0 \text{ in.}}{0.3 \text{ in./day}} = 10 \text{ days}$$

2. Hours of operation for an irrigation system operated continuously except during moving

= 22 hr/day x 10 days
= 220 hr

3. Gross depth

$$= \frac{3 \text{ in.}}{\text{irrigation efficiency}}$$

$$= \frac{3 \text{ in.}}{0.75}$$

= 4 in.

4. System flow rate

$$= \frac{449 \times 40 \text{ acres} \times 4.0 \text{ in.}}{220 \text{ hr}}$$

= 326 gpm

5. Required flow rate

$$= \frac{326 \text{ gpm}}{40 \text{ acres}}$$

= 8 gpm per acre (approx.)

Figure 4.13 Ways to improve uniformity and efficiency of sprinkler irrigation systems.

- Determine the application rate and average depth of water applied.
- Irrigate during low-wind periods when feasible. (The uniformity of irrigation is greatly reduced at wind speeds greater than 10 to 15 mph.)
- Offset lateral locations to improve seasonal uniformity.
- Use flow-control nozzles when the pressure variation between the first and last nozzle exceeds 20 percent.
- Repair leaks and malfunctioning nozzles.
- Maintain adequate pressure (above 35 psi at the last nozzle for wheel lines) by adjusting the pump impeller of semi-open impellers, repairing or replacing a worn pump, or reducing the number of laterals operating.
- Use the same nozzle size throughout the irrigation system.
- Use closer spacing, boom-mounted nozzles, and/or rotating-type nozzles for center-pivot systems.

Flood Systems

The uniformity of flood irrigation depends on how long water stands or ponds on the soil surface at various distances along the border length. The longer the ponding time at a particular distance, the more water infiltrates. The ponding time depends on how fast the water flows to the end of the field (this speed is determined by border length, inflow rate, infiltration rate, slope, and surface roughness) and how fast the water disappears after the irrigation water is cut off.

Generally, water stands longer along the upper part of a field than along the lower part, resulting in more infiltration along the upper part.

Uniformity of flood systems can be improved by getting the water to the end of the field faster. To improve uniformity, use higher flow rates into the border, shorten border lengths, and improve land leveling. The higher the flow rate, the faster water flows to the end of the field and the more uniform the application. The appropriate field length depends on soil type (Table 4.8). Field lengths for clay loam soils should not exceed ¼ mile; field lengths for sandy soils should not exceed ⅛ mile. The width should be compatible with the system flow rate and also with the harvesting equipment. Many of these efforts to increase uniformity may increase surface runoff, thus requiring a tailwater return system to capture and reuse the runoff. Failure to do so could result in higher pumping costs and increased water use.

Table 4.8. Suggested field lengths and unit flow rates for border or flood irrigation of slopes of 0.1 to 0.2 percent.

SOIL TYPE	LENGTH (FT.)	UNIT FLOW RATE (GPM/FT. OF WIDTH)
Clay	1,300	7–10
Clay loam	1,300	10–15
Loam	1,300	25–35
Loam	600	15–20
Sandy loam	600	25–30
Sandy	600	30–40

Source: 1974. Border Irrigation. SCS National Engineering Handbook, Section 15. Washington, DC.

IRRIGATION STRATEGIES FOR LIMITED WATER SUPPLIES

Sometimes the supply of irrigation water (from a pumping plant or an irrigation district) is insufficient to supply the full seasonal water requirements of alfalfa. When this occurs, irrigate fully in the spring rather than trying to "spread out" an insufficient water supply and deficit-irrigate for the entire season. The amount of irrigation water required per ton of alfalfa is less for the first cutting than for the second or third. Temperatures are cooler in the spring and the chance of rainfall is greater. First-cutting yields usually surpass second- and third-cutting yields. Also, the quality and price of first-cutting hay is usually higher than those of second-cutting hay.

Research and field experience throughout much of California have demonstrated that irrigation water can be withdrawn or reduced following the first cutting without significantly reducing stand density or yields the following year. Deficit irrigating forces alfalfa into a drought-induced dormancy. The stand usually recovers fully when it receives adequate water the next production season.

ADDITIONAL READING

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CHAPTER FIVE

FERTILIZATION

Roland D. Meyer, Daniel B. Marcum, and Steve B. Orloff

Providing an adequate supply of nutrients is important for alfalfa production and is essential to maintain high and profitable yields. However, proper plant nutrition can be a complex and often difficult management process. The process includes an analysis of which nutrients are needed, selection of the proper fertilizer, application timing and placement, economics, record keeping, and environmental considerations. This chapter serves as a guide to alfalfa fertilization in the Intermountain Region and includes information on appropriate methods of sampling alfalfa and interpreting soil and tissue tests.

Before applying fertilizer to alfalfa, examine other factors affecting yield. It makes little sense to fertilize with a nutrient when another factor is more limiting to plant growth. For example, an application of sulfur, even when sulfur is deficient, may not increase yields if water is not sufficient to allow plants to grow in response to applied fertilizer.

Since historical trends help with management decisions, thorough, well-organized records of plant tissue and soil-test information are important. Records should include information about date of sampling; crop yield and fertilizer history; and, most importantly, the location of the samples.

DAN MARCUM

ESSENTIAL PLANT NUTRIENTS

Seventeen elements are needed, in varying amounts, for plant growth. Carbon, hydrogen, and oxygen come from water and from carbon dioxide in the air. The other 14 elements are obtained from either the soil or fixation of atmospheric nitrogen by bacteria in root nodules. Another nutrient, cobalt, is essential to legumes, for nitrogen fixation. Growth slows or stops when a plant is unable to obtain one or more of these elements. Thus, all nutrients must be available to the plant in adequate quantities throughout the production season. The nutrients that are most commonly needed are sulfur, followed closely by phosphorus, then potassium, boron, and molybdenum (Table 5.1).

DIAGNOSIS OF NUTRIENT DEFICIENCIES

A key aspect of designing a fertilization program is evaluating the nutrition status of the alfalfa. This can be done by visual observation, soil analysis, or plant tissue testing. Using all three in combination provides the best results.

Visual Observation

Nutrient deficiencies may exhibit visual plant symptoms such as obvious plant stunting or yellowing. Table 5.2 summarizes visual symptoms of common deficiencies. (Also see color photos 5.1 through 5.7.) Unfortunately, visual symptoms are not definitive and can be easily confused or mistaken for symptoms caused by other factors—insect injury, diseases, restricted root growth. The other problem with using visual observation of plant symptoms to diagnose nutrient deficiencies is that significant yield losses may have already occurred by the time the symptoms appear. Always confirm visual diagnosis with laboratory diagnosis or test strips with selected fertilizers.

Table 5.1. Nutrition needs of alfalfa in the Intermountain Region.

ELEMENT NEEDED	SYMBOL	FERTILIZER REQUIRED[1]
Nitrogen	N	Seldom
Phosphorus	P_2O_5	Frequently
Potassium	K_2O	Less frequently
Calcium	Ca	Never
Magnesium	Mg	Never
Sulfur	S	Frequently
Iron	Fe	Seldom
Manganese	Mn	Never
Chlorine	Cl	Never
Boron	B	Less frequently
Zinc	Zn	Never
Copper	Cu	Never
Molybdenum	Mo	Less frequently
Nickel	Ni	Never
Cobalt	Co	Never[2]

1. Frequently: Over 25% of the acreage shows need for fertilization with this nutrient.
   Less frequently: Less than 25% of the acreage shows need for fertilization.
   Seldom: Less than 1% of the acreage shows need.
   Never: A deficiency has never been reported or observed.
2. Necessary for nitrogen fixation only.

Laboratory Analysis

Both soil and plant tissue test results are used to detect plant nutrient deficiencies. These two tests differ in their ability to reliably diagnose nutrition problems in alfalfa (Table 5.3). To fully understand and correct problems, test both soil and tissue.

Soil testing

Soil tests provide an estimate of nutrient availability for uptake by plants and are most useful for assessing the fertility of fields prior to planting. Soil sampling methods are critical, since soil samples must adequately reflect the nutrient status of the field. Because a representative sample of an entire field gives an average of all the variation in that field, it is not the best way to develop recommendations for parts of the field that are less productive. The best technique is to divide each field into two or three areas representing good, medium, and poor alfalfa growth. Within each area establish permanent benchmark locations approximately 50 x 50 feet in size (Figure 5.1). To ensure that

Table 5.2. Nutrient deficiency symptoms observed in alfalfa.

DEFICIENCY	SYMPTOMS
Nitrogen	Generally yellow, stunted plants
Phosphorus	Stunted plants with small leaves; sometimes leaves are dark blue-green
Potassium	Pinhead-sized yellow or white spots on margins of upper leaves; on more mature leaves, yellow turning to brown leaf tips and edges
Sulfur	Generally yellow, stunted plants
Boron	Leaves on the upper part of plant are yellow on top and reddish purple on the underside; internodes are short
Molybdenum	Generally yellow, stunted plants

Table 5.3. Relative reliability of soil and plant tissue testing for nutrient deficiency.

NUTRIENT	SOIL TESTING	TISSUE TESTING
Sulfur	Very poor	Excellent
Phosphorus	Good	Excellent
Potassium	Good	Excellent
Boron	Poor	Excellent
Molybdenum	Not recommended	Excellent

you will be able to find each benchmark area again, describe it in relation to measured distances to specific landmarks on the edge of the field. By using this method to collect soil and plant tissue samples, you will be able to compare areas of the field with different production levels, develop appropriate management responses, and track changes over the years.

The best time to sample soil is soon after an irrigation or rainfall, so the probe easily penetrates the moist soil. Before taking a soil sample, remove debris or residual plant material from the soil surface. The sample can be taken with a shovel, but an Oakfield tube or similar sampling probe is preferred. Sample the top 6 to 8 inches of soil. Take 15 to 20 cores at random from each benchmark area and mix them thoroughly in a plastic bucket to produce a single 1 pint composite sample for each benchmark area. Place each sample in a separate double-thick paper bag and dry the soil at room temperature before mailing to the laboratory. To get a complete profile of the nutrition status of an alfalfa field, perform all the soil and tissue tests cited in Table 5.4. A list of laboratories is found in University of California Special Publication 3024, *California Commercial Laboratories Providing Agricultural Testing.*

Taking soil samples every year may not be necessary once historical trends have been established. Sampling benchmark areas every time alfalfa is planted is usually sufficient to establish trends. If poor alfalfa growth is observed in other parts of the field, take samples from both good and poor growth areas so the fertility level of the two areas can be compared. Table 5.5 lists guidelines for interpreting soil tests. Values are given for deficient, marginal, adequate, and high levels. An economic yield response to fertilizer application is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.

Plant tissue testing . . . by far the most precise method of determining the nutrient needs of alfalfa.

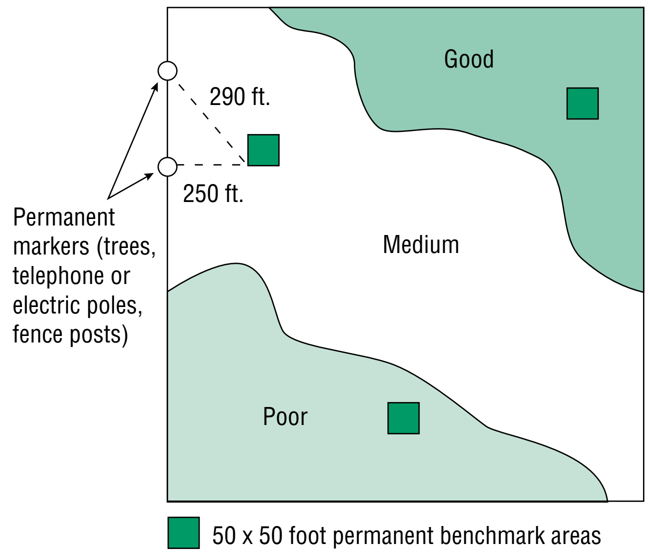

Figure 5.1. Sound soil and plant tissue-testing procedure involves establishing permanent benchmark sampling locations (50 x 50 feet in size) within areas of the field that support good, medium, and poor alfalfa growth. Define these benchmark areas in relation to measured distances to specific landmarks on the edge of the field.

Table 5.4. Suggested tests for a complete examination of soil and alfalfa tissue.

SOIL	PLANT TISSUE
pH[1]	Sulfur (SO_4–S)
Phosphorus	Phosphorus (PO_4–P)
Potassium	Potassium
EC_e[1]	Boron
Calcium, magnesium, sodium[1]	Molybdenum
SAR[1]	Copper

1. These tests evaluate factors that affect the availability of nutrients and the presence of undesirable salt levels. ECe (electrical conductivity of saturation extract (mmho/cm). SAR (Sodium absorption ratio)

Plant tissue testing

By far the most precise method of determining the nutrient needs of alfalfa is plant tissue testing. Such tests are the best reflection of what the plant has taken up and are far more accurate than soil tests, particularly for sulfur, boron, and molybdenum. Plant tissue tests are useful in monitoring the nutrition status and evaluating the effectiveness of current fertilization practices.

The best time to take a tissue sample is when the crop is in the 1⁄10 bloom growth stage or when regrowth measures ¼ to ½ inch in length. (Alfalfa is often cut prior to 1⁄10 bloom to attain high-quality forage.)

When alfalfa is cut prior to 1⁄10 bloom (for example, bud stage) nutrient concentrations should be approximately 10 percent higher than when sampled at 1⁄10 bloom. Samples can be collected at any cutting, but collection at first cutting is preferred because it is the best time to detect a sulfur deficiency. Collect 40 to 60 stems from at least 30 plants in each of the benchmark areas.

Different plant parts are analyzed for different nutrients (Figure 5.2). Cut each sample into three sections of equal length. Discard the bottom third; place the top one third in one paper bag and the middle one third in another. Dry the samples in a warm room or oven. After drying, separate leaves from stems in middle one third sample by rubbing the sample between your hands. Put leaves and stems into separate bags. Figure 5.2 and Table 5.4 list the analyses that should be performed on the samples. Table 5.6 lists guidelines for interpreting plant tissue-test results. Entire plant samples or baled hay samples are not recommended because they can only detect extreme nutrient deficiencies.

Tissue tests can determine only the single most limiting nutrient affecting plant growth—the concentration of other nutrients may actually increase due to reduced growth. Therefore, correct the most severe deficiency first. After it is corrected, take new plant tissue samples to determine if other nutrients are deficient. Also, low concentrations of a nutrient in plant tissue may not always indicate a deficiency in the soil. Remember that plant analysis reflects nutrient uptake by the plant; a problem affecting roots, such as nematodes, can affect nutrient uptake as well.

CORRECTION OF NUTRIENT DEFICIENCIES

Apply fertilizer to correct nutrient deficiencies after careful consideration of the amount of nutrients removed by alfalfa, the yield potential of the field, current soil-test levels, and historical responses to fertilization. Table 5.7 indicates the amount of nutrients removed by 4-, 6- and 8-ton alfalfa crops.

Nitrogen

Applying nitrogen fertilizer to alfalfa is seldom beneficial or profitable. Adequate nitrogen is provided by the symbiotic nitrogen-fixing bacteria (*Rhizobia*) that live in nodules on alfalfa roots. *Symbiotic* means that both the plant and bacteria benefit; the alfalfa benefits from the nitrogen provided by *Rhizobia* bacteria and the bacteria benefit from the food source (carbohydrates) provided by alfalfa. Because of this relationship, applying nitrogen to alfalfa seldom results in an economic yield response. In those rare cases where nitrogen fertilizer does result in a yield increase, the problem is probably ineffective inoculation or conditions that inhibit or retard the development of the *Rhizobia* bacteria (that is, low soil pH, waterlogged soils, cold conditions, compacted soil, or extremely shallow root zone). Molybdenum and cobalt deficiencies are other possibilities.

Plant tissue tests can only determine the most limiting nutrient for plant growth.

Symptoms of nitrogen deficiency include stunted growth and a light green or yellow color. A nitrogen deficiency is suspected when the field contains stunted or small yellow plants with scattered tall dark green inoculated plants (color photos 5.2 and 5.3). Examination of roots usually shows no nodules on the stunted yellow plants and several nodules on the green healthy plants. Poor nodulation is often associated with fields having no history of alfalfa production; use of outdated inoculant; or hot, dry seedbed conditions.

The most common cause of nitrogen deficiency is poor inoculation and nodule formation after planting. Proper inoculation is necessary to ensure that alfalfa has an adequate supply of nitrogen. For effective

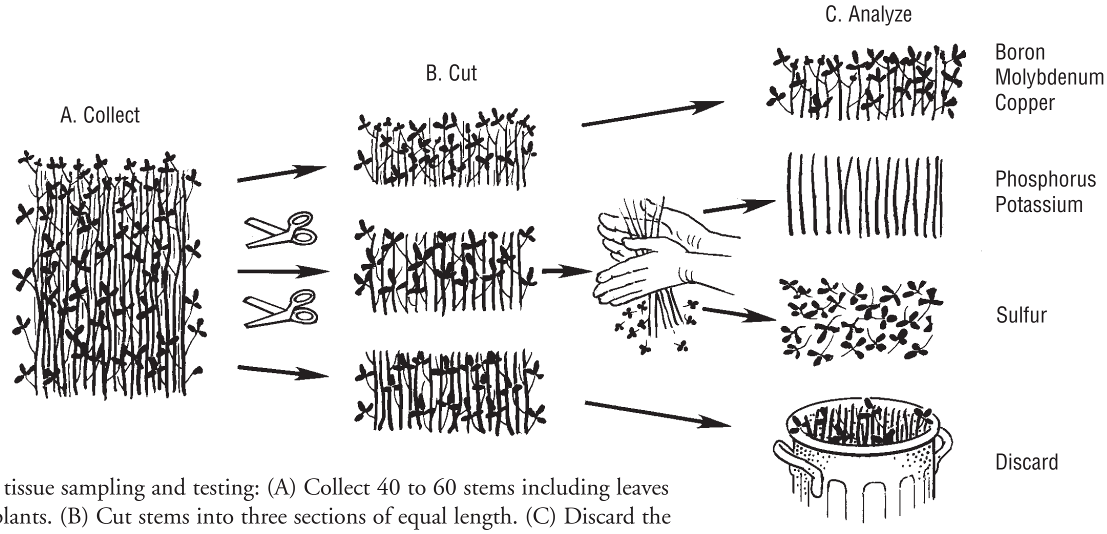

Figure 5.2. Plant tissue sampling and testing: (A) Collect 40 to 60 stems including leaves from at least 30 plants. (B) Cut stems into three sections of equal length. (C) Discard the bottom third. Place the top third in one paper bag and the middle third in another. Dry the samples. Separate leaves from stems in middle third by rubbing between hands. Put leaves in one bag and stems in another bag. Analyze top-third sample for boron, molybdenum, and copper. Analyze leaves from the middle third for sulfur (SO_4–S) and the stems from middle third for phosphorus (PO_4–P) and potassium.

Table 5.5. Interpretation of soil test results for alfalfa production.

NUTRIENT	EXTRACT[2]	SOIL VALUE (PPM)[1]			
		DEFICIENT	MARGINAL	ADEQUATE	HIGH
Phosphorus	Bicarbonate	< 5	5–10	10–20	>20
Potassium	Ammonium acetate	< 40	40–80	80–125[3]	>125
	Sulfuric acid	< 300	300–500	500–800	> 800
Boron	Saturated paste	< 0.1[4]	0.1–0 .2	0.2–0 .4	>0.4[5]

1. An economic yield response to fertilizer applications is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.
2. Soil test values are based on use of the cited extract; values for other extracts are different.
3. If ammonium acetate levels are <100 ppm, it is advisable to request sulfuric acid extractable K.
4. Soil testing is not a suitable method to diagnose a deficiency. Use a plant tissue test.
5. Possible toxicity to sensitive crops such as cereals.

Table 5.6. Interpretation of test results for alfalfa plant tissue samples taken at 1⁄10 bloom.[1]

NUTRIENT	PLANT PART	UNIT	PLANT TISSUE VALUE[2]			
			DEFICIENT	MARGINAL	ADEQUATE	HIGH
Sulfur (SO_4–S)	Middle third, leaves	ppm	0–400	400–800	800–1000	Over 1000
Phosphorus (PO_4–P)	Middle third, stems	ppm	300–500	500–800	800–1500	Over 1500
Potassium	Middle third, stems	%	0.40–0.65	0.65–0.80	0.80–1.5	Over 1.5
Boron	Top third	ppm	Under 15	15–20	20–40	Over 200 [3]
Molybdenum	Top third	ppm	Under 0.3	0.3–1.0	1–5	5–10 [4]

1. Concentrations should be higher if alfalfa is cut at bud stage (multiply tabular values by 1.10).
2. An economic yield response to fertilizer applications is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.
3. A concentration over 200 may cause reduced growth and vigor.
4. A concentration over 10 may cause molybdenosis in ruminants.

Table 5.7. Nutrients contained in 4, 6, and 8 tons of alfalfa hay.[1]

		Nutrient yield (lb/a)		
Nutrient	**Symbol**	**4-ton crop**	**6-ton crop**	**8-ton crop**
Nitrogen	N	200.0	300.0	400.0
Phosphorus	P_2O_5	48.0	71.0	95.0
Potassium	K_2O	173.0	260.0	346.0
Calcium	Ca	128.0	192.0	256.0
Magnesium	Mg	27.0	40.0	53.0
Sulfur	S	16.0	24.0	32.0
Iron	Fe	1.5	2.3	3.0
Manganese	Mn	1.0	1.5	2.0
Chlorine	Cl	1.0	1.5	2.0
Boron	B	0.2	0.4	0.5
Zinc	Zn	0.2	0.3	0.4
Copper	Cu	0.06	0.1	0.13
Molybdenum	Mo	0.008	0.012	0.016

1. 100% dry matter

nodulation, inoculate seed with fresh inoculant and do not expose it to hot, dry conditions prior to germination. This is particularly critical in fields planted to a first crop of alfalfa. Fields with a history of alfalfa plantings seldom have inoculation problems, because of high residual *Rhizobia* populations from previous crops. If poor nodulation occurs in a young stand of alfalfa, inoculate seed at 2 to 5 times the normal rate and drill it into the stand at 3 to 5 pounds seed per acre. Follow with a light irrigation. Usually, after a growing season, all plants in the field will be inoculated.

Light green or yellow plants may also indicate a sulfur or molybdenum deficiency. Use a plant tissue test to identify the specific deficiency. Nitrogen deficiency may also result from a molybdenum deficiency, since molybdenum has a role in nitrogen fixation. Sulfur and molybdenum deficiencies will be discussed later in this chapter.

Phosphorus

Currently, phosphorus may be the most commonly deficient nutrient in alfalfa in the Intermountain Region. Prior to planting, use a soil test to assess the phosphorus status of the soil. As indicated in Table 5.5, soil with a phosphorus level less than 5 parts per million (ppm) is considered deficient, soil with 5 to 10 ppm phosphorus is marginal, and that with 10 ppm or greater phosphorus is adequate. A tissue test for phosphorus is preferred after alfalfa is established.

Phosphorus deficiency is very difficult to identify visually (color photo 5.1).

To correct a phosphorus deficiency, a high-analysis phosphorus fertilizer such as 0–45–0 or 11–52–0 is usually the most economical. In alfalfa these two common phosphorus sources result in the same yield response. Liquid or granular phosphorus fertilizers with water solubility values greater than 55 percent are nearly equal in terms of plant availability. Rock phosphate, however, is not recommended because of low phosphate availability, particularly when applied to anything other than very acidic soils (those with a pH less than 5.5). If before planting you use a nitrogen-phosphorus fertilizer such as 16–20–0 to stimulate young seedlings, take care to control weeds; the supplemental nitrogen will stimulate their growth.

Currently, phosphorus may be the most commonly deficient nutrient in alfalfa in the Intermountain Region.

Before planting, use soil tests to determine the amount of phosphorus needed (Table 5.8). Recent

Table 5.8. Recommended phosphorus and potassium application rates based on results of soil or plant tissue tests.

NUTRIENT	SOIL OR PLANT TISSUE TEST RESULT			
	YIELD LEVEL (TONS/A)	DEFICIENT[1] (LB/A)	MARGINAL (LB/A)	ADEQUATE (LB/A)
Phosphorus (P_2O_5)	4	60–90	30–45	0–20
	8	120–180	60–90	0–45
Potassium (K_2O)	4	100–200	50–100	0–50
	8	300–400	150–200	0–100

1. An economic yield response to fertilizer applications is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.

research indicates that even if high rates of phosphorus are applied, it may be economical to reapply after 2 years. Incorporate no more than a 2-year supply of fertilizer into the top 2 to 4 inches of soil. Use tissue analysis to determine the need for phosphorus after the seedling year. Applying phosphorus fertilizers on the soil surface in an established stand has been very effective. Apply fertilizer any time, but applications made from October through February are preferred because alfalfa responses to phosphorus fertilizer are not usually observed until 60 to 90 days after application.

Table 5.8 gives a range of application rates because some soils and growing conditions require larger amounts to meet nutrition requirements and maintain high alfalfa yields. Various combinations of phosphorus amounts and application timing can be used to achieve the rates recommended. Recent research has indicated that fewer applications (at least every 2 years) of higher rates can be applied more economically than lower rates (less than 50 pounds P_2O_5 per acre) applied each year. Take plant tissue samples 60 to 90 days after a fertilizer application to re-evaluate fertility status.

Potassium

Potassium deficiency is found less frequently in the Intermountain Region of northern California. Like a lack of phosphorus, a potassium deficiency can be diagnosed by either a soil or a plant tissue test. The visual symptoms of potassium deficiency are pinhead-sized white or yellow spots on new leaves (see color photo 5.6). Unlike the symptoms of other nutrient shortages, those of potassium deficiency are distinctive and fairly reliable. Note, however, that genetic differences between alfalfa plants affect symptom development; not all potassium-deficient plants show deficiency symptoms. Also, some insects and diseases cause symptoms similar to those of potassium deficiency.

The most economical fertilizer for correcting this deficiency is muriate of potash (0–0–60). Sometimes potassium sulfate (0–0–52, 18% sulfur) is used when sulfur is also deficient. However, compared to muriate of potash, potassium sulfate and other mixed fertilizers are usually more expensive per pound of potassium. Table 5.8 lists recommended potassium rates for both preplanting and surface applications. Applications on the soil surface are very effective and can be made anytime. Like the response to phosphorus, the growth response to applied potassium may not be observed until 60 to 90 days after fertilizer application.

Sulfur

Historically, sulfur has been the most commonly deficient nutrient in alfalfa in the Intermountain Region. Visual deficiency symptoms include stunting and a light green or yellow color—symptoms that may also indicate nitrogen or molybdenum deficiency (see color photos 5.2 and 5.4). Only tissue testing can confirm a sulfur deficiency; soil tests do not provide reliable results. It is important to have an adequate level of available sulfate sulfur in the soil at the time of planting. Two principal sources of sulfur exist: (1) long-term slowly available elemental sulfur and (2) short-term rapidly available sulfate. The most economical practice is to apply and incorporate before planting 200 to 300 pounds elemental sulfur per acre. Elemental sulfur is gradually converted to the sulfate form and should last 4 to 7 years. It may be necessary to repeat the application once in the life of a 6- to 10-year stand.

To ensure a multiple-year supply of available sulfur, the particle size of elemental sulfur must range from large to small. Small particles are rapidly converted to the sulfate form; the large particles will continue to release sulfate over several years. Ideally, 10 percent of elemental sulfur should pass through a 100-mesh screen; 30 percent, through a 50-mesh screen; and the remaining 60 percent, through a 6-mesh screen. Very fine grades of sulfur are readily available but do not persist long enough to provide a multiple-year supply.

Fertilizers used to supply the sulfate form of sulfur include gypsum (15 to 17% sulfur), 16–20–0 (14 to 15% sulfur), and ammonium sulfate 21–0–0 (24% sulfur). Some growers apply 300 to 500 pounds gypsum per acre every other year rather than using elemental sulfur. The advantage to this practice is a quick response (about 2 weeks). The disadvantages are the higher cost per pound of sulfur and the fact that more sulfur is applied than is necessary. Perhaps the most important reason to avoid overfertilization with sulfur is that it can decrease the selenium concentration in the alfalfa hay. Livestock producers throughout the Intermountain Region want forage that is as high in selenium as possible because their animals often suffer from selenium deficiency.

Iron

On rare occasion, growers have observed symptoms of iron deficiency in alfalfa, but only tissue tests have been effective in confirming the problem. The deficiency usually produces nearly white or canary yellow plants in areas where drainage is poor. Iron deficiency in alfalfa is characteristically associated with high pH or poorly drained soils high in lime. If the soil pH is greater than 8.0 and free lime is present, begin to correct the iron deficiency by applying high rates of elemental sulfur (at least 1,000 pounds per acre); this will lower the soil pH. Also, improve drainage in low areas of the field.

Boron

Although deficiency symptoms are easily identified, boron deficiency is more effectively confirmed with a plant tissue test (color photo 5.7). Adequate supplies of boron are more important for production of alfalfa seed than hay. When tissue tests indicate boron is deficient and boron-sensitive crops such as cereals are likely to be planted in the field within 12 months, apply 1 to 3 pounds boron per acre to the soil surface. Use 3.5 to 7 pounds per acre if boron-tolerant crops such as alfalfa, sugarbeets, or onions will be grown for the next 24 months. Use the lower rates on sandy soils; the higher rates are suggested for fine-textured soils. Higher rates of boron will often last 5 to 7 years. The most common boron fertilizers are 45 to 48 percent borate (14.3 to 14.9% boron) and 65 to 68 percent borate (20.4 to 21.1% boron). Boron is usually applied as a granular product, either by air or through the small seed box in a grain drill. Some forms can be applied as a liquid along with herbicide applications; make sure the boron and herbicide are compatible before mixing them.

Molybdenum

Molybdenum deficiency is infrequent in the Intermountain Region, but it has occurred in several areas. Symptoms of molybdenum deficiency are like those of nitrogen and sulfur deficiency: light green or yellow stunted plants (color photo 5.5). A positive response to ammonium sulfate fertilizer could mean a nitrogen, sulfur, or molybdenum deficiency. A positive response to urea rules out a sulfur deficiency but could indicate a shortage of nitrogen or molybdenum. Plant tissue testing or applying sulfur and molybdenum fertilizers to separate trial strips are the only means of confirming a molybdenum deficiency.

The most common molybdenum fertilizer is sodium molybdate (40% molybdenum), but ammonium molybdate can be used as well. Apply 0.4 pound molybdenum per acre during the winter or before regrowth has occurred after cutting. A single application of molybdenum should last from 5 to 15 years. Thorough records of molybdenum application times and amounts along with repeated tissue testing are essential to determine when to apply or reapply the nutrient.

Do not apply excessive molybdenum (that is, double or triple coverage)—the concentration of the element in alfalfa may become so high that the forage becomes toxic to livestock. For the same reason, do not apply molybdenum to foliage. Analyzing the top third of the plant for both copper and molybdenum can detect deficiencies and suboptimum ratios of these elements. Consult a nutrition specialist if you suspect molybdenum problems.

RECORD KEEPING

Clear and complete records are essential to a successful alfalfa fertility program. Keep a record for each field and include the location of permanent benchmark areas, dates of sampling, soil and plant tissue test results, fertilizer application dates, fertilizers applied and the rate of application, and crop yields. This information can help you evaluate both the need for and the response to applied fertilizer and allow you to develop an economical, long-term fertilization program.

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CHAPTER SIX

WEEDS

Jerry L. Schmierer and Steve B. Orloff

Weeds compete with alfalfa for water, nutrients, light, and space. If weeds are left uncontrolled, they can reduce alfalfa yields and weaken or even destroy the stand. Weeds also reduce the quality and value of alfalfa hay because most weeds are less palatable and less nutritious than alfalfa. Some weeds—such as hare barley (commonly called foxtail), downy brome (cheatgrass), and green foxtail (bristlegrass)—can injure the mouths of livestock, rendering the forage less palatable. Others, such as fiddleneck and yellow starthistle, are poisonous and, if present in sufficient quantities, make the forage unsuitable for livestock consumption.

Weed control can be particularly challenging in the Intermountain Region because of long alfalfa stand life. Weeds invade the open areas that often occur in older depleted alfalfa stands. Weed control is problematic when fields remain in the same crop for many years and where few rotation crops are grown, two conditions that are common in many parts of the Intermountain Region.

WEED BIOLOGY

Effective weed management requires an understanding of weed biology. Weeds are classified according to their life cycle and fall into three groups: annuals, biennials, and perennials. Table 6.1 lists common weeds that occur in intermountain alfalfa fields.

Annual weeds emerge from seed, grow, flower, produce seed, and die within a year. Plants the next season must emerge from seed. Annual weeds are divided into winter and summer annual weeds, depending on growth pattern. Winter annual weeds germinate in the fall through early spring (October to March), when soil temperature and moisture are favorable. They grow rapidly in the spring and are usually a problem only in the first cutting of alfalfa. Summer annual weeds germinate as temperatures rise in the late spring (April to May) through summer, whenever soil moisture is adequate. Summer annual weeds are not a problem in the first cutting of established stands, but they appear in the second and later alfalfa cuttings. Only a few weeds in alfalfa are classified as biennials, which require 14 to 24 months to complete their life

Table 6.1. Problem weeds of alfalfa in the Intermountain Region of California.

COMMON NAME	BOTANICAL NAME	FAMILY
WINTER ANNUAL WEEDS		
Shepherdspurse	*Capsella bursa-pastoris*	Mustard
Flixweed	*Descurainia sophia*	Mustard
Tansymustard	*Descurainia pinnata*	Mustard
Tumble mustard/Jim Hill mustard	*Sisymbrium altissimum*	Mustard
Field pepperweed	*Lepidium campestre*	Mustard
Yellowflower pepperweed	*Lepidium perfoliatum*	Mustard
Prickly lettuce	*Lactuca serriola*	Lettuce
Downy brome (cheatgrass)	*Bromus tectorum*	Grass
Hare barley (foxtail)	*Hordeum leporinum*	Grass
Wild oats	*Avena fatua*	Grass
Volunteer cereals		Grass
SUMMER ANNUAL BROADLEAF WEEDS		
Pigweed	*Amaranthus spp.*	Amaranth
Lambsquarters	*Chenopodium album*	Goosefoot
Russian thistle	*Salsola iberica*	Goosefoot
Common sunflower	*Helianthus annuus*	Thistle
Dodder	*Cuscuta spp.*	Morningglory
Witchgrass	*Panicum capillare*	Grass
Green foxtail (bristlegrass)	*Setaria viridis*	Grass
Stinkgrass (lovegrass)	*Eragrostis cilianensis*	Grass
Barnyardgrass	*Echinochloa crus-galli*	Grass
Italian ryegrass	*Lolium multiflorum*	Grass
PERENNIAL AND BIENNIAL WEEDS		
Swamp knotweed	*Polygonum coccineum*	Buckwheat
Chicory	*Cichorium intybus*	Thistle
Common dandelion	*Taraxacum officinale*	Thistle
Cheeseweed	*Malva spp.*	Mallow
Canada thistle	*Cirsium arvense*	Thistle
Bull thistle	*Cirsium lanceolatum*	Thistle
Poverty sumpweed	*Iva axillaris*	Thistle
Buckhorn plaintain	*Plantago lanceolata*	Plantain
Bulbous bluegrass	*Poa bulbosa*	Grass
Foxtail barley	*Hordeum jubatum*	Grass
Kentucky bluegrass	*Poa pratensis*	Grass
Squirreltail	*Sitanion hystrix*	Grass
Quackgrass	*Elytrigia repens*	Grass
Perennial ryegrass	*Lolium perenne*	Grass
Tall fescue	*Festuca spp.*	Grass
Muhly	*Muhlenbergia spp.*	Grass
Meadow foxtail	*Alopecurus pratensis*	Grass

cycle. In alfalfa, perennial weeds are much more common than biennials. They live for 3 years or longer. Some perennials, such as dandelion and plantain, reproduce from seed. Others, such as field bindweed, quackgrass, and Canada thistle, are creeping perennials with vegetative structures (stolons or rhizomes) that permit them to produce asexually, without seed.

WEED CONTROL

An integrated approach that employs cultural, mechanical, and chemical control is the most effective method for controlling weeds in alfalfa. (Table 6.2 gives an overview of herbicides registered for use in California alfalfa fields.) Controlling weeds in a thin, weak alfalfa stand is very difficult or even impossible. Agronomic practices that promote a dense vigorous stand of alfalfa are a primary component of any successful weed control program. These practices (which include managment of planting date, fertilization, irrigation, and harvest) are explained in detail in other chapters of this book.

Weed management in alfalfa involves two distinct phases: weed control in seedling alfalfa and weed control in established alfalfa. Control of perennial weeds occurs in seedling alfalfa and established alfalfa; it will be discussed last.

WEED CONTROL IN SEEDLING ALFALFA

Alfalfa is most vulnerable to weed competition when it is in the seedling stage. Alfalfa seedlings grow slowly and do not compete well with weeds, which are often more vigorous. Aside from the poor quality of a weedy first cutting, weeds in seedling alfalfa can severely reduce stand. In the absence of adequate control measures, severe weed infestations can cause stand establishment failures.

Cultural Control

Crop rotation can be effective for reducing weed populations in seedling alfalfa. Some weeds are more easily controlled in other crops than they are in alfalfa. For example, relatively inexpensive phenoxy herbicides control most broadleaf weeds in grain. By con-

Table 6.2. Time of application and method of activity for herbicides used in alfalfa.

	CROP STAGE		TIME OF HERBICIDE APPLICATION			HERBICIDE ACTIVITY	
Herbicide	Seedling Alfalfa	Established Alfalfa	Preplant	Before Weed Emergence	After Weed Emergence	Soil Active	Foliar Active
Eptam (EPTC)	Yes	Yes	Yes	Yes	No	Yes	No
Balan (benefin)	Yes	No	Yes	Yes	No	Yes	No
Butyrac, Butoxone (2,4-DB)	Yes	Yes	No	No	Yes	No	Yes
Buctril (bromoxynil)	Yes	No	No	No	Yes	No	Yes
Poast (sethoxydim)	Yes	Yes	No	No	Yes	No	Yes
Kerb (pronamide)	Yes	Yes	No	Yes	Yes	Yes	No
Gramoxone (paraquat)	Yes	Yes	Yes	No	Yes	No	Yes
Velpar (hexazinone)	Yes[1]	Yes	No	Yes	Yes	Yes	Some
Karmex, Direx (diuron)	No	Yes	No	Yes	Some	Yes	Slight
Lexone, Sencor (metribuzin)	No	Yes	No	Yes	Yes	Yes	Some
Treflan (trifluralin)	No	Yes	No	Yes	No	Yes	No

1. California registration only

Alfalfa is most vulnerable to weed competition when it is in the seedling stage.

trolling broadleaf weeds in a grain crop that precedes alfalfa, the weed infestation in a seedling alfalfa field is lessened. Similarly, weed infestations are generally low following high-value row crops which are often maintained nearly weed-free.

Further reduce weed problems in alfalfa by planting when weed populations are low and growing conditions are optimal for alfalfa. Low temperatures favor the growth of winter annual weeds over alfalfa; high temperatures favor summer annual weed growth. A window of opportunity for planting occurs in late summer. This is the time when summer annual weeds decline in number and vigor and before most winter annual weeds emerge. Summer annual weeds that emerge in the late summer go into a reproductive stage sooner than summer annual weeds that emerge in spring. During this stage the weeds compete less than usual with alfalfa. Summer annual weeds that emerge with the crop are subsequently killed by fall frosts. Therefore, plant during this window, when moderate temperatures favor alfalfa growth over the weeds. A similar window occurs in the spring, after most of the winter annual weeds have emerged but before summer annual weeds become troublesome.

Weed problems can be reduced by preirrigating and then cultivating with a harrow or disc after weed emergence. This does not completely eliminate weeds, but it reduces their population and makes other control measures more effective.

Healthy alfalfa is an excellent competitor with weeds. Therefore, a key to effective weed management is to maintain a dense, vigorous stand of alfalfa. Select an adapted alfalfa variety, and plant weed-free certified alfalfa seed. An adequate seeding rate and proper seedbed preparation help ensure a dense stand (see chapter 2). High alfalfa seeding rates enhance the competitiveness of alfalfa, but an excessive seeding rate is an expensive weed control method. Proper fertility is also important in maximizing the competitiveness of seedling alfalfa.

Small-grain companion crops are sometimes used for weed control in seedling alfalfa. A companion crop replaces undesirable weedy species and is itself a desirable forage that, the grower hopes, is not too competitive. To avoid excessive competition with alfalfa, companion crop seeding rates should not exceed 20 pounds per acre. Such a low seeding rate can usually only suppress weeds, not provide complete control. (See chapter 2 for more information on companion crops.)

Early mowing or clipping can be an effective way to rescue an alfalfa planting that is heavily infested with weeds. Mowing tall weeds improves sunlight penetration into the canopy. Many weeds do not recover after cutting, which allows alfalfa to compete more successfully. Also, weeds are more palatable and nutritious when cut early. However, if some weed species, especially grasses, are cut too early (for example, prior to bloom), they recover after mowing and contaminate subsequent cuttings. Realize that early mowing depletes stored carbohydrate root reserves, reducing the vigor of alfalfa. So mow early only when weeds are overtopping and shading the alfalfa. After cutting early, lengthen the time interval between the first and second cuttings. This will allow sufficient time for root reserves to be replenished.

Table 6.3. Application times for herbicides registered for use in seedling alfalfa fields.

TIME OF APPLICATION	HERBICIDE
Preplant	Roundup (glyphosate)
Postemergence to weed	Gramoxone (paraquat)
Preplant	Balan (benefin)
Pre-emergence to weed	Eptam (EPTC)
	Mixture of Balan and Eptam
Postplant	Buctril (bromoxynil)
Postemergence to weed	Butyrac, Butoxone (2,4-DB)
and alfalfa	Kerb (pronamide)
	Poast (sethoxydim)
	Gramoxone (paraquat)[1]
Postplant	Velpar (hexazinone)
Newly established alfalfa	Gramoxone (paraquat)

1. Apply at a low rate; follow manufacturer's instructions.

Chemical Control

Cultural control practices alone are often insufficient to adequately control weeds in seedling alfalfa; they must be supplemented with herbicides. Several herbicides are registered for use in seedling alfalfa fields (Table 6.3). No single herbicide used in seedling alfalfa will control the entire spectrum of weeds in intermountain alfalfa fields (Table 6.4). Therefore, weed identification is fundamental to proper herbicide selection. *Weeds of the West* (listed under Additional Reading at the end of this chapter) is an excellent weed identification reference.

Preplant foliar herbicides

Nonselective herbicides can control emerged weeds prior to the planting of alfalfa. Both glyphosate (Roundup) and paraquat (Gramoxone) are registered for this use. These herbicides control emerged weeds only; they do not control weeds that emerge after application. Preplant foliar herbicides are most effec-

Table 6.4. Weed susceptibility to herbicides registered for use on seedling alfalfa[1]

	PREPLANT		POSTEMERGENCE				
	BALAN	EPTAM	BUCTRIL	2,4-DB	KERB	POAST	GRAMOXONE
WINTER ANNUAL WEEDS							
Downy brome (cheatgrass)	P	C	N	N	C	P-C	C
Hare barley (foxtail)	P	P	N	N	C	P-C	C
Volunteer cereals	P	C	N	N	C	C	P-C
Fiddleneck	C	P	C	N-P	N	N	P-C
Flixweed	N	N	P	C	N	N	C
Tumble mustard	N	N	C	C	N	N	P
Shepherdspurse	N	P	C	C	N	N	P
Prickly lettuce	N	C	P-C	C	N	N	C
Clasping pepperweed	–	–	C	C	N	N	C
Filaree	C	C	N	C	P	N	P
SUMMER ANNUAL WEEDS							
Barnyardgrass	C	C	N	N	N	C	P
Green/yellow foxtail	C	C	N	N	P	C	C
Lovegrass	C	C	N	N	C	C	C
Witchgrass	C	C	N	N	C	C	C
Lambsquarters	C	C	C	C	N	N	P-C
Nightshade	N	C	C	C	N	N	C
Pigweed	C	C	P	C	N	N	P-C
Russian thistle	P	P	C	P	P	N	P
Knotweed	C	P	P	P	N-C	N	P
Dodder	N	N	N	N	P	N	P
PERENNIAL WEEDS							
Bulbous bluegrass	–	–	N	N	C	–	C
Foxtail barley	P	P	N	N	C	P	P
Kentucky bluegrass	–	–	N	N	C	P	P
Quackgrass	–	P	N	N	C	P	N
Field bindweed	N	N	N	N-P	–	N	N
Dandelion	–	–	N	CSO	N	N	P
Plantain	–	–	N	CSO	N	N	–

N = no control; P = partial control; C = control; – = no information available; CSO = control of seedling weeds only

1. Weed susceptibility to Velpar is found in Table 6.5.

tive for early spring plantings where the seedbed is prepared in the fall and weeds emerge with winter rains. The field is treated, and then the alfalfa is drilled with a no-till or conventional drill, without disturbing the soil. Soil disturbance brings weed seeds to the surface, reducing the effectiveness of this treatment.

Preplant soil herbicides

EPTC (EPTAM) AND BENEFIN (BALAN)
These herbicides are used before planting and prior to weed and crop emergence. Do not use them when a small-grain companion crop is planted; it will be killed. Eptam and Balan are generally applied to the soil surface and mechanically incorporated into the soil. Eptam can also be injected into irrigation water. These herbicides are often applied and incorporated in the same pass. To minimize volatilization losses, avoid spraying Eptam onto moist soil. Herbicides can be incorporated with a power-driven rotary tiller or by discing twice, at right angles. Set power-driven tillers to the desired depth of incorporation; set discs or ground-driven tillers to twice as deep as the desired incorporation depth. For most annual weeds, incorporation depth should be 1 to 2 inches. When using Eptam to control volunteer cereals, quackgrass, and wild oats, incorporation depth should be 2 to 3 inches. Balan is more expensive but more persistent than Eptam—the soil life of Balan is 3 to 5 months; that of Eptam is 1 to 2 months. Alfalfa is seldom injured from applications of Balan, but Eptam has caused stunted plants with malformed (cupped and clasped) leaves (color photo 6.1). However, crop injury is usually confined to alfalfa grown in coarse-textured soils, and symptoms are usually temporary. Postemergence applications of 2,4-DB following preplant Eptam applications can cause excessive injury because Eptam reduces the protective cuticle layer of alfalfa, allowing it to absorb more 2,4-DB than it would otherwise.

Late application is the most common reason for postemergence herbicide failure.

Eptam and Balan are more suited to a spring planting than a late summer or fall planting. They control a broad spectrum of summer annual weeds but do not control many of the problem winter annual weeds, such as those in the mustard family. Results have been somewhat erratic in the Intermountain Region, even on spring plantings. This may be due to inadequate incorporation procedures. Eptam and Balan can be tank-mixed at lower rates of each to expand the spectrum of weeds controlled. Consult manufacturer's instructions before mixing.

Postemergence herbicides

Postemergence herbicides are often used in preference to preplant herbicides because they allow the grower to evaluate the weed pressure, identify weed species prior to application, and select an herbicide according to its effectiveness on the weed species present. Proper application timing is critical because small weeds are much easier to control than large ones. Late application is the most common reason for postemergence herbicide failure. In general, apply postemergence herbicides when alfalfa reaches the minimum growth stage stated on the herbicide label. Figure 2.4 shows seedling alfalfa growth stages. Remember, that a true alfalfa leaf is trifoliolate (it has three leaflets attached to a single petiole); do not confuse cotyledons or unifoliolate leaves with true leaves, or you may apply the herbicide too soon.

2,4-DB (BUTYRAC, BUTOXONE) The herbicide 2,4-DB is very effective at controlling many of the broadleaf weeds that emerge with alfalfa in both spring and late summer or fall plantings. Only the amine formulation of 2,4-DB is currently available, and its performance is inferior to that of the ester formulation, which was used formerly. Research has indicated that the activity of 2,4-DB amine can be improved to a level comparable to that of the ester formulation by adding a nonionic surfactant at 0.25 percent (one quart per 100 gallons spray volume). Young, vigorously growing weeds are most susceptible. Apply when alfalfa has two to four trifoliolate leaves. The best control is obtained when several days of warm sunny weather follow 2,4-DB applications. Apply as soon as possible after an irrigation or rainfall. Irrigation or significant rainfall within 3 to 5 days after application can cause alfalfa injury (color photo 6.2). Because of rain, spring applications of 2,4-DB can be difficult to accomplish in the Intermountain Region.

BROMOXYNIL (BUCTRIL) Like 2,4-DB, Buctril is used for broadleaf weed control in seedling alfalfa. Alfalfa must have a minimum of four trifoliolate leaves before it can be treated safely with Buctril. Weed size is critical when using this chemical. Be sure weeds are not taller than 3 inches and do not exceed the four-leaf stage. Do not apply when temperatures may exceed 80°F (27°C) during or following application; Buctril may injure alfalfa if the temperature is too high (color photo 6.3). Excessive injury can also occur in the Intermountain Region when an application follows a period of cool, overcast weather. For these reasons, applying Buctril in spring or summer can be difficult. A drawback of Buctril is that it does not completely control pigweed (especially if it is taller than 2 to 3 inches), a common summer annual weed in spring- and summer-planted alfalfa. However, it is more effective than 2,4-DB for fiddleneck and Russian thistle control. Combinations of Buctril and 2,4-DB can be effective for controlling a broader spectrum of weeds than either herbicide can control when used alone.

SETHOXYDIM (POAST) This chemical controls emerged grasses selectively, with no injury to seedling alfalfa or broadleaf weeds. Poast can be applied safely at any alfalfa growth stage; however, treatment is preferable when grasses are small, before the alfalfa canopy covers grass seedlings. For best results, apply Poast when grasses are growing vigorously, not when they are moisture-stressed. In addition to weedy grasses, Poast can control dense stands of volunteer cereals or an aggressive companion crop. Poast has not been widely used in the Intermountain Region, because problems with grass are not common in spring-planted seedling alfalfa. Hare barley (foxtail) and downy brome (cheatgrass) may appear in fall-planted fields, but under most conditions Poast provides only partial control of these weeds. (The product Poast Plus controls these weeds, but is not currently registered in California.) Poast will not control bluegrass species.

PRONAMIDE (KERB) Used in seedling alfalfa to control winter annual grasses and volunteer cereals, Kerb is active in soil. It provides both pre-emergence and postemergence control of susceptible weeds. Kerb controls certain broadleaf weeds at high application rates, but not at the low rates used in alfalfa. (Higher rates are generally not cost-effective.) Inconsistent or incomplete weed control may occur in soils containing more than 4 percent organic matter. Kerb is safe for use on seedling alfalfa and may be applied to alfalfa with one to four trifoliolate leaves. Approximately ½ inch of rainfall or overhead irrigation is required after application to move the herbicide into the root zone. Greater quantities of water may wash Kerb too deep into the soil, resulting in poor weed control. The time span between application and incorporation is not as critical in cool temperatures (those below 55°F, or 13°C) as in warm temperatures. Kerb acts slowly, requiring as long as 60 days from the time of incorporation to kill many grasses. If a Kerb-treated field needs to be replanted, residual herbicide can injure emerging alfalfa seedlings.

PARAQUAT (GRAMOXONE) Do not apply Gramoxone to alfalfa with fewer than three trifoliolate leaves. As the manufacturer's label warns, stands will be reduced by application when alfalfa is too young; reduction can be so severe that replanting is necessary. The rate and safety of Gramoxone use increase when alfalfa reaches the six-trifoliolate leaf stage and again when the plant reaches the nine-trifoliolate-leaf stage. Alfalfa foliage present at the time of application will be burned; compared to young plants, more mature alfalfa is better able to withstand the injury. Do not use Gramoxone on a spring planting, because it does not control some of the common summer annual weeds (such as lambsquarters and pigweed) and because crop injury is likely. The best use for Gramoxone is on newly established alfalfa during the first dormant season after planting.

HEXAZINONE (VELPAR) Like Gramoxone, Velpar can be used for weed control in seedling alfalfa, though crop safety is marginal. The advantages of Velpar are that it controls a broad spectrum of grass and broadleaf weeds and it is less expensive than most other herbicides for seedling alfalfa. Apply Velpar only to alfalfa plants that have lateral secondary growth and roots longer than 6 inches. Applications can be made only in the winter months, when alfalfa plants are not actively growing. Therefore, the use of Velpar on first-year alfalfa in the Intermountain Region is restricted to dormant applications with low rates to newly established alfalfa planted by mid-August.

IMAZETHAPYR (PURSUIT) At the time of publication, January 1995, Pursuit is not registered in California. Pursuit, a postemergence herbicide, has been evaluated in field trials in the Intermountain Region and throughout California. It controls most of the winter and summer annual weeds encountered in intermountain seedling alfalfa fields, including filaree, pigweed, nightshade, and weeds in the mustard family (such as tansymustard, flixweed, tumble mustard, and shepherdspurse). It suppresses many grasses and therefore should not be applied when a cereal is planted as a companion crop to alfalfa. Only a few common broadleaf weeds escape control. Pursuit only stunts Russian thistle and lambsquarters, unless it is applied when these weeds are very small. This herbicide cannot control prickly lettuce and annual sowthistle. Pursuit is slow acting, especially when temperatures are cool. Susceptible weeds stop growing soon after application; they die within a few weeks. Pursuit has tremendous potential for weed control in seedling alfalfa fields; however, do not consider using this herbicide until it receives California registration.

WEED CONTROL IN ESTABLISHED ALFALFA

Weed management in established alfalfa can be divided into three categories: control of winter annual weeds, control of summer annual weeds, and control of perennial weeds.

Winter Annual Weed Control

Winter annual weeds emerge with fall and winter rain. Winter weather kills some species, but enough weeds usually either survive or emerge late to infest the first cutting of alfalfa and contaminate the hay. Cultural controls are largely ineffective, because alfalfa does not compete well with weeds that emerge before the crop breaks dormancy.

Light cultivation with a harrow (a spring-toothed harrow, spike-toothed harrow, or Danish tine harrow) to uproot winter annual weeds can be partially effective under some circumstances. Timing is critical. The field must be harrowed after most of the weeds have emerged but just prior to the time alfalfa breaks dormancy and resumes growth. If fields are cultivated too early, subsequent rains can germinate a new crop of weeds. Injury to alfalfa crown buds and regrowth increase when the field is harrowed too late. Damage to crowns increases their susceptibility to disease. Fields heavily infested with weeds can be mowed early, but with the same drawbacks discussed earlier (in the section on weed control in seedling alfalfa).

Herbicides are usually required for complete control of winter annual weeds.

Herbicides are usually required for complete control of winter annual weeds. The herbicides diuron (Karmex or Direx), hexazinone (Velpar), metribuzin (Sencor or Lexone), and Gramoxone are registered for use in established alfalfa. Effective weed control programs for the Intermountain Region may use these herbicides alone or in combination. Factors to consider when selecting the proper herbicide or herbicide combination include the following:

- weed history
- soil texture
- soil organic matter
- likelihood of rainfall for incorporation of herbicides
- remaining stand life (Will the field be taken out of production after the current production season?)
- economics

These factors will be discussed later in this chapter in relation to specific herbicides.

Soil-active herbicides

VELPAR, KARMEX, AND SENCOR These three chemicals control a broad range of annual and perennial weeds (Table 6.5). These herbicides are soil active and inhibit photosynthesis in susceptible plants. Alfalfa must be established for at least one year before Karmex or Sencor can be applied. If alfalfa is not dormant significant injury can occur (color photo 6.4). Soil-active herbicides must be incorporated into the soil by rainfall or sprinkler irrigation.

Velpar controls most winter annual weeds and suppresses many perennial weeds that infest intermountain alfalfa fields. In fact, of the soil-applied herbicides, Velpar has the broadest spectrum of activity. Its activity is similar to that of Sencor, but Velpar is more effective at controlling shepherdspurse, one of the most common weeds infesting alfalfa (Figure 6.1). It is even effective on soils high in organic matter, such as those in the Tulelake Basin. Velpar is more effective on emerged weeds than other soil-active herbicides, particularly when a nonionic surfactant is added. However, do not add surfactant after alfalfa growth begins, or significant crop injury may result. Use rates vary according to weed species and soil types; refer to herbicide labels for specific rate recommendations. Reduced rates of Velpar (such as 0.375 pound active ingredient per acre on sandy loam soil low in organic matter) have been used successfully where Velpar is used 2 or more years in succession. Velpar is persistent in soil. Do not plant other crops for at least two years following an application of Velpar.

Karmex, also sold as Direx, controls a broad spectrum of winter annual weeds in alfalfa. It is less expensive than Velpar but less effective on emerged weeds, particularly emerged grasses such as downy brome (cheatgrass). If the population of emerged weeds is large, tank-mix Karmex with Velpar or Gramoxone for improved control. (Karmex is frequently tank-mixed with Velpar at reduced rates of each. This broadens the weed spectrum controlled and reduces cost.) Do not apply Karmex to sandy soil.

The activity of Sencor, also sold as Lexone, is similar to that of Velpar. It is commonly used in the last year of production of an alfalfa field, especially in fields where potatoes follow alfalfa. In addition to being labeled for use on alfalfa, Sencor is labeled for use on mixed stands of alfalfa and grasses. Low rates can be used to control weeds and to prevent excessive competition from grasses.

Foliar herbicides

GRAMOXONE AND 2,4-DB These two foliar herbicides are registered for use in established alfalfa. The herbicide 2,4-DB is comparatively expensive and controls only small broadleaf weeds. Alfalfa injury from 2,4-DB is more prevalent in established than in seedling alfalfa. Therefore, in the Intermountain Region, limit its use to seedling alfalfa.

Gramoxone controls a range of winter annual weeds (Table 6.5) and is widely used in the Intermountain Region. Because Gramoxone is inactive in soil, it is well suited for use in the last year of an alfalfa stand. It is especially effective on winter annual grasses such as hare barley (foxtail) or downy brome (cheatgrass). Small, vigorously growing weeds are most susceptible,

(A)

(B)

Figure 6.1. (A) Shepherdspurse and (B) tansy-mustard are the most common winter annual weeds found in intermountain alfalfa fields.

Table 6.5. Weed susceptibility to herbicides registered for use on established alfalfa.

	VELPAR	SENCOR/ LEXONE	GRAMOXONE	KARMEX/ DIREX	TREFLAN	POAST	KERB	EPTAM	2,4-DB
WINTER ANNUAL WEEDS									
Shepherdspurse	C	C	P	C	N	N	N	P	P–C
Flixweed/Tansymustard	C	C	P–C	C	N	N	N	N	C
Jim Hill mustard	C	C	P	C	N	N	N	N	C
Field pepperweed	C	C	C	C	N	N	N	—	C
Yellowflower pepperweed	P–C	C	C	C	N	N	N	—	C
Downy brome (cheatgrass)	C	C	C	P	C	P–C	C	C	N
Hare barley (foxtail)	C	C	C	C	C	C	C	P	N
Wild oats	P–C	N	P	N–P	N	C	C	C	N
Volunteer cereals	P–C	P	C	C	N	C	C	C	N
	VELPAR	SENCOR/ LEXONE	GRAMOXONE[1]	KARMEX/ DIREX	TREFLAN	POAST	KERB	EPTAM	2,4-DB
SUMMER ANNUAL WEEDS									
Pigweed	C	C	N–P	C	P	N	N	C	C
Lambsquarters	P	P	N–P	C	P	N	N	C	C
Russian thistle	P	P	—	P	P	N	N	P	P
Common sunflower	—	—	—	—	—	—	—	—	C
Dodder	N	N	N–P	N	C	N	P	N	N
Prickly lettuce	C	C	P–C	P–C	N	N	N	P	C
Witchgrass	P	P	—	P	C	C	C	C	N
Green foxtail (bristlegrass)	N	P	N	P	C	C	P	C	N
Lovegrass (stinkgrass)	P	—	—	C	C	C	C	C	N
Barnyardgrass	P	C	P	P	C	C	N	C	N
	VELPAR	SENCOR/ LEXONE	GRAMOXONE	KARMEX/ DIREX	TREFLAN	POAST	KERB	EPTAM	2,4-DB
PERENNIAL WEEDS									
Swamp knotweed	—	—	N–P	—	N	N	N	—	P
Chicory	—	—	—	—	—	—	—	—	P
Common dandelion	N–P	P	—	—	N	N	—	—	C*
Cheeseweed	P*	P*	P	P	N	N	N	N	N
Canada thistle	N	N	P*	—	N	N	N	N	P*
Bull thistle	—	—	P*	—	N	N	N	N	C*
Povertyweed	—	—	—	—	—	—	—	—	—
Buckhorn plantain	N–P	—	—	N–P	N	N	N	—	C*
Bulbous bluegrass	P–C	C	C	P	P	—	C	—	N
Foxtail barley	P	C*	P–C	P–C*	—	—	C	P–C	N
Squirreltail	—	—	—	—	—	—	C	—	N
Kentucky bluegrass	P	P	P	—	N	P	C	—	N
Quackgrass	P*	—	N	P	N	P	C	P	N
Perennial ryegrass	—	—	—	—	—	—	C	—	N
Tall fescue	—	—	—	—	—	—	C	—	N
Muhly	—	—	—	—	—	—	C	—	N
Meadow foxtail	—	—	—	—	—	—	C	—	N

C = control; P = partial control; N = no control; * = control of seedling weeds only; — = no information available.
1. Gramoxone is not usually applied when summer weeds have emerged.

but weeds up to 6 inches tall can be treated. Gramoxone is strictly a postemergence contact herbicide; once it comes into contact with soil, or with even a thick layer of dust on leaves, it is deactivated. For best results, apply it after most of the weeds have emerged (in March in most areas). However, never apply it after alfalfa has 2 inches of growth. Lassen County studies showed that treating alfalfa when it was 4 inches tall rather than 1 to 2 inches tall resulted in a 0.5-ton yield reduction.

Always add a nonionic surfactant with Gramoxone; otherwise, weed control will decrease significantly. The visible effects of Gramoxone are observable after approximately 4 days. An evaluation of control can be made after 7 days. If the growing point is not visibly desiccated, weeds may recover.

Gramoxone can be tank-mixed with low rates of a soil-active photosynthetic inhibitor. The addition of the photosynthetic inhibitor (Velpar, Karmex, or Sencor) retards the initial contact activity of Gramoxone. Tank mixing improves the effectiveness of Gramoxone and broadens the spectrum of weeds controlled. The combination of Gramoxone and a photosynthetic inhibitor is particularly well suited to application in March, when most weeds have emerged but rainfall may be insufficient to incorporate soil-active herbicides. As with Gramoxone alone, treatment must be made before alfalfa has 2 inches of growth. An application window of approximately 2 weeks usually occurs in March, depending on the year and location. The tank mix is effective when applied to soils high in organic matter where soil-active herbicides alone have sometimes failed.

Application timing for winter-weed control

Proper application timing is essential for effective weed control and for avoidance of crop injury (Table 6.6). Soil-active herbicides can be applied anytime between November and February, when alfalfa is dormant. However, treatments from late December to early January may be difficult because soil-active herbicides should not be applied to frozen or snow-covered ground. Although not common, applications in November to early December have several advantages. Because alfalfa is completely dormant, risk of injury is comparatively low. The likelihood of sufficient precipitation for incorporation of herbicides is greater and the cost is usually less (soil-active herbicides do not need to be combined with Gramoxone). Weed control is often better because many of the winter annual weeds have not emerged or are very small. Disadvantages are that some weeds may escape treatment when rodent activity brings untreated soil to the surface. Also, areas treated with a soil-active herbicide cannot be reseeded, which may be necessary when winterkill of alfalfa is severe.

Provided soils have thawed and snow has melted, soil-active herbicides can also be applied in late January through February and as late as March in high-elevation valleys. This may be difficult when winters are severe. As soon as snow melts or soils thaw, alfalfa resumes growth. If herbicides are applied after alfalfa has broken dormancy, yellowing (chlorosis) of alfalfa and reduced yields occur (color photo 6.4). Symptoms of late treatment may not be apparent unless treated areas can be compared to untreated areas.

Apply Gramoxone, or tank mixes of Gramoxone and soil-active herbicides, in spring, before alfalfa has grown 2 inches. If growth is greater than 2 inches, do not use an herbicide; consider early mowing if weed infestation is severe.

SUMMER ANNUAL WEED CONTROL

A dense, vigorous alfalfa stand permits little light to reach below the canopy, preventing summer annual weeds from becoming established. Proper fertilization, irrigation, and production practices usually make an herbicide application unnecessary. Residual activity of winter herbicides in soil also helps lessen, but does not always eliminate, summer annual weed problems. For example, soil residual from Karmex controls lambsquarters but is only partially effective for green foxtail (bristlegrass) control.

Occasionally, pigweed, lambsquarters, green foxtail, Russian thistle, and other weeds infest second and third cuttings. These weeds, with the possible exception of green foxtail, are usually a problem only in older, depleted stands. Green foxtail is an aggressive summer annual grass (Figure 6.2). It has been a major problem in the Central Valley of California for many years and is an increasing problem in some areas of the Intermountain Region. Trifluralin (Treflan TR–10) is

Table 6.6. Application times for herbicides registered for use in established alfalfa fields.[1]

TIME	WINTER ANNUALS	SUMMER ANNUALS	PERENNIAL WEEDS
Nov.–Feb. (before fields turn green)	Velpar (with surfactant) Lexone/Sencor Karmex/Direx		Kerb
Feb.–Mar. (some weed growth before alfalfa shows any green)	Velpar (without surfactant) Lexone/Sencor Karmex/Direx Karmex/Direx plus Velpar	Karmex/Direx plus Velpar	
Mar. (before alfalfa spring growth is 2 in. tall)	Gramoxone Gramoxone plus Velpar Gramoxone plus Lexone/Sencor Gramoxone plus Karmex/Direx		
Mar.–early May		Treflan TR-10	
May–Aug.		Poast	Poast

1. Slash (/) between herbicides means that the names cited are 2 different trade names for the same chemical.

very effective against green foxtail, barnyardgrass, and most common summer annual broadleaf weeds. Apply Treflan in March to early May, before summer annual weed emergence (actual date depends on area). Rainfall or overhead irrigation must follow within 3 days, or else reduced weed control may result. Because of the short growing season and small number of cuttings in the Intermountain Region, reducing the rates or using Treflan every other year is usually sufficient for excellent summer annual weed control.

Poast (discussed earlier, in the seedling section) can also be used to control green foxtail. After first or second cutting, apply Poast to emerged green foxtail prior to seedhead formation. Green foxtail should not be moisture-stressed at the time of application. Delay application until after an irrigation if grasses are moisture-stressed, but do not apply Poast if alfalfa growth prevents spray coverage of the grass.

PERENNIAL WEED CONTROL

Several perennial weeds—such as dandelion, quackgrass, bluegrass (both Kentucky and bulbous), and buckhorn plantain—commonly infest intermountain alfalfa fields. Perennial weed invasion is favored by the lack of tillage during the life of an alfalfa stand. Perennial weeds can be extremely difficult to control in established alfalfa. This is especially true for perennial broadleaf weeds; to selectively remove a perennial broadleaf weed from a perennial broadleaf crop such as alfalfa is almost impossible.

Figure 6.2. Green foxtail (commonly called bristlegrass) is an increasing problem in portions of the intermountain alfalfa production region.

A dense vigorous stand is by far the best defense against perennial weeds

Proper site selection is a key component of perennial weed control. Avoid planting alfalfa in fields heavily infested with perennial weeds such as quackgrass, dandelion, or Canada thistle. Prior to planting alfalfa, control these weeds through crop rotation, mechanical control, or with nonselective herbicides. An application of Roundup in the fall, prior to planting alfalfa, is effective. Plowing or multiple discings prior to planting can also control noncreeping perennial weeds, such as dandelion or buckhorn plantain. Also, avoid planting in fields with poor drainage, because poor drainage will retard alfalfa growth but help many weed species to thrive.

After clean fields are attained, the best approach for dealing with perennial weeds is to prevent them from reinvading. Sound cultural practices that maximize the competitive ability of alfalfa can minimize or delay encroachment by perennial weeds. A dense vigorous stand is by far the best defense against perennial weeds, because perennials first get a foothold in thin or weak areas of a field. Since most perennial weeds can be controlled in their seedling stage by using herbicides registered for use in alfalfa fields, annual herbicide applications prevent or delay perennial weed infestations.

Once perennial weeds become established in alfalfa, control options are limited. One option is to live with the weeds. Fortunately, perennial weeds do not always reduce the dietary value of the forage. For example, dandelions do not significantly detract from nutritional quality, though they do turn black after curing. This detracts from the alfalfa's appearance and reduces its price. When cut early, quackgrass-infested alfalfa is often marketed to feed stores as alfalfa-grass mixed hay. However, most buyers of dairy-quality hay will not purchase weed-infested alfalfa, so some method of controlling established perennials in alfalfa is needed.

Soil-active herbicides suppress some perennial weeds (such as dandelion, quackgrass, and bluegrass) after they become established. Velpar is usually the most effective. Kerb, applied at high rates (for example, 1.5 pounds active ingredient per acre), controls quackgrass and Kentucky bluegrass. However, these rates are generally cost-prohibitive for alfalfa production. They are recommended only for spot treatment of isolated grass patches or when pockets of perennial grasses are observed in a relatively young field. Kerb applications should be made before mid-February, when temperatures are cool and subsequent rainfall is ordinarily sufficient to incorporate the chemical into the soil.

Foliar-active herbicides have limited usefulness for controlling perennial weeds. Poast suppresses quackgrass, but repeated applications are needed to achieve measurable control. This treatment is expensive for the degree of control achieved. Therefore, treat quackgrass with Poast only in the year of establishment, before the rhizomes (underground stems) become too large and difficult to kill. Roundup is effective for spot treatment of most perennial weeds but is not recommended for widespread infestations; label restrictions permit no more than 10 percent of a field to be treated. Also, significant alfalfa injury can result if Roundup is applied when alfalfa is not completely dormant (color photo 6.5).

THE ECONOMICS OF CHEMICAL WEED CONTROL

Opting to treat alfalfa with herbicides can be a difficult management decision. Several factors must be considered: weeds species, their infestation level, alfalfa stand density, herbicide cost, alfalfa market, and probability of successful weed control. For treatment to be economical, weed infestations must be severe enough to reduce quality or alfalfa stand density. The value of improved forage quality or stand density must exceed the cost of treatment. In addition, the alfalfa stand density must be high enough to respond to the decreased competition after weeds are controlled. Herbicide applications to sparse, severely weed-infested stands will increase forage quality but can decrease total forage yield. Alfalfa does not spread into open areas, so removing weeds in sparse stands often results in reinfestation.

The anticipated market for alfalfa hay sometimes determines if treatment is economical. For example, herbicides may be unnecessary when hay is fed to livestock (cattle or horses) on the ranch and weed infestations are not too severe. Those who buy for dairies or feed stores, however, tolerate few weeds. If the market demands high quality, herbicide treatment is usually justified. Herbicide treatment during stand establishment is often justified by an increase in alfalfa stand density. Herbicides not only provide the immediate benefit of weed control, but they also reduce weed seed reserves in the soil. Because of the depletion of weed seeds in the soil, herbicide application every other year may be sufficient in some intermountain alfalfa fields. This is often the case when seedling alfalfa fields are treated during the establishment year. A benefit of weed control that is difficult to measure is the reduction in weeds that occurs in subsequent crops.

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CHAPTER SEVEN

INSECTS

Steve B. Orloff and Roger W. Benton

One of the advantages of the intermountain environment as compared with other alfalfa production areas is that insect pests are rarely a problem. Harsh winters and cool nights slow the development of insect pests. Therefore, in most years, insect populations do not reach levels that necessitate treatment. On the rare occasions when insect pests are present in significant numbers, their damage can be devastating to yield and quality. In fact, damage caused by insect feeding often surpasses yield losses due to poor variety selection, low fertility, and mismanagement. An effective pest management program can preclude significant yield losses.

A pest management program should include the following:

- correct identification of both harmful and beneficial insects
- proper monitoring or surveillance of fields
- reliable treatment thresholds
- effective prevention and control methods

INSECT IDENTIFICATION

The importance of proper insect identification cannot be overstated. You must be able to distinguish beneficial, innocuous, and harmful insects before you can choose methods to encourage beneficial ones and prevent damage from harmful species. Insecticide treatments can sometimes be avoided when sufficient populations of beneficial insects are present (Figure 7.1). Effective prevention and control strategies have been developed for most insect pests of alfalfa. The preferred pest management method varies depending on the pest, its population density, and environmental conditions. Pest management methods include planting resistant varieties, harvesting at a time that lessens pest damage, and using biological controls and insecticides.

Harmful insect populations must be kept below threshold levels. The threshold is that point at which economic damage by an insect population is imminent and treatment is recommended. The University of California (UC) has developed treatment thresholds for most of the major insect pests. The thresholds are linked to the value of the crop and can be adjusted in accordance with the anticipated market price. The ability to apply threshold data successfully depends on the frequency of field monitoring, which in turn depends on the season and the pest. At the very least, you should sample fields once a week when pests are likely to occur (Figure 7.2).

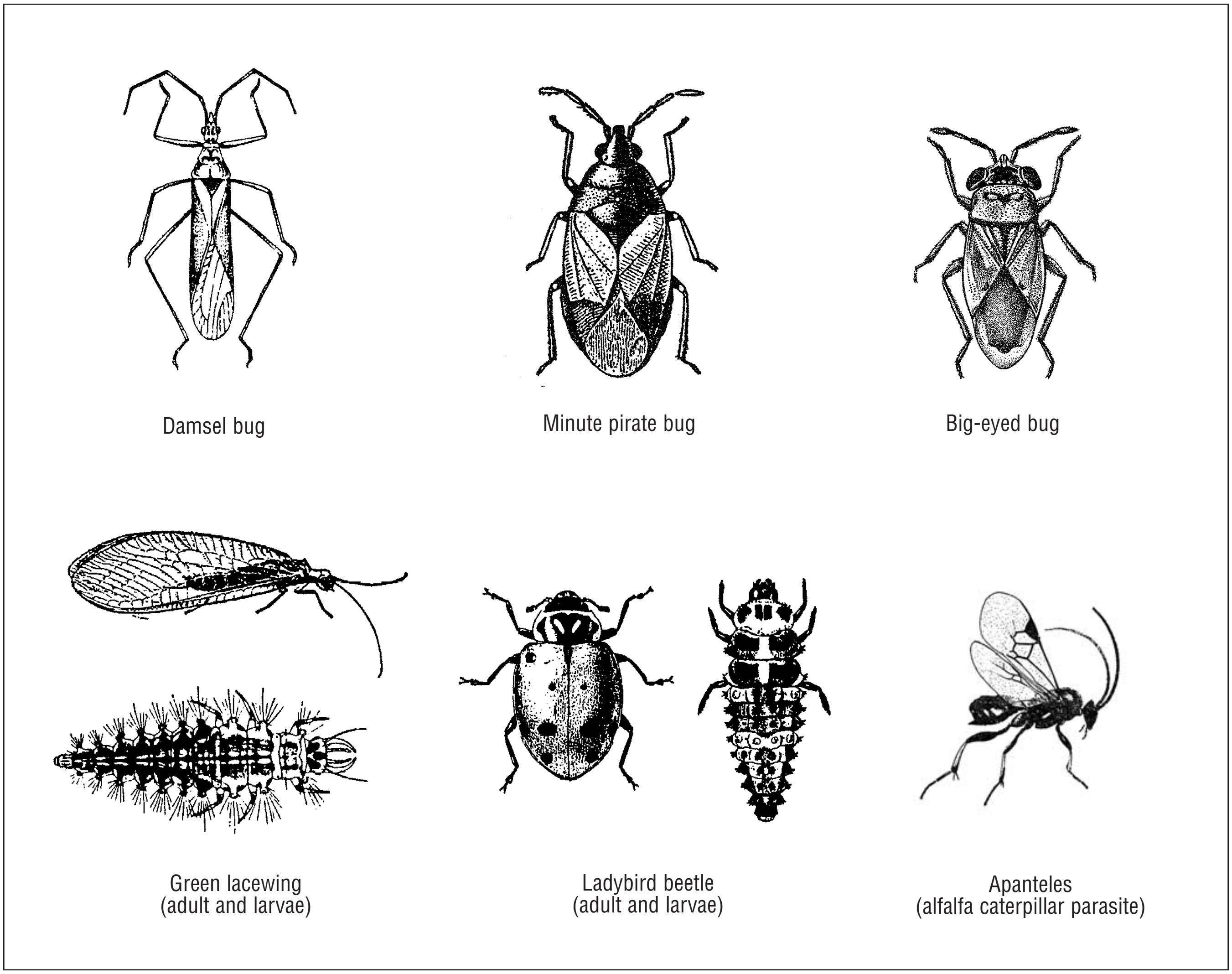
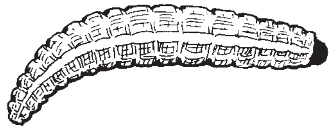


Figure 7.1. Beneficial insects commonly found in alfalfa.

The rest of this chapter describes the primary insect pests encountered in intermountain alfalfa fields. For each insect pest there is a description of its biology or life cycle, the damage it causes, monitoring techniques, and recommended management programs for the Intermountain Region. For more detailed descriptions and information (including color photographs) consult *Integrated Pest Management for Alfalfa Hay,* available from UC Cooperative Extension Offices.

ALFALFA WEEVIL



Alfalfa weevil (*Hypera postica*) is the most destructive insect pest in intermountain alfalfa fields. By chewing and skeletonizing leaves, this pest can dramatically reduce yield and quality. Larval feeding can be so severe that plants are defoliated, giving the entire field a gray cast. The alfalfa weevil is primarily a pest of the first cutting; when extreme population pressures occur, however, the effects of weevil feeding can carry over into the second cutting. Also, beware of alfalfa weevil damage in the second cutting if cool spring temperatures slow the development of the insect.

Depending upon temperatures, weevil larvae may appear in late March but are ordinarily most prevalent from mid-April to mid-June. A weevil larva is a small worm about 3/8 inch long when fully grown. It is pale green with a white stripe down the center of the body and a dark brown to black head (color photo 7.1).

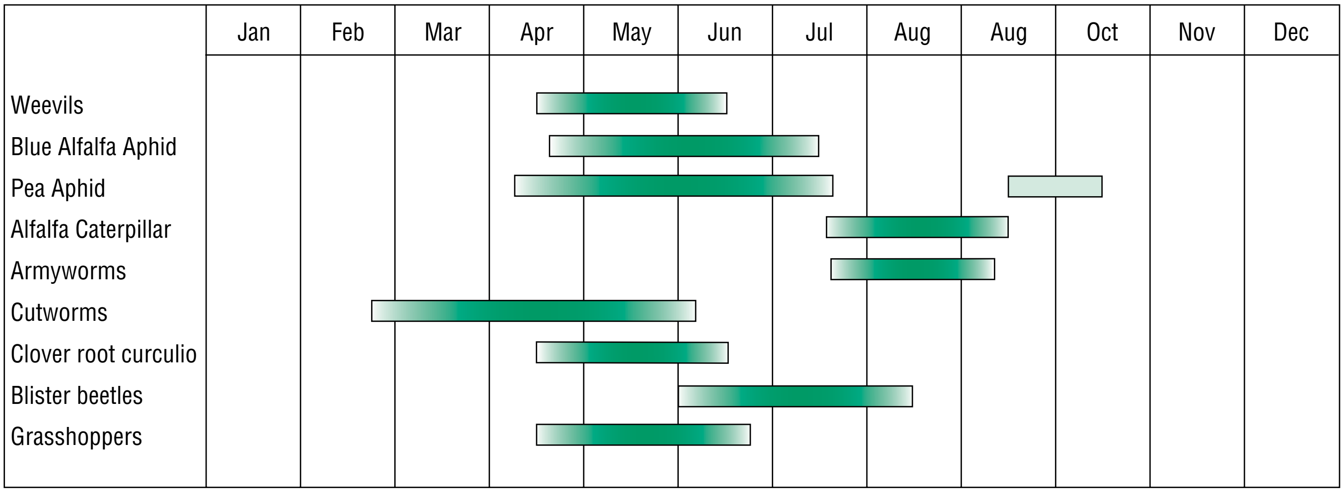


Figure 7.2. Seasonal occurrence of insect pests in the Intermountain Region.

Alfalfa weevils have four instars, or growth stages. Initially, weevils are pale or yellowish. They become an increasingly bright green as they develop. The first two instars feed on the tightly folded young leaves at the end of shoots, where they cause significant damage. These young worms can be difficult to locate, but small pinholes in young leaves signal their presence. The worms can be observed by carefully tearing apart the terminal leaves of shoots, where weevil feeding is apparent. Compared to younger worms, third- and fourth-instar larvae are more voracious feeders and cause significantly more damage. Larvae complete their growth in 3 to 4 weeks. Once mature, larvae spin silken cocoons either on the leaves or, more commonly, in debris on the soil surface (color photo 7.2). They mature into adults 1 to 2 weeks later.

An adult weevil is dark gray to brown, with a dark brown stripe on the back (color photo 7.3). It has a distinctive weevil snout approximately 3/16 inch in length. Adults feed for a short time, not causing significant damage, before most leave the field and enter a resting stage. The resting period is usually spent in weedy areas near the field or in field trash. Adults emerge in late winter or early spring, when they mate. Females deposit their eggs in alfalfa stems, completing the life cycle of the alfalfa weevil.

Alfalfa weevil is the most destructive insect pest in intermountain alfalfa fields.

Management guidelines

Alfalfa weevil populations are monitored with a sweep net. (Every grower should own a sweep net so that insects can be monitored on a regular basis. Contact your local Farm Advisor's office for a list of sweep net manufacturers.) A standard insect sweep net is a 15-inch-diameter wire loop fitted with a cone-shaped net bag attached to a 26-inch handle. Once weevil larvae are found, check the field every 2 to 4 days.

A single sweep consists of one 180-degree arc taken as you step forward (Figure 7.3). Hold the net vertically so that the lower rim is 1 or 2 inches ahead of the upper rim and at least 4 inches into the alfalfa (Figure 7.4). This positioning will allow you to catch any insects that fall from the plants. Take single or consecutive sweeps. In each field take several sweeps from all quadrants, and average the total number of larvae per sweep.

Parasitic wasps, *Bathyplectes curculionis* and others, have been released by U.S. Department of Agriculture (USDA) and Cooperative Extension researchers to keep weevil populations low. Though these wasps may be present, they often fail to keep weevil populations below the threshold level. Unfortunately, there is little a grower can do to initiate or encourage biological control other than follow sound integrated pest management (IPM) practices and use chemical treatments only when necessary.

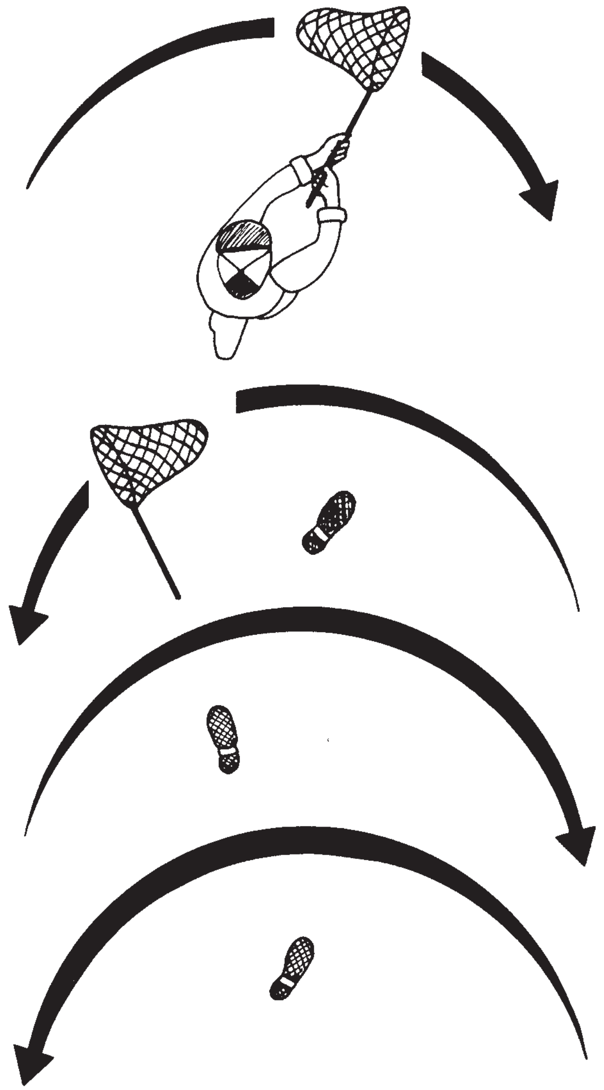


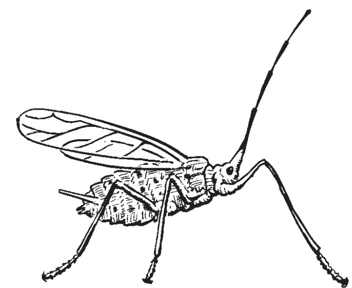
Figure 7.3. A single sweep is one 180-degree arc taken as you step forward. A sweep can be made singly or consecutively. To calculate the average number of insects per sweep, simply divide the total number of insects caught by the number of 180-degree sweeps.

At what point should you apply an insecticide? Implement chemical controls when counts approach 20 larvae per sweep. Sometimes significant populations of weevil larvae are present early in the season, before the alfalfa is tall enough to be swept. Under such conditions, use insecticides when 30 percent of the plant terminals show obvious signs of weevil feeding.

An alternative to insecticide treatment is early cutting of fields that are close to harvest. Weevil larvae are usually killed during harvesting. Occasionally, when weevil populations are extremely high, enough weevils survive in the windrow to prevent alfalfa from regrowing. Therefore, carefully check regrowth for signs of damage to the second cutting.

Figure 7.4. Sweeping alfalfa for alfalfa weevil larvae. Hold the net vertically so that the lower rim is 1–2 inches ahead of the upper rim and at least 4 inches into the alfalfa.

APHIDS



Both the pea aphid (*Acyrthosiphon pisum*) and the blue alfalfa aphid (*Acyrthosiphon kondoi*) damage alfalfa. They may be present in the field at the same time as the alfalfa weevil but are usually found slightly later (Figure 7.2). The pea aphid can survive warmer temperatures than can the blue alfalfa aphid and can therefore be found later in the spring and may even occur in late summer or early fall. These two aphids reproduce asexually and can multiply rapidly. Both are green, and they are similar in appearance. The easiest way to distinguish the two is to examine their antennae with a hand lens. Pea aphid antennae are green with a narrow dark band at the tip of each segment; those of the blue alfalfa aphid are uniformly brown (see color photo 7.4). Also, the blue alfalfa aphid is generally found on young tender shoots and developing leaves, whereas the pea aphid can be found over most of the plant. Ability to distinguish between these two species is important because the blue alfalfa aphid is more damaging.

Both aphids can stunt alfalfa and reduce yield by sucking plant juices with their piercing mouthparts. They secrete a sticky substance referred to as honeydew. Honeydew can hinder the baling process, and it promotes the growth of a black fungus that can reduce the palatability of the hay. In addition, the blue alfalfa aphid injects a growth-reducing toxin into the plant.

Management guidelines
Fortunately, aphid populations in the Intermountain Region seldom necessitate treatment. Predators, parasites, and fungi keep aphid populations in check most years, but population explosions can occur. Consider beneficial insect populations before applying an insecticide treatment. Common predators include convergent lady beetles (ladybugs), green lacewings, bigeyed bugs, minute pirate bugs, and damsel bugs (Figure 7.1). Aphid populations may increase when insecticides applied for control of the alfalfa weevil kill beneficial insects.

Resistant varieties of alfalfa have successfully minimized aphid damage. Alfalfa varieties resistant to pea aphid are readily available in the Intermountain Region. Nondormant varieties resistant to blue alfalfa aphid are available, but resistance has not been incorporated into most dormant varieties.

Stem samples are used to signal the need for aphid control. Cut the stem close to the ground, and hit it sharply against a stiff piece of white paper or into a white pan. This dislodges the aphids so they can be counted. Take several stems from different areas of the field. Short alfalfa is more severely damaged than tall alfalfa; therefore, the treatment threshold varies according to the height of the alfalfa (Table 7.1). Treatment thresholds are high; the mere presence of aphids in a field does not necessitate treatment. As mentioned, aphid populations rarely reach these levels in the Intermountain Region.

Sweep nets are used in some states to sample aphid populations. Although commonly used, this method is not precise or efficient. Collection of 100 pea aphids per sweep (a golf ball-sized ball of aphids) indicates the treatment threshold; for the blue alfalfa aphid, the total is lower.

Table 7.1. Treatment thresholds for pea aphid and blue alfalfa aphid.[1]

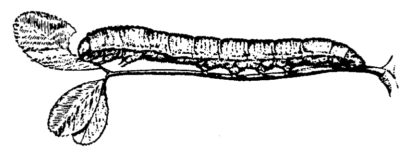
PLANT HEIGHT	PEA APHID/ STEM	BLUE ALFALFA APHID/STEM
Under 10 in.	40–50	
Over 10 in.	70–80	40–50
Over 20 in.	100	

1. Data apply to the stem-shaking method of sampling, not to sweeping. This chapter describes the shaking method in the section on aphids.

CATERPILLARS

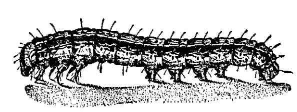
Alfalfa caterpillar (*Colias eurytheme*), beet armyworm (*Spodoptera exigua*), western yellowstriped armyworm (*Spodoptera praefica*), and alfalfa looper (*Autographa californica*) all feed on alfalfa during the summer. Temperatures are seldom warm enough for these pests to be a serious problem in the Intermountain Region, however.

Alfalfa caterpillar



Also referred to as alfalfa butterfly, this insect has a velvety green appearance. The larger larvae have a white stripe down both sides of their body. An invasion of alfalfa caterpillars is preceded by a large influx of the adult form, a yellow or white butterfly. The life cycle of the alfalfa caterpillar is closely synchronized with the cutting schedule of alfalfa. Infrequent cutting and a short growing season usually prevent it from reaching economically damaging levels in intermountain alfalfa fields. Furthermore, a parasitic wasp (*Apanteles medicaginis*) is very effective in controlling this pest; if alfalfa caterpillars are a suspected problem determine whether this wasp is present. Simply pull the worm apart—if a white larva pops out, the alfalfa caterpillar has been parasitized.

Armyworms



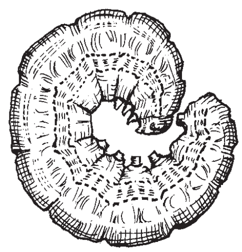
Beet armyworm and western yellowstriped armyworm are the most commonly occurring caterpillar pests. They appear during the hot periods of July and August. A problem often arises when one field is cut and armyworms migrate to adjacent fields. Natural enemies can frequently control these caterpillars. Population levels are cyclic and armyworms only sporadically occur in large numbers. In the Intermountain Region, the western yellowstriped armyworm predominates.

Both beet armyworm and western yellowstriped armyworm are smooth skinned. The beet armyworm is most often olive green, but it ranges in color from bright green to purplish green. The western yellow-striped armyworm is usually black with orange stripes down the sides. Both armyworms lay their eggs in clusters on the upper side of leaves. The eggs are covered with scales: Those of the beet armyworm are white and cottony, those of the western yellowstriped armyworm gray. Larvae hatch and skeletonize leaves, causing alfalfa terminals to flag. These leaves make detection of armyworms relatively easy even from considerable distances.

Management guidelines

Table 7.2 lists treatment thresholds for summer worms. These thresholds are based on sweep net counts using the same technique described in the alfalfa weevil section. Both alfalfa caterpillars and armyworms are often controlled by parasites and diseases, so the presence of parasitized and diseased worms should be determined before treatment.

CUTWORMS



Although a number of cutworm species attack alfalfa in the Intermountain Region, the variegated cutworm (*Peridroma saucia*) is most common. Cutworms are occasional pests in seedling alfalfa and less frequently a problem in established alfalfa. They can cause serious damage to seedling alfalfa fields by cutting off the seedlings at or just below the soil surface. Cutworms injure established fields by cutting off new growth or feeding on alfalfa foliage.

Cutworms can be extremely frustrating to the grower because they are difficult to detect. They feed primarily at night and hide under debris or in cracks in the soil during the day. Cutworms develop in weedy areas, later moving into an alfalfa field. Fully grown larvae are smooth skinned, are 1½ to 2 inches long, and are brown, gray, or blackish. They often have stripes or spots on their back. When disturbed, cutworms curl up. Adults are dull brown and gray moths that are nocturnal and often attracted to lights.

Management guidelines

Cutworms are most injurious in fields with high plant residue. Historically, cutworms are a problem in early, spring-seeded seedling fields. Tillage prior to seeding is an effective means of preventing cutworm damage. After seedling alfalfa has reached a height of at least 3 inches, flood irrigation can significantly suppress cutworm populations. A thorough harrowing may provide adequate control when cutworms are actively feeding in established fields. Definitive monitoring and treatment guidelines have not been developed because cutworms are a sporadic problem. However, when the number of cutworms exceeds one or two per foot of row or damage is severe, treatment is usually warranted. Spray in the late evening or night, when cutworms are actively feeding.

CLOVER ROOT CURCULIO

The clover root curculio (*Sitona hispidulus*) adult is similar in appearance to the alfalfa weevil adult but is about one-third smaller and has a shorter, blunter snout. It has a mottled brownish coloration on its back rather than the dark brown "stripe" of the adult alfalfa weevil. The adult clover root curculio feeds on alfalfa foliage during the summer and causes irregularly shaped notches in leaf margins. The white grublike larval form causes the most damage by feeding on the roots. Larvae begin feeding on root nodules and fibrous roots and subsequently chew large cavities along the sides of the taproot (color photo 7.5).

The clover root curculio overwinters as an adult under trash and debris on the soil surface. Females lay

Table 7.2. Control action thresholds for summer worms.[1]

PEST	NUMBER OF WORMS/SWEEP
Alfalfa caterpillar	10 nonparasitized and disease-free worms
Beet armyworm	15 nonparasitized worms ½ in. or longer
Western yellowstriped armyworm	15 nonparasitized worms ½ in. or longer

1. Data apply to the sweeping method of sampling, which this chapter describes in the section on alfalfa weevils.

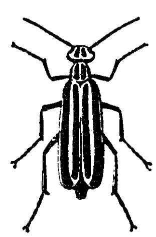
At the very least, sample fields once a week when pests are likely to occur.

their eggs on leaves or on the ground early in the spring. The larval stage lasts about 3 weeks. A larva is about ¼ inch long with a white body and a light chocolate-colored head.

Management guidelines

Clover root curculio has been found in numerous fields in the Intermountain Region. It is a perplexing problem for several reasons. First, to detect a problem, the grower must dig up plants and inspect the roots. Second, the magnitude of damage caused by this pest is not well understood. Some suggest that larval feeding contributes to winter heaving and may enhance the entry of disease organisms such as bacterial wilt and root rots. Some research has attributed significant losses of quality, stand, and yield to the clover root curculio, but only when infestation is severe. Third, control is extremely problematic; no insecticides are registered for the control of clover root curculio and no resistant varieties of alfalfa have been developed. Plant stress from the feeding of clover root curculio larvae is affected by soil moisture content, with greater injury occurring in dry soils. Therefore, maintaining soil moisture at optimum levels is one method of mitigating the effects of clover root curculio.

BLISTER BEETLES



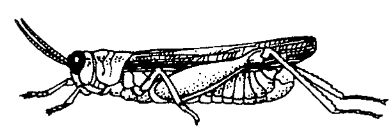
Blister beetles are an occasional, isolated problem in parts of the Intermountain Region. Some species produce the toxin cantharidin, an irritant that can cause blisters on internal and external body tissues. The toxin, not beetle feeding, is extremely significant because it causes sickness in livestock and can even kill them. Even if beetles are killed, the problem may not be solved. Cantharidin remains in the bodies of dead beetles and can still cause injury if baled with the hay. There are very few reported fatalities in cattle and sheep, but contaminated hay can be deadly to horses (cantharidin from only a few dead beetles can kill a horse). Therefore, do not sell blister beetle-infested hay to horse owners.

Blister beetles are rather large (½ to 1 inch long) and can be various colors (black, gray, brown, or striped). They have long, soft cylindrical bodies and a pronounced "neck" area that makes them easy to distinguish from other beetles. Blister beetles overwinter as larvae in the soil and emerge as adults in the spring. Females deposit from 50 to several hundred eggs in soil crevices. After hatching, larvae feed on grasshopper and cricket eggs. Adults fly into alfalfa fields, where they feed on alfalfa foliage. The beetles are usually found in late spring and summer. Blister beetles are often worse in alfalfa fields adjacent to weedy grassy areas that contain an abundance of grasshopper eggs.

Management guidelines

Before treating an alfalfa field, ascertain whether the beetles contain cantharidin by having the beetles identified by a trained entomologist. Treating blister beetle species that do not is probably unnecessary. Managing blister beetles is difficult. Treatment thresholds have not been established, and chemical controls often do not eliminate the problem (because dead beetles can be picked up in the hay and more beetles can migrate into the alfalfa field). Several insecticides are registered for blister beetle control. Strip-spraying field edges may be the best approach when blister beetles are observed in adjacent areas.

GRASSHOPPERS

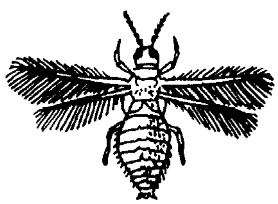


Grasshoppers (*Melanoplus* spp.) are an infrequent problem in alfalfa. However, left uncontrolled, severe outbreaks are capable of destroying crops. Populations are often worst in drought years. Grasshoppers are most often a problem in isolated fields in foothill areas near weedy or grassy areas where they overwinter. Grasshoppers deposit their eggs in soil in the fall and hatch in the spring. A nymph, the immature form, becomes an adult in 40 to 60 days. Mass migration of grasshoppers to alfalfa fields from overwintering sites can occur in the spring, when the natural vegetation starts to dry.

Management guidelines

In areas with a history of grasshopper infestations, check overwintering sites to detect potential problems while infestations are isolated and insignificant. An effective control measure involves creating a 60-foot vegetation-free buffer strip around the field and applying an insecticide bait to the strip. Insecticide use in a field is advised when grasshopper populations reach 20 per square yard in field margins or 8 per square yard within the field. Spot treatment can be very effective when grasshopper populations are isolated.

THRIPS



Thrips (*Frankliniella* spp.) are tiny insects with rasping mouthparts. These insects are very common in the Intermountain Region, and their feeding causes wrinkled and distorted leaves (color photo 7.6). There are no data to suggest that they cause economic injury. Although leaves can be severely distorted and look unsightly, treatment is not recommended.

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CHAPTER EIGHT

NEMATODES

Harry L. Carlson and Becky B. Westerdahl

Plant-parasitic nematodes are microscopic, nonsegmented roundworms that feed on plants and may cause yield or stand loss (Figure 8.1). Over 10 different types of plant-parasitic nematodes have been found in California alfalfa fields, but only two types—stem nematode (also called stem and bulb nematode) and root-knot nematode—have been associated with serious alfalfa crop damage in northeastern California. A third type, root-lesion nematode, is common in the region and has been shown to injure alfalfa in other areas. However, serious problems with root-lesion nematode in alfalfa in northeastern California have been rare.

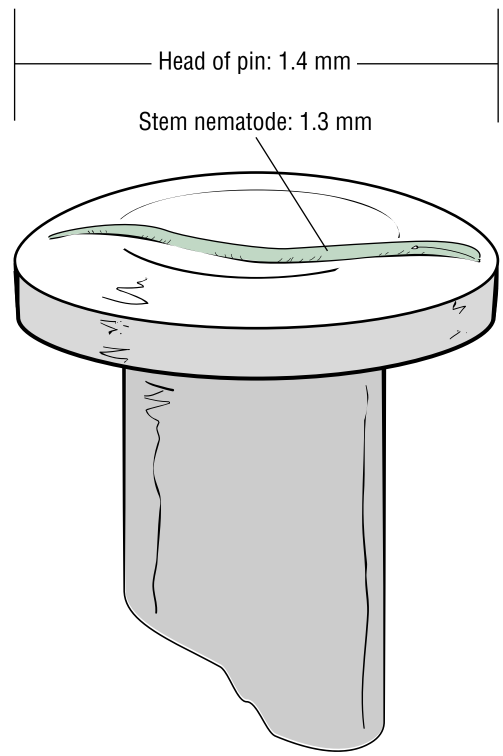

Figure 8.1. Plant-parasitic nematodes are too small to identify with the naked eye. Note the size of a stem nematode in relation to the head of a pin.

STEM NEMATODE

Significant alfalfa yield losses may occur in fields infested with stem nematode (*Ditylenchus dipsaci*). This nematode infests alfalfa stems and crowns. Affected stems are stunted and often turn yellow. Young infested shoots appear swollen, with shortened internodes, which gives the stems a dwarfed appearance (color photo 8.1). The thickened stems are usually spongy and brittle and are especially prone to frost damage—they may succumb to only moderate frosts. The stem nematode also attacks buds and leaves and may destroy young seedlings if present in large numbers.

Normally, symptoms of stem-nematode damage appear in patches of the field, reflecting the patchy distribution of the nematode (color photo 8.3). The nematode moves in free water, so infestation and damage are most severe during moist, cool, cloudy periods, when water films persist for extended times. Accordingly, stem nematode is most often a problem in cool inland valleys under sprinkler irrigation or in foggy coastal areas. In the Intermountain Region, stem nematode may present a problem only in the first or possibly the second cuttings, because hot, dry summer weather reduces nematode activity. Crop damage and yield loss from this nematode can be severe nonetheless.

Nematode infestation begins in one or more stems and, if weather conditions remain favorable, spreads throughout the crown. The nematode persists in the alfalfa crown throughout the year. When alfalfa is not being grown, the nematode survives in plant debris or on the soil surface. Stem and bulb nematodes are spread from field to field in infested plant debris that may be carried by harvest or tillage equipment, wind, irrigation water, or animals.

ROOT-KNOT NEMATODE

Root-knot nematode infests and feeds on plant roots. It gets its name from the small galls that form on plant roots in response to nematode infestation. These galls can generally be found in the branches of lateral roots and distinguished from the nodules of nitrogen-fixing bacteria by gently rubbing the roots with your fingers (color photo 8.4). Nitrogen-fixing nodules are easily dislodged by rubbing; nematode root galls are not. In addition to root galls, root-knot nematodes often cause an increase in the branching of lateral alfalfa roots.

Aboveground symptoms of root-knot nematode infestation are generally more difficult to identify than are underground symptoms. With modest infestation, symptoms may include noticeable yield loss or increased plant sensitivity to nutrient or water stress. A severe nematode infestation may cause stunting in patches of the field and result in yield loss.

Only . . . stem nematode and root-knot nematode have been associated with serious alfalfa crop damage in northeastern California.

Two species of root-knot nematode are of primary concern to alfalfa producers in the Intermountain Region: the northern root-knot nematode (*Meloidogyne hapla*) and the Columbia root-knot nematode (*Meloidogyne chitwoodi*). Two separate races of Columbia root-knot nematode are present in the region. Columbia root-knot nematode race 1 does not do well or reproduce in significant numbers on alfalfa. Columbia root-knot nematode race 2 attacks alfalfa roots and successfully reproduces on alfalfa host plants.

Often the most serious consequences of root-knot nematode infestations in alfalfa is the damage the nematodes cause in subsequent crops (Table 8.1). Following several years of alfalfa production, populations of root-knot nematodes may be large enough to seriously injure higher-value crops such as potatoes, onions, or sugarbeets.

ROOT-LESION NEMATODE

Female root-lesion nematodes (*Pratylenchus* spp.) lay their eggs in root tissue or in the soil. Both larval and adult forms enter plant roots and migrate through root tissue while feeding on cell contents. Root-lesion nematodes are commonly found throughout the Intermountain Region. The two species most likely to be found in the area are *P. penetrans* and *P. neglectus*. Of the two, *P. penetrans* is the more likely to injure alfalfa. Both species are capable of feeding on many crop plants and weeds, but the extent to which they damage crops, including alfalfa, is not clear. Reported problems caused by root-lesion nematode in alfalfa in the Intermountain Region are rare. However, research conducted in other regions of the United States has shown that high root-lesion nematode levels can cause yield losses in established alfalfa and stand losses in fields of spring-seeded alfalfa seedlings. Root-lesion nematodes have also been shown to predispose alfalfa to infection by fusarium root and crown rot organisms.

Alfalfa may support fairly high populations of these nematodes without apparent loss of yield. However, if populations become extreme and environmental conditions are right for nematode development, alfalfa plant growth may become visibly stunted. Such stunting is the only obvious symptom of root-lesion nematode infestation.

NEMATODE DETECTION AND IDENTIFICATION

Unfortunately, plant-parasitic nematodes in alfalfa usually go undetected until visible plant injury occurs. When nematode damage is suspected, a nematologist must examine the soil or infected plants to determine

Table 8.1. Host potential of various crops in regard to root-knot nematode.

NEMATODE SPECIES	CROP					
	ALFALFA	SMALL GRAINS	POTATOES	SUGARBEETS	ONIONS	PASTURE GRASSES
Northern root-knot *M. hapla*	Host	Nonhost	Host	Host	Nonhost	Nonhost
Columbia root-knot *M. chitwoodi* race 1	Nonhost	Host	Host	Host	Host	Possible host
Columbia root-knot *M. chitwoodi* race 2	Host	Host	Host	Host	Possible host	Possible host

When nematode damage is suspected, a nematologist must examine the soil or infected plants to determine the species involved.

the species involved. Many factors—such as nutrient stress, moisture stress, or severe weather—may cause symptoms similar to those caused by nematodes.

Take soil, root, and plant-tissue samples to a diagnostic laboratory whenever alfalfa vigor seems limited without an apparent cause. To begin this sampling, visually divide the field into areas that represent differences in soil texture, drainage patterns, or cropping history. When soil is moist, take several samples from each area and include feeder roots if possible. Because nematodes feed on roots, they are more prevalent in the rooting zone of the current or previous crop than elsewhere. A series of samples from throughout the field is necessary because nematodes are usually not uniformly distributed. In an established field, collect samples from areas that show symptoms and from adjacent healthy areas. Sampling at the edge is usually better than sampling the middle of an unhealthy area—roots in the center of an infested area may be too decayed to support a nematode population. Mix samples from the same area together, and place 1 quart of the mixed soil and roots into a plastic bag. Seal the bag, place a label on the outside, keep the samples cool (do not freeze them), and, as soon as possible, take the bag to a diagnostic laboratory. Prolonged exposure of sealed plastic bags to direct sunlight may cause sufficient heating to kill nematodes. Be certain to inform the laboratory that alfalfa is the current or planned crop for the field so the technicians will use appropriate extraction techniques. Your local Farm Advisor can help you locate a diagnostic laboratory.

Careful soil sampling and examination by a qualified nematologist can detect nematode problems before planting. Because of the time and expense involved, most growers do not test for nematodes prior to alfalfa planting, though such tests are done before planting higher-value rotation crops (such as onions or potatoes). Take the presence of nematodes in soil samples or previous crops into account before establishing an alfalfa crop.

CONTROL

The primary tools available for nematode control in alfalfa are nematicides, resistant varieties, and crop rotation. Cost precludes the use of nematicides in alfalfa fields. However, nematicides may be economical for higher-value crops grown in rotation with alfalfa.

Crop Rotation

Neither root-knot nematode nor stem nematode can persist in the soil for long periods without a host crop.

Therefore, rotation with nonhost crops can be an effective means of reducing soil populations of these pests.

Many races of stem nematode can infest many plant species; however, the most likely alternative hosts for stem nematode in northeastern California are red clover, ladino clover, and sweet clover. Two years of crop rotation to nonhost crops—such as small grains, sugarbeets, or potatoes—should reduce soil populations below levels that cause economic loss in alfalfa. For a nonhost crop rotation to be effective, take care to control all volunteer alfalfa in the rotation crop.

Crop rotation can effectively control root-knot nematode also, but proper identification of the root-knot species is critical to the selection of the rotation crop. Different root-knot species and races prefer different hosts (Table 8.1). For example, rotation to a cereal crop is an effective way to lower soil populations of northern root-knot nematode, but cereal rotation will tend to maintain populations of Columbia root-knot nematode. Likewise, alfalfa is an excellent rotation crop for row crops infested with Columbia root-knot nematode race 1 but is unsuitable for controlling Columbia root-knot nematode race 2.

If no suitable nonhost crop can be identified, a year of noncrop, weed-free fallow can be effective in lowering soil populations of root-knot nematode. For maximum effectiveness, cultivate the fallow field during the fallow season. This disturbs nematodes and plant debris and helps control weeds and volunteer alfalfa that may be nematode hosts.

Crop rotation may affect root-lesion nematode population numbers, but it will probably not control the pest because of the number of crop and weed species that are suitable hosts for it.

Variety Resistance

If a field has a history of stem nematode infestation, plant it with alfalfa after crop rotation has lowered soil nematode populations. Use only varieties with demonstrated resistance to stem nematode. Many resistant varieties adapted to the Intermountain Region are available.

Although some varieties are resistant to root-knot nematode, the value of this resistance is not clear-cut. This is largely due to the time, effort, and difficulty of screening alfalfa cultivars against all the root-knot species and races known to infest alfalfa. Before purchasing a variety, discuss the potential effectiveness of cultivar resistance to specific root-knot nematode species with the seed dealer or with a University of California Farm Advisor.

Varieties with resistance to root-lesion nematode are not available, although breeding programs to increase cultivar resistance to nematodes are in progress.

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CHAPTER NINE

DISEASES

R. Michael Davis, Steve B. Orloff, and Kristen D. Marshall

Alfalfa is susceptible to a wide range of bacterial, fungal, and viral diseases. These diseases can attack foliage, crowns, or roots and may substantially reduce yield, stand life, and forage quality. Some diseases can be difficult to control because, except for seed treatment, no fungicides are registered for use on alfalfa. Fortunately, alfalfa diseases are not as economically damaging in the Intermountain Region as in other parts of the state; the cold winters, short growing season, and relatively dry conditions that prevail over most of the region are not conducive to them.

Planting varieties with genetic resistance to the most prevalent diseases is the primary method of disease management in alfalfa. Most diseases can be effectively managed using this approach. However, a field planted to a variety classified as resistant may contain diseased plants. Alfalfa is genetically diverse (heterogeneous), and there will always be some plants susceptible to disease even in a resistant population. For example, in a variety rated as having resistance to a particular disease, only 31 to 50 percent of the plants are resistant (Table 9.1). Resistance ratings represent the results of standardized tests performed on seedling plants. Such tests do not take into account various growth stages and environmental stresses that may influence diseases in the field. Therefore, genetic resistance should not be the only method used to control diseases in alfalfa. Crop management, such as irrigation and harvesting practices, plays an important role in preventing or minimizing losses caused by disease.

VERN MARBLE

This chapter outlines the most predominant or potentially threatening diseases in the Intermountain Region. They are grouped into four categories: damping-off diseases, root and crown rots, foliar diseases, and wilt diseases.

DAMPING-OFF DISEASES

Several soilborne fungi cause early wilting and death of young seedlings pre- or postemergence, a scenario commonly referred to as damping-off. The causes of damping-off are species of *Pythium, Phytophthora, Rhizoctonia,* and *Fusarium.* These fungi are most com-

Phytophthora root rot is only important where soil-water is excessive.

mon in wet soils where drainage is poor or during periods of heavy rain or overirrigation. Damping-off typically occurs during cool, wet conditions in the spring, and less often in the fall. Control measures include planting at a rate that will allow for thinning due to seedling diseases and planting at a time of year when growing conditions favor rapid seedling development. Fortunately, seedlings more than 1 to 2 weeks old rarely become infected with these diseases.

Damping-Off Caused by Pythium

Pythium species are the most common cause of seed rotting and damping-off in seedlings. These fungi can greatly reduce a stand of alfalfa, especially in wet areas. *Pythium* survives in the soil or on crop residue. Swimming spores, called zoospores, infect seed or seedlings during periods of free moisture in the soil. Alfalfa seedlings become resistant to *Pythium* damping-off about 5 days after emergence, but infection of feeder roots can occur at any stage. Low temperatures and high soil moisture are favorable for disease development. The disease tends to be more severe in acidic soils.

Seeds infected by *Pythium* during germination turn into a soft brown mass, or the seedling root and cotyledon leaves become brown and soft soon after emergence. Infection at later stages causes lesions on the shoot and root. The lesions eventually collapse, causing damping-off or stunting and small dark green cotyledons. The root appears pinched off (color photo 9.1). Infected seedlings may fall over and die within a few days. Under optimal growing conditions, a seedling with a diseased primary root may survive by producing secondary roots above the lesions.

To compensate for seed loss due to *Pythium* fungi, seed at a higher-than-normal rate. Also, see the discussion of fungicides in the next section, about *Phytophthora.*

Table 9.1. Plant resistance ratings.

Percentage of resistant plants	Resistance class
0–5	Susceptible
6–14	Low resistance
15–30	Moderate resistance
31–50	Resistance
>50	High resistance

Damping-Off Caused by *Phytophthora*

Symptoms of damping-off caused by *Phytophthora* fungi on seedling alfalfa are similar to those caused by *Pythium* fungi. The area below the cotyledons (hypocotyl) becomes water-soaked and limp, then collapses and withers. Seedlings are stunted and have small, dark green cotyledons and die within a few days.

A seed treatment fungicide, such as metalaxyl (Apron), can be used as a seed dressing to protect against seedling diseases caused by *Pythium* and *Phytophthora* species. However, use has not been found to be beneficial in tests in California; seed treatment fungicides are recommended only where seedling damping-off is known to be a problem. The preferred method for controlling this disease in the field is to optimize seedling growth by preparing a firm seedbed and adjusting soil pH and fertility to levels optimum for alfalfa growth. Avoid overirrigation. Also, plant when soil conditions favor rapid emergence and early seedling growth, such as in late summer (see chapter 2).

Damping-Off Caused by *Rhizoctonia*

Rhizoctonia fungi are another cause of seedling damping-off. Symptoms of this seedling disease include reddish brown, shrunken lower stems and roots. These fungi require a food base before infecting a plant; thus, excessive organic residue in the soil encourages them. Excessive soil moisture also favors them. However, unlike the seedling damping-off diseases already mentioned, infection by *Rhizoctonia* generally occurs during periods of high temperature and can affect seedlings at any growth stage.

No control measures are generally taken against *Rhizoctonia.* Ensuring decomposition of organic matter by adequately incorporating plant residue prior to planting alfalfa seed may reduce seedling infection.

ROOT AND CROWN ROTS

Root and crown rots are the most common and possibly most devastating diseases of alfalfa. They can be caused by a complex of fungi, including *Phytophthora* spp., *Stagonospora meliloti, Rhizoctonia* spp., and *Colletotrichum trifolii.* Stand decline is the most noticeable symptom. Decline usually begins during the 2nd year after planting and gradually becomes more severe. Early symptoms include yellowing and wilting of stem tips or entire shoots, which eventually die. Plants may be stunted and have an increased number of small, shortened stems and small leaves. Crowns of infected plants always exhibit some degree of rot. Control is difficult. This disease complex is a major factor contributing to early stand decline.

Phytophthora Root and Crown Rot

One of the primary organisms responsible for root and crown rot is *Phytophthora megasperma.* It is soilborne and occurs wherever alfalfa is grown. The greatest damage occurs under flood irrigation and with poorly leveled and poorly drained soils. Phytophthora root and crown rot can be injurious to seedling stands, but it is more commonly a problem in established fields.

Although *Phytophthora* fungi primarily infect roots, symptoms are expressed in all parts of the plant. Leaves wilt, turn yellow to reddish brown, and drop. Plants grow slowly after cutting and may wilt and die. Root symptoms are diagnostic for this disease. Tan to brown lesions on taproots usually appear where a lateral root emerges. Lesions eventually turn black; the center of the root is yellow. Taproots can be affected at any depth where water drainage is impeded. Red-orange to yellow streaks spread up several inches from the rotted end of the root (color photo 9.2). This disease can devastate large areas of a field, but frequently only individual plants are affected.

Phytophthora root rot is only important where soil-water is excessive. The fungi can survive for long periods in an inactive state in soil or in plant debris and become active when there is too much water. Rot caused by *Phytophthora* is most common at the tail end of flood-irrigated alfalfa fields. Spores of these fungi can be carried in irrigation water. Thus, if tail water is channeled from an infected field back to an irrigation canal, the disease can spread. The most frequent points of infection are the tips of small roots and the bases of fine lateral roots. The disease may be limited to a portion of the root or may spread up the taproot to the crown. If the crown becomes infected, the plant will likely die as soon as 1 week after infection. If infection is limited, the plant may continue growing at a reduced rate, but it will be far more susceptible to winter injury.

Alfalfa is genetically diverse and there will always be some plants susceptible to disease even in a resistant population.

Soil and water management is the most important cultural control. Reduce the amount of time that soil is saturated by reducing soil compaction with deep tillage (see chapter 2). Reducing the length of flood irrigation runs, shortening irrigation time, and leveling land all help alleviate disease severity. Cultivars resistant to phytophthora root rot are available; use them along with sound cultural practices in fields known to have problems with *Phytophthora* fungi.

Stagonospora Root and Crown Rot

Crown and root rot caused by the fungus *Stagonospora meliloti* is widespread in California but is not a major problem in the Intermountain Region. It can be one of the primary reasons for early stand decline, however. The vigor of an alfalfa stand decreases because of a slow necrosis, or dying, of crowns. Bark tissue on infected roots and crowns is often cracked. A diagnostic symptom is the presence of red flecks in root tissue. Fine red streaks also occur in the xylem (the water-conducting tissue) in the center of the root, below rotted portions of the crown. The pathogen may also infect leaves, causing irregular tan lesions and defoliation.

Spores of *S. meliloti* are spread by water that splashes on infected leaves, stems, or plant debris. The fungus enters the crown through stems and grows slowly downward into the taproot. Although the infection can take 6 months to 2 years to kill a plant, it reduces plant vigor and yield. Leaves and stems are generally infected during spring rains, but crown infections can occur anytime. The disease is most damaging when alfalfa is not actively growing.

No resistant cultivars are available. Rotation out of alfalfa for 2 or 3 years eliminates sources of inoculum within a field.

Rhizoctonia Root and Crown Rot

This disease, caused by *Rhizoctonia* fungi, attacks established as well as seedling alfalfa. It occurs wherever alfalfa is grown and at any stage of plant growth. Root cankers are tan or buff elliptical, sunken lesions. When the pathogen is inactive during cool months, cankers heal and turn black. If the lesions girdle the taproot, the plant may die; otherwise, new roots will emerge and the plant will survive.

Rhizoctonia species persist in soil as sclerotia (an inactive stage of fungal development) associated with plant residue. They can also survive saprophytically—that is, living on dead organic matter—in the absence of a living host. These fungi require a food base before infecting a plant; thus, excessive organic matter in the soil favors the disease. After entering through wounds, the fungi travel from lateral roots to taproots and from crowns to crown buds. High temperatures and excessive soil moisture promote rhizoctonia rot.

No control measures are generally practiced. To reduce seedling infection, ensure decomposition of organic matter by adequately incorporating it before planting.

Anthracnose

Anthracnose, caused by the fungus *Colletotricum trifolii,* is a sporadic and relatively rare problem in the Intermountain Region, but, when it occurs, losses can be significant. Anthracnose can affect leaves, stems, and crowns of alfalfa, but crown rot has been the most significant symptom in the Intermountain Region. The most apparent symptom of anthracnose is the bluish black, V-shaped rot that can be observed on the crown when dead stems are removed. On stems, anthracnose causes small irregularly shaped blackened areas that may become large, sunken oval or diamond-shaped straw-colored lesions with black borders (color photo 9.3). Black fruiting bodies, which under a hand lens look like small dots, develop in the lesion. As lesions enlarge, they may coalesce, girdle, and kill one to several stems on a plant. In summer and fall, dead shoots (straw to pearly white in color) are scattered throughout the field.

The fungus persists in alfalfa debris and crowns. The disease reaches maximum severity during late summer and early fall. During the growing season, spores on stem lesions are a source of inoculum. Spores may also be spread with seed contaminated during the threshing process.

Anthracnose spreads rapidly during warm and humid weather. Splashing rain and irrigation water disperse spores onto growing stems and petioles.

To control anthracnose, grow resistant cultivars. Clean debris off all harvesting equipment before the first spring harvest and also during the growing season when moving from an infected to a noninfected field. Cut infected alfalfa before losses become too severe. Rotating with crops other than clover and alfalfa for 2 years or more will eliminate sources of inoculum in the field.

FOLIAR DISEASES

Several foliar diseases attack alfalfa, including common leaf spot, stemphylium leaf spot, spring black stem, and downy mildew. Of these, downy mildew is generally the only foliar disease of concern in the Intermountain Region.

Downy Mildew

Downy mildew, caused by the fungus *Pernospora trifoliorum,* occurs in cool, wet, or humid conditions and is favored by sprinkler irrigation. It can be found anytime during the growing season in the Intermountain Region but is most common in spring. Damage is most serious in seedling alfalfa fields. Loss from downy mildew in established stands is usually restricted to the first cutting.

Downy mildew is easy to distinguish from other foliar diseases; the symptoms it causes are unique. During cool moist weather or when humidity is high, a fine grayish growth of spores is usually apparent on the underside of leaflets. The upper side of infected leaves is light green to yellow (color photo 9.4). Symptoms are usually restricted to portions of leaflets, but, if the infection is systemic, they may appear on entire leaves or shoots. Infected leaves are twisted and curled. On infected stems the internodes (the stem areas between leaves) are shorter and thicker than those of normal stems. Plant growth is stunted.

Pernospora trifoliorum overwinters as resting spores in the crown of surviving plants and in plant debris. Spores are produced during periods of near-100-percent relative humidity. They are fragile and survive for several hours to a few days, depending on environmental conditions. Dispersal is primarily by wind and splashing rain. Spores fall on young, susceptible leaves and germinate in free water. Germination of spores occurs from 39° to 84°F (4° to 29°C), with optimum germination at 65°F (18°C). The fungus produces large numbers of spores during periods of abundant moisture.

Cultivars resistant to downy mildew have been developed and are the most economical means of control. However, varietal resistance is not well documented, so choosing a resistant cultivar is difficult. Fortunately, downy mildew is rarely of economic importance in the Intermountain Region, and growers can manage it with cultural practices. Allowing longer intervals between irrigations, with more water per irrigation, can help reduce symptoms if fields are sprinkler irrigated. In rare cases when mildew is severe, cut alfalfa early to save foliage. Harvesting removes the inoculum source of the short-lived spores, removes young susceptible leaves, and reduces the relative humidity of the plant canopy. Normal increases in seasonal temperatures reduce the chance of downy mildew reinfection.

WILT DISEASES

Bacterial Wilt

Bacterial wilt, caused by the bacterium *Clavibacter insidiosum,* is present wherever alfalfa is grown, but it is rarely seen today due to the development of wilt-resistant cultivars. Infected plants are easily detected by their yellow-green color and stunted growth. Diseased plants may be scattered throughout the field. Mildly affected plants are short. They have mottled leaves and slightly cupped leaflets or leaflets that curl upward. Severely diseased plants are stunted, are yellow-green in color, and have spindly stems and small, distorted leaflets (color photo 9.5). Disease symptoms are most evident in regrowth after clipping. A cross section of an infected taproot reveals a yellowish tan color in the center. Often, small areas or pockets on the inside of the bark tissue turn brown.

The bacterium survives in plant residue in soil and enters plants through wounds in the roots and crown or through the cut ends of freshly mowed stems. Once a susceptible plant is infected, it usually does not recover. Disease symptoms rarely appear before the 2nd or 3rd year. Plants die within 5 to 8 months after showing symptoms. Disease severity and incidence increase with the presence of nematodes. The bacterium can survive in dry plant tissue or seed for at least 10 years and can be disseminated over long distances in seed and dry hay. However, populations of the organism in the soil decline quickly when infected plant residue decomposes. Bacterial wilt can be spread by surface water, tillage, mowing, and harvesting equipment. Plants with bacterial wilt are prone to winter kill. The greatest incidence of the disease occurs in poorly drained areas of fields; large areas can be infected during periods of continuous wet weather.

Resistant cultivars keep the disease under control. Nearly all dormant alfalfa varieties currently marketed are rated as resistant or highly resistant to bacterial wilt. If you discover the disease in a susceptible cultivar, limit disease spread by mowing new stands before old stands. Also, do not mow wet plants.

Fusarium Wilt

Fusarium oxysporum is a fungus that causes fusarium wilt, which occurs wherever alfalfa is grown. The disease is not generally important in the Intermountain Region because of the availability of resistant cultivars. Fusarium wilt progresses over several months. The fungus enters roots through wounds in the taproot and continues into the xylem, or water-conducting tissue. Shoots and leaves may wilt during the day but regain turgidity at night. As the infection progresses, stems become bleached. Toxins produced by the fungus discolor host tissue; a red discoloration appears on leaves. The xylem eventually becomes plugged, causing death. Fusarium wilt can be identified by the dark reddish brown discoloration in the stele, or center, of the taproot (color photo 9.6). Fusarium oxysporum may persist in soil for several years.

> ***Fusarium wilt is not generally important in the Intermountain Region because of the availability of resistant cultivars.***

Fusarium wilt is more severe when plants are infested with root-knot nematodes. Soil moisture does not affect the severity of the disease, but high soil temperatures favor infection.

Cultivars with resistance to both fusarium wilt and root-knot nematode offer the best control when both organisms are present. Sound cultural practices that encourage alfalfa growth reduce incidence of the disease.

Verticillium Wilt

Verticillium albo-atrum, a fungus that causes Verticillium wilt, was first found in the United States in 1976 on alfalfa growing in the Yakima Valley and in the Columbia Basin of central Washington. Since then, it has been reported in most northern states, south to Kansas and Maryland. It has also been found in the high desert of Southern California and the coastal counties of central and northern California. It was discovered in the summer of 1993 in the Intermountain Region, but the extent of its spread is unknown at this time.

Verticillium wilt is a potentially serious problem; it can reduce yield by up to 50 percent and shorten stand life severely. It has been an insidious problem over seasons and years rather than a devastation in a single year. Note that the disease is usually only expressed under certain environmental conditions (cool wet weather followed by hot days). Therefore, the fungus could exist in a field that appears healthy. Also, the disease is apparently more serious in irrigated fields than in dryland fields.

Verticillium wilt symptoms are distinctive, but laboratory analysis must verify field diagnosis. Diseased plants are usually scattered throughout the field. At first glance, the symptoms look like gopher damage, except that the plants do not pull out of the ground.

A V-shaped yellowing, or chlorosis, discolors leaflet tips (color photo 9.8). At the end of the stem, the margin of some leaflets is rolled (color photo 9.9). Leaves on individual stems dry, turn brown, and may fall off. Infected stems do not wilt and often retain their green color until all the leaves are dead. Internodes (the stem areas between leaves) are often short toward the end of a stem. Eventually, the pathogen spreads to the crown, and affects all the stems, and the plant wilts and dies. Although internal root tissue can turn brown, this reaction is variable and is not a dependable symptom for diagnosis.

Contaminated hay and pellets can introduce the pathogen into new areas. The disease can also be spread by the manure of animals who ate infected hay, by insects, by water, and by infected seed. The wind can disseminate fungal spores (conidia) over short distances. *Verticillium albo-atrum* does not usually survive more than 1 year in field debris after an infested field is taken out of alfalfa production. It can survive up to 3 years in dry hay. It can also survive in several weed species, including *Medicago* spp., but does not cause problems for most other crops. *Verticillium dahliae,* a related fungus, causes wilt of many other plant species but not alfalfa.

Verticillium albo-atrum grows best between 68 and 77ºF (20º to 25ºC). The pathogen survives the temperatures used to produce dehydrated alfalfa products and can pass unharmed through the digestive system of sheep.

As a control for verticillium wilt, crop rotation has limited effectiveness because the pathogen can survive on several broad-leaved weeds. However, if crop rotation and weed control are practiced, the inoculum can be significantly reduced in 2 to 3 years. Avoid introducing the pathogen on contaminated hay. Clean plant debris from equipment with high-pressure water or steam before entering new fields. Cut clean fields before diseased fields.

Planting resistant varieties is by far the best method to control the disease. Fortunately, most certified dormant varieties are relatively resistant. The University of California recommends planting only resistant (R) or highly resistant (HR) varieties in the Intermountain Region (see chapter 3). Resistant varieties have kept verticillium wilt from becoming an economically significant disease in areas of the Pacific Northwest, where the fungus has been present for many years.

ADDITIONAL READING

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CHAPTER TEN

VERTEBRATE PESTS

Steve B. Orloff, Terrell P. Salmon, and W. Paul Gorenzel


TRACY BORLAND

Vertebrate pests are often a serious problem in the Intermountain Region of California. Rodents (gophers, ground squirrels, and meadow mice) are the most injurious of the vertebrate pests. In annual cropping systems, frequent field cultivation usually discourages large rodent colonies. In the intermountain area, however, the effects of cultivation are offset by the predominance of perennial crops adjacent to uncultivated land. For rodents, alfalfa fields are highly desirable habitat.

Vertebrate feeding and nesting behavior cause a range of problems to above- and belowground portions of alfalfa plants. In addition, burrowing activity—particularly by pocket gophers and the Belding ground squirrel—can disrupt harvest operations and damage harvest equipment. Mounds caused by burrowing can cover plants, resulting in further production losses. Burrowing also adversely affects the efficiency of irrigation systems, primarily in flood-irrigated fields.

Many pests are managed using the concept of threshold levels. In other words, when the pest population density reaches the level where control is economically justified, control measures are undertaken. This approach is less useful for vertebrate pests than for others, because treatment threshold levels have not been developed. Very low vertebrate pest populations can be tolerated. Their great reproductive capacity mandates that populations be maintained at low levels to prevent an unmanageable population outbreak. Table 10.1 summarizes the control methods this chapter will discuss.

POCKET GOPHERS

Pocket gophers (*Thomomys* spp.) are the most common and often the most destructive vertebrate pest of alfalfa. Unfortunately, alfalfa is a preferred food of gophers, and it provides ideal conditions for gopher population buildup. Pocket gophers feed primarily on the taproot and often kill plants. Their feeding can lead to significant yield reduction, and their burrows cause damage to harvest machinery. The damage done by gophers to an alfalfa stand is permanent; even after gophers have been controlled, the effect of previous gopher feeding continues to affect yields.

Pocket gophers are (6- to 8-inch-long) stout-bodied, short-legged rodents well adapted for burrowing (color photo 10.1). The name *pocket gopher* refers to the fur-lined external cheek pouches, or pockets, used to carry food and nesting materials. The pocket gopher can close its lips behind its four large incisor

Table 10.1. Vertebrate pest control measures for alfalfa.[1]

CONTROL MEASURE	RODENTICIDE	TIMING	COMMENTS
POCKET GOPHERS			
Hand-baiting	Strychnine-treated grain and anticoagulant baits	Late winter and throughout growing season	Useful for small isolated infestations. Strychnine-treated grain is more effective than anticoagulant baits.
Mechanical baiting	Strychnine-treated grain	Late winter to early spring, before alfalfa breaks dormancy. May be done throughout the growing season after a cutting.	Effective for widespread infestations. Proper soil moisture content is critical. Use mechanical burrow builder only in areas where gophers are present, not as a preventive measure.
Trapping		Late winter and throughout growing season	Effective but very time-consuming. Set traps in pairs, facing opposite directions.
GROUND SQUIRRELS			
Deep tillage		Fall or spring (fall preferred)	Deep tillage destroys burrow system and is believed to reduce populations.
Shooting		Whenever observed above ground	Time-consuming, expensive, and marginally effective for large infestations. Most effective when squirrels first emerge after hibernation.
Fumigation	Acrolein (Magnacide)	When squirrels emerge after hibernation (Feb.) through June	Effective but time-consuming. Retreatment of survivors improves control considerably. Concentrate efforts on low infestations or young fields.
	Gas cartridges	March through June in the spring.	Usually only 30 to 40 percent effective, possibly due to cold, dry soils. Follow-up treatments improve control.
	Aluminum phosphide (Phostoxin, Fumitoxin)	Same as gas cartridges	Same as gas cartridges
Baiting	Chlorophacinone or diphacinone	May through June	Must be used in bait stations placed around perimeter of fields or in a grid within fields. Requires multiple feedings.
MEADOW MICE			
Vegetative cover control		Late fall (Oct. to early Dec.)	Keep vegetative cover low through dormant period by mowing or grazing.
Baiting	Zinc phosphide	Late fall to early spring, before alfalfa breaks dormancy	Apply before spring breeding, by hand or with a mechanical broadcaster. Do not treat more often than once every 6 months. Can be used outside field at any time of year.
	Chlorophacinone or diphacinone	Any time of year	Not to be used in alfalfa fields, only along fence rows and surrounding noncrop areas. Requires multiple feeding. Hand-baiting every other day for 5 days is recommended.
DEER AND ANTELOPE			
Deer fences			Must be 8 ft high and made of woven 4-by-4-in. mesh. Almost never worth the expense and effort.

1. Rotation to annual crops is also effective for reducing the population of rodent pests.

teeth, keeping soil out of its mouth while burrowing. Pocket gophers use their short whiskers and tails to help navigate tunnels. They seldom travel above ground; however, they are sometimes seen feeding, pushing dirt out of their burrow system, or moving to a new area. They have a keen sense of smell, which they use to locate food. Pocket gophers do not hibernate and can be active in the snow. They are more active in the spring and fall than they are during the heat of summer. The female usually produces one or two litters per year but may produce up to three litters in irrigated alfalfa. Average litter size is 5 or 6 young. Births generally occur from March through June. Pocket gophers have a maximum life span of about 5 years.

Pocket gophers are extremely territorial and antisocial, living by themselves in an extensive underground burrow system that can cover an area from a few hundred square feet up to more than 1,000 square feet. Territories are smaller in habitat with abundant food, such as alfalfa fields. Mounds of fresh soil indicate their presence. The burrow system may be linear or highly branched (figure 10.1). A single burrow system may be up to 200 yards long. Tunnels are 2 to 3 inches in diameter and usually from 6 to 12 inches below the ground, but they may be more than 6 feet deep. Tunnels are usually deeper in sandy soils than in clay soils. One gopher may create several mounds in a day or as many as 200 mounds per year. Mounds are usually crescent-shaped (figure 10.2) and appear at the end of short lateral tunnels.

Control Methods

A successful pocket gopher control program depends on early detection and control measures appropriate to the location and situation. Most alfalfa growers have relied on poison baits for gopher control. Where populations are low or poison baits have been ineffective, try traps. In a field with a heavy infestation, drag the field before imposing control measures. Dragging will enable you to identify active burrow systems. Concentrate gopher control efforts in late winter to early spring, when the alfalfa is breaking dormancy and before the gophers have given birth. Flood irrigation may reduce gopher populations, but it does not eliminate the problem. Rotation to row crops or other field crops—such as barley, wheat, oats, rye, or sudangrass—may help reduce gopher population levels.

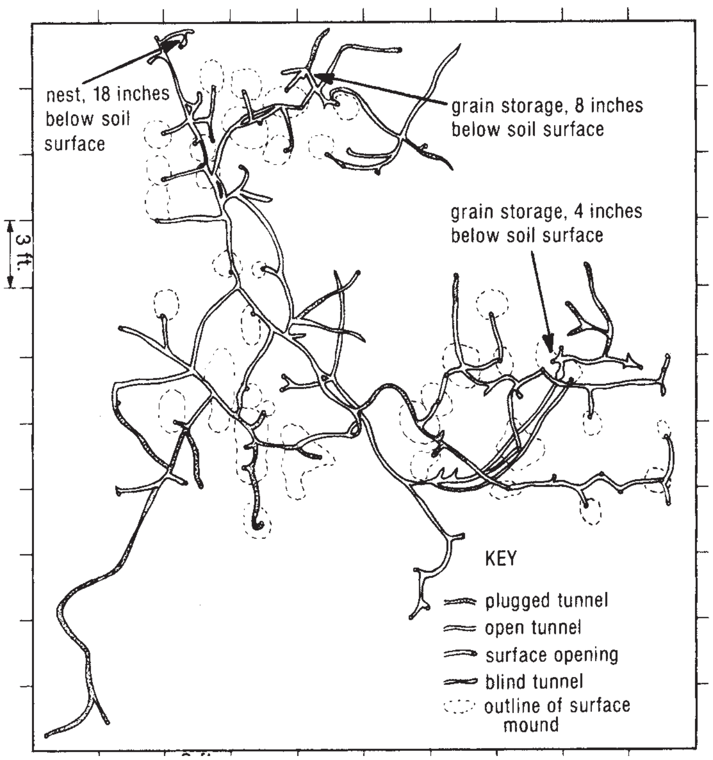
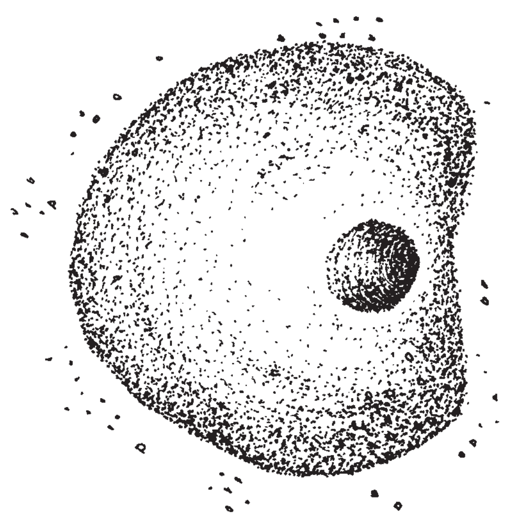


Figure 10.1. (left) The burrow system of a single pocket gopher can cover from a few hundred square feet to more than 1,000 square feet.

Figure 10.2. (below) The pocket gopher pushes soil out of a burrow, creating a crescent-shaped mound; then the gopher closes the hole with a plug.



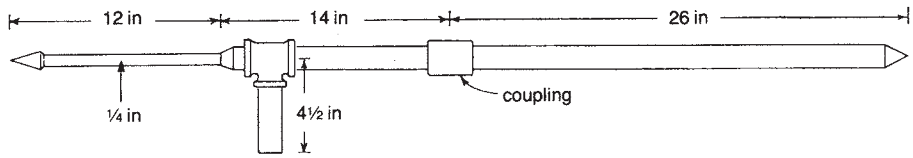


Figure 10.3. A probe for locating pocket gopher tunnels can be built in a shop. The shaft may be in one piece or divided by pipe coupling for convenient carrying when it is not in use. (Drawing not to scale.)

Toxic baits (rodenticides)

HAND-BAITING Successful hand-baiting depends on accurately locating the gopher's main burrow. To do so, use a gopher probe (figure 10.3). Look for the freshest mounds, because they indicate an area of recent gopher activity. You will usually see a small circle or depression representing a plugged lateral tunnel. This plug is generally bordered on one side by soil, giving the mound a crescent shape. Often the main burrow goes between two mounds. Begin probing 8 to 12 inches from the plug side of the mound. When the probe penetrates the gopher's burrow, it should suddenly drop about 2 inches (figure 10.4.). Enlarge the opening the probe has made in the soil by rotating the probe or inserting a larger rod or stick. Then carefully pour a tablespoon of the bait into the opening. A funnel is useful to prevent spillage. Close the probe hole with a rock, clod, or some other material. This will exclude light and prevent soil from falling on the bait. Treat two or three different places in the burrow system. If gopher activity continues for more than 2 days after treatment, treat the burrow again or use another control method.

Strychnine-treated grain is the most common pocket gopher bait. Only strychnine bait of 0.5 percent or less may be used for hand-baiting. Anticoagulant baits are also available for hand-baiting, but they are generally less effective because the gopher must ingest multiple doses over time. All gopher bait is poisonous: Use it with caution. Read and follow product label instructions carefully.

MECHANICAL BAITING One-time use of a mechanical bait applicator (also called a burrow builder or gopher machine) can control gophers over large areas. This tractor-drawn device (color photo 10.2) constructs an artificial underground burrow and deposits poison-treated grain at preset intervals and quantities. The artificial burrow will intercept most of the natural gopher burrow systems. Gophers, by nature, readily explore these artificial tunnels and consume the bait. The percentage of strychnine allowable in mechanical baiting (1.8 percent strychnine) is higher than that in hand-baiting.

Before using the mechanical bait applicator, determine the depth of existing gopher tunnels by using a shovel. The depth of the burrow builder should be set to that of the existing gopher tunnels. As you create the artificial tunnel, examine it periodically to make sure that it's forming properly and that the bait is properly dispensed (sometimes the applicator tube gets clogged with soil). Proper soil moisture is essential. If the soil is too wet, the tractor will bog down and the tunnel may have an open slot at the top, allowing sunlight to penetrate. If the soil is too dry, the artificial tunnel will cave in, resulting in poor control. Space burrows at 20- to 25-foot intervals. Treat the perimeter of the field to delay re-invasion from outside areas. Use the gopher machine only in areas where gophers are present, not as a preventive measure. Gophers seek areas with low resistance to digging; if you build a tunnel where gophers are not present, you can actually facilitate their spread. Raise

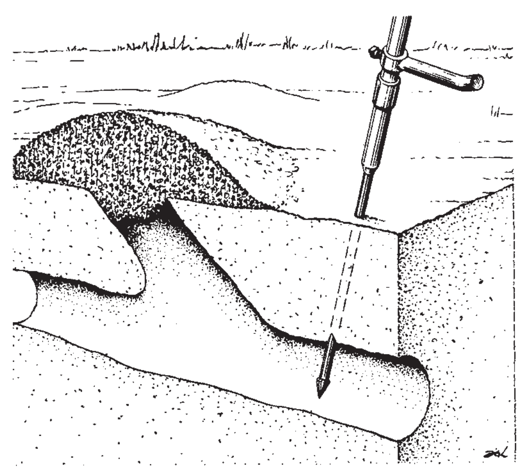


Figure 10.4. The probe has entered a main tunnel when the probe suddenly drops about 2 inches. Enlarge the probe hole to insert poisoned bait.

Use the gopher machine only in areas where gophers are present and not as a preventative measure.

the shank of the gopher machine out of the ground when crossing uninfested areas of the field.

Trapping

Trapping can be a safe and effective method to control pocket gophers when populations are low. It is most effective in spring and fall. Several types and brands of gopher traps are available. A two-pronged pincher trap (such as the Macabee) is the most common. The gopher triggers it by pushing a flat vertical pan. Another popular trap is the squeeze-type box trap.

As with hand-baiting, trapping requires that you locate the main tunnel by using a probe. Use a shovel to open the main tunnel, and insert traps in pairs facing opposite directions. This placement will intercept a gopher coming from either direction. A box trap is somewhat easier to set than a pincher trap, but placing it requires more excavation because of its large size. Wire all traps to stakes or flags so you will not lose track of them or have the trap, with gopher, stolen by a predator. Remember that you will get best results when light is excluded from the burrow. If light enters the tunnel, the gopher may plug the burrow with soil, filling the traps and making them ineffective. Cover the opening with soil, sod, cardboard, or some other material. Sift fine soil around the cover to ensure a light-tight seal. Check traps and reset them when necessary. Move the traps to a different location if 3 days elapse without catching a gopher.

Gas cartridges

Gas cartridges (smoke bombs) are not recommended for pocket gopher control. They are costly and time-consuming and provide variable control. Their ineffectiveness may be due to the extensive nature of gopher tunnel systems and diffusion of the gas in soil. Because soil moisture reduces the amount of gas diffusion, treating very moist soils results in better control than treating dry soil.

GROUND SQUIRRELS

Ground squirrels *(Spermophilus* spp.) can be serious problems. Both California ground squirrels and Belding ground squirrels are found in and around intermountain alfalfa fields. California ground squirrels have a flecked coat and a long bushy tail. In contrast, Belding ground squirrels are slightly smaller, have a short flat tail, and are solid brown (color photo 10.3). California ground squirrels are generally more of a nuisance than a serious problem in alfalfa because they prefer to stay on field edges, along fence rows or roadsides. However, Belding ground squirrels are a very serious problem. They consume large amounts of alfalfa and inhabit the interior of alfalfa fields, constructing massive mounds that can damage hay-harvesting equipment. One study estimated that 123 squirrels per acre removed about 1,800 pounds of alfalfa per acre in 44 days. This section pertains primarily to Belding ground squirrels, not California ground squirrels.

Unlike pocket gophers, ground squirrels are frequently visible in the field. They spend much of their time out of the burrow, sunning, feeding, or socializing. The burrows provide protection and a place to rear young, store food, and rest and sleep. Their burrow system is not as extensive as that of pocket gophers, but it can be as deep as 6 feet. Ground squirrel burrow systems are much larger in diameter than are gopher systems, and their burrow entrances are always unplugged.

Belding ground squirrels come out of hibernation and are first visible from mid-January to mid-February. They breed in late February and in March. The breeding season lasts 3 to 6 weeks. Young are born in the spring. About 4 weeks after birth, the young squirrels emerge from the burrow. Females have only one litter per year. They may appear to have multiple litters because the young squirrels are visible for a long period, but this is not the case. The fact is that older females breed first and then the younger females breed, thus giving the impression of multiple litters. Litter size ranges from 3 to 12 young and averages about 7 young. Females may live 10 years or more and have a life span twice that of males.

When they first emerge after hibernation, the squirrels may eat nothing at all, surviving on stored fats, or they may subsist on alfalfa foliage. They prefer green foliage in early spring and will not eat seeds like grain until later in the season. About June 15 to July 1 some of the adult males go into hibernation for the winter. The adult females begin to hibernate later, and then, as fall approaches, the young born that year begin. Although squirrels are not active for much of the year, they are very energetic and nearly double their body weight in a few months.

Control Methods

Deep tillage

Preventing excessive populations is much easier than bringing high populations under control. Therefore, the first step in squirrel management—deep tillage—should occur when an alfalfa field is taken out of production. Deep tillage is thought to be effective for controlling squirrels because it disrupts burrow systems. It is believed to be more effective when done in fall than in spring.

Shooting

As a means of controlling large squirrel populations, shooting is seldom effective when used by itself. Shooting is time-consuming, and squirrels become gun-shy. Shooting is best used for fields with low populations or to control survivors that remain following other control operations. Do not approach shooting haphazardly. Section off the field and systematically concentrate efforts in 1-to 2-acre grids.

Fumigants

Acrolein

Registered in California for the control of burrowing rodents in the spring of 1993, Acrolein (Magnacide) is the most effective method currently available to control ground squirrels. It has achieved up to 95-percent control of both California and Belding ground squirrels in field trials and commercial applications. A dispensing rod, with nitrogen gas as the propellant, injects Magnacide into squirrel holes. A Restricted Use Permit from the Agricultural Commissioner's Office is required. Other notification requirements may exist as well; if so, they will be stated on the permit. Magnacide can be very hazardous. Those who use it must receive training from company representatives or other qualified persons.

Before using this fumigant, drag the fields to determine which holes are part of active burrow systems. Treat every hole, because distinguishing active burrows by looking at the location of the holes is impossible. Do not treat burrows until aboveground squirrel activity is apparent. The best time for treatment is early in the season, after the squirrels become active but before significant alfalfa growth has occurred. (Alfalfa growth masks burrow openings, making them difficult to locate.) Applying the fumigant before the young are born in the spring is best. Cover holes after treatment. Reopened holes indicate that squirrels were not controlled or that the burrow system was invaded by neighboring squirrels. Revisit treated areas to retreat any open burrow systems. If squirrels remain active, burrow systems can be treated after the first cutting. Do not treat holes in the summer or fall; at that time squirrels start going into hibernation and plug off their tunnels—rendering Magnacide ineffective.

Keep squirrel populations at manageable levels by concentrating efforts on young fields or fields with low infestations.

This fumigant is too costly and time-consuming to be used on older fields with high squirrel populations. Keep squirrel populations at manageable levels by concentrating control efforts on young fields or fields with low infestations.

Gas cartridges and aluminum phosphide

Smoke bombs and aluminum phosphide (such as Phostoxin and Fumitoxin) have been used with limited success. Although Phostoxin has been effective for control of California ground squirrels, it is only 30 to 40 percent effective for control of Belding ground squirrels. Cold dry soils, which prevent the toxicant from penetrating far, may partially explain the poor results. Also, the burrow system of the Belding ground squirrel is so extensive that perhaps not enough toxicant is released to be lethal.

If you use Phostoxin before March, cold soil will reduce its effectiveness. To determine which holes are active, drag the field before using gas cartridges or Phostoxin. Gas cartridges are often preferred over Phostoxin because they help the user determine which holes are part of the same burrow system—smoke escapes from holes in the same system. Seal the hole from which smoke escapes by stomping on it. Determining which holes belong to the same burrow system is difficult when using Phostoxin. Two holes that are next to each other are not necessarily part of the same burrow system, but two holes 25 feet apart may be. Therefore, you must place Phostoxin tablets or pellets in every hole.

Baits

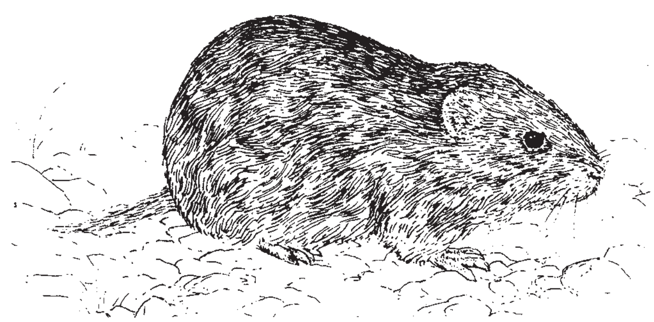
Anticoagulant baits (chlorophacinone or diphacinone) have been used in some areas of the Intermountain Region. Do not use them before May, because squirrels will not feed on grain early in the season. For baits to be effective, squirrels must feed on them for at least 5 days, with interruptions of no longer than 48 hours between feedings. Greater than 90-percent control has been achieved when anticoagulant baits have been used properly. Grain baits can no longer be broadcast on fields; they must be used in bait stations (figure 10.5). Place bait stations around the perimeter of the field and within the field at spacings no larger than 100 feet.

Squirrel management requires the integration of several control practices, each employed at the correct time. These practices include deep cultivation in the fall, fumigation with Magnacide, shooting, and anticoagulant baits.

MEADOW MICE

Meadow mice (*Microtus* spp.)—also referred to as meadow voles, or field mice—are another serious rodent pest of alfalfa in portions of the Intermountain Region. They have been especially problematic in Scott Valley and the Tulelake Basin. Meadow mice are 4 to 6 inches long when mature. They have heavy bodies, short legs and tails, and small, rounded ears. Their soft dense fur is blackish brown to grayish brown.

Meadow mice are active all year long. Alfalfa is an ideal habitat for them. They feed on all parts of the plant, foraging on stems and leaves in summer and fall and roots and crowns in winter and early spring. They dig short, shallow burrows and make underground nests of grass, stems, and leaves. Their presence is indicated by well-worn trails, approximately 2 inches wide, leading to entrance holes without mounds (color photo 10.4). Their trails are especially evident in late winter, before the alfalfa resumes growth.



Meadow mouse

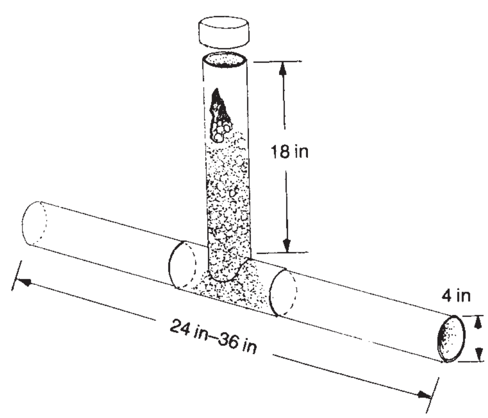


Figure 10.5. This bait station for ground squirrels is made of PVC pipe. Check bait stations on a regular basis to ensure a constant supply of bait.

Spring is the peak breeding period; a second, shorter breeding period occurs in fall. Female meadow mice can produce between two and five litters per year. An average litter contains four or five young. Meadow mouse populations fluctuate dramatically from year to year, depending on habitat and weather conditions. The populations increase rapidly under favorable conditions and the damage they cause can be dramatic. Heavily infested fields can support a population of 1,000 to 3,000 meadow mice per acre.

Control Methods

An important component of meadow mouse control is making the field and surrounding areas a less favorable habitat. Controlling weeds and cultivating along fence rows, roadsides, and ditchbanks can help reduce meadow mouse populations by reducing the number of invading mice. Dense vegetative cover in the field encourages meadow mice by providing food and protection from predators and environmental stress. Hence, the amount of alfalfa cover remaining on a field as winter begins affects meadow mouse populations and damage. In areas where meadow mice are known to be a problem, graze or mow the field in late October to early December, after alfalfa has “frozen back” and is no longer actively growing. This is particularly important in years with snow cover, because snow protects meadow mice from predators. Fences can be constructed to exclude meadow mice, but they are not cost-effective for protecting alfalfa fields.

Trapping

Trapping is not a cost-effective control measure in alfalfa fields, but it is useful to monitor populations. When mouse damage is visible along the edge of a field, set two trap lines of 50 traps each. The number of mice caught in one night per 100 traps is used to assess the population level. Infestations that yield fewer than 5 meadow mice per 100 traps are considered light; 10 per 100 traps, moderate; and 20 or more per 100 traps, heavy. Begin treatment when the population is moderate.

Baits

Toxic baits are necessary where mouse problems are serious. However, at the time of publication, no baits are registered for use in alfalfa during the growing season. Zinc phosphide (a restricted-use pesticide) is registered for use in alfalfa only during the dormant period, although it can be used in areas around alfalfa fields at any time of year. Treat heavily infested alfalfa fields with zinc phosphide (a single-feeding bait) in the late fall to early spring, before alfalfa breaks dormancy and before mice begin spring breeding. Use a mechanical broadcaster to apply bait. Monitor areas around the alfalfa and treat them as needed, at any time of year. Zinc phosphide requires only one feeding to be lethal. Bait shyness, a condition that results when meadow mice consume only enough to make them sick and then discontinue feeding, is a potential problem with zinc phosphide. Follow label instructions to limit the potential for bait shyness, and do not treat more often than every 6 months.

Anticoagulant baits may not be used in alfalfa at any time of year, but they can be used at any time along fence rows and in the surrounding noncrop areas. To be effective, meadow mice must consume an anticoagulant over a period of at least 5 days. Therefore, the bait must be available to the mice until the population is controlled. The usual procedure is to hand-bait the runways near burrow openings every other day for 5 days. Read label instructions to ensure the proper rate of application.

DEER AND ANTELOPE

Deer and antelope can be problematic, consuming significant amounts of alfalfa in some fields in the Intermountain Region. Their feeding can be considerable in fields adjacent to wooded or brush areas.

After obtaining a depredation permit from the California Department of Fish and Game, you are permitted to shoot deer. Shooting is unlikely to solve the problem, however. Using traps, poisons, and toxic bait to control deer and antelope is illegal. Deer fences are the only legal, somewhat effective control measure. A fence should be 7 to 8 feet high and made of woven mesh wire (4- by 4-inch mesh). A few strands of barbed wire no more than 4 inches apart can extend the height of shorter fences. Deer fences are costly and almost never worth the expense and effort. Damage from deer and antelope is largely unavoidable—consider it one of the losses associated with growing alfalfa in the Intermountain Region.

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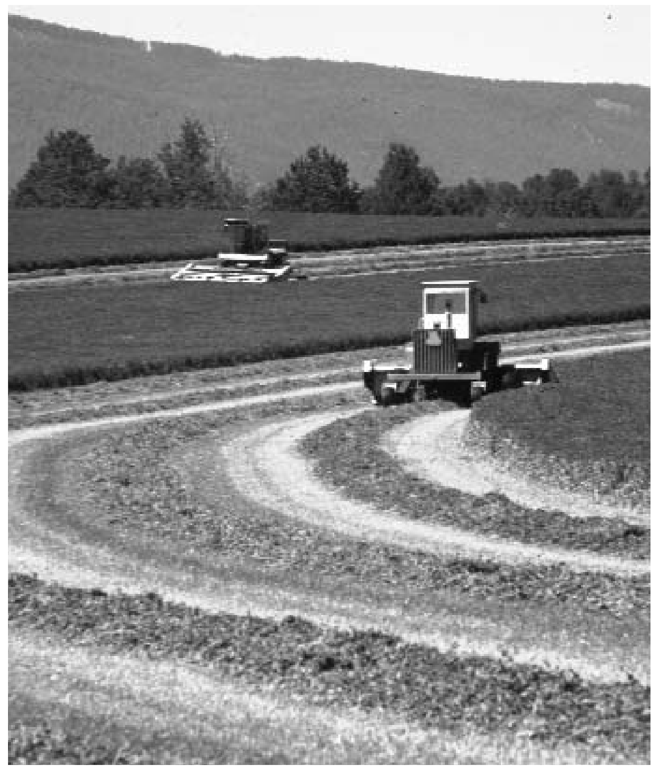
CHAPTER ELEVEN

HARVEST MANAGEMENT

Steve B. Orloff and Vern L. Marble



Harvest management is the primary method by which growers can influence the nutritional quality of alfalfa hay, and it has profound effects on forage yield and stand life. Deciding when to cut alfalfa is a difficult management decision because the grower must make trade-offs among yield, quality, and stand persistence.

ALFALFA GROWTH AND ROOT RESERVES

To understand the effects of time of cutting, it is helpful to review some principles of plant growth and alfalfa development. Plants utilize energy from the sun, through the process of photosynthesis, to transform carbon dioxide from the air and water from the soil into carbohydrates (Figure 11.1).

As a perennial plant, alfalfa stores some of the carbohydrates in its crown and roots. These stored carbohydrates are commonly called root reserves. They provide the energy for survival through winter, growth in the spring, and regrowth after cutting. During these periods an alfalfa plant pulls carbohydrates from roots until new leaves can photosynthesize carbohydrates sufficient to exceed the needs of the growing plant. After cutting, this takes about 2 to 3 weeks, or until the alfalfa attains a height of 6 to 8 inches. From this point the plant begins replenishing root reserves (Figure 11.2). Carbohydrate reserves in roots and crowns increase with plant maturity until full flowering of the alfalfa. Cutting alfalfa at excessively immature growth stages—which occurs when cutting intervals are very short—does not allow enough time for the alfalfa to replenish root reserves. Vigor of new growth is affected. Stand life may also be reduced if alfalfa is repeatedly cut before root reserves are restored.

THE EFFECTS OF TIME OF CUTTING

Alfalfa yields per cutting increase as plants mature and the interval between cuttings increases. Yield increases

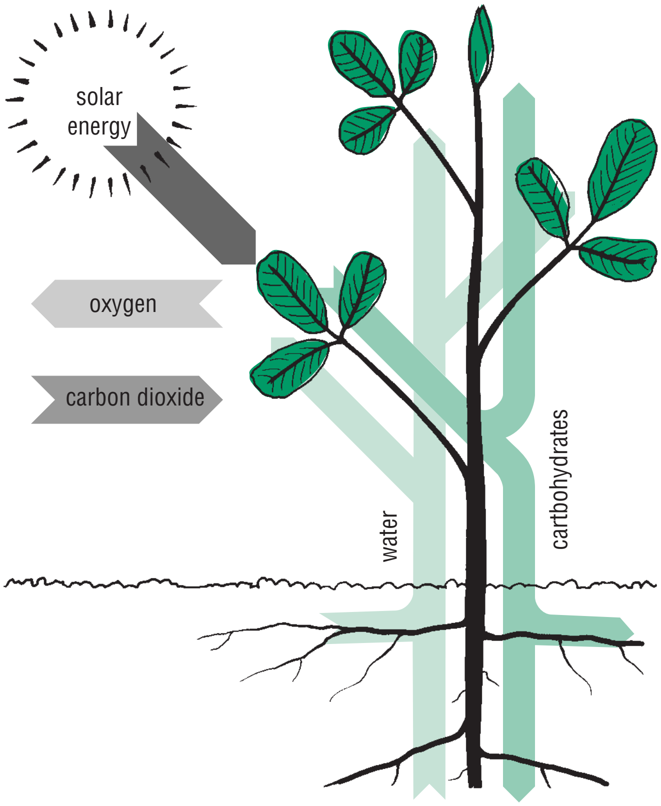


Figure 11.1. Through the process of photosynthesis, plants utilize energy from the sun to transform carbon dioxide and water into carbohydrates. Carbohydrates are used for new growth or are stored in the root for future growth and development. When stored in the root, carbohydrates are called root reserves.

approximately 120 pounds per acre per day in the Intermountain Region. In theory, the grower should obtain maximum yield when alfalfa reaches full bloom (Figure 11.3). Due to leaf aging (senescence) and loss from lower portions of mature alfalfa plants, however, the highest yields are sometimes obtained at around 50-percent bloom.

In contrast to yield, forage quality declines with advancing alfalfa maturity (Figure 11.4). Two reasons explain this decline. The first involves the proportion of stem weight. During the vegetative stages of alfalfa growth, the weight of leaves exceeds that of stems. However, as alfalfa matures beyond the early flowering stage, the weight of stems surpasses that of leaves as stems become longer and larger (Table 11.1). Therefore, much of the yield increase after bud stage can be attributed to increased stem weight, not increased leaf weight. Since leaves contain more nutrients than do stems, forage quality declines. The second reason why quality declines with maturity is that the fiber content of the stem increases as it matures.

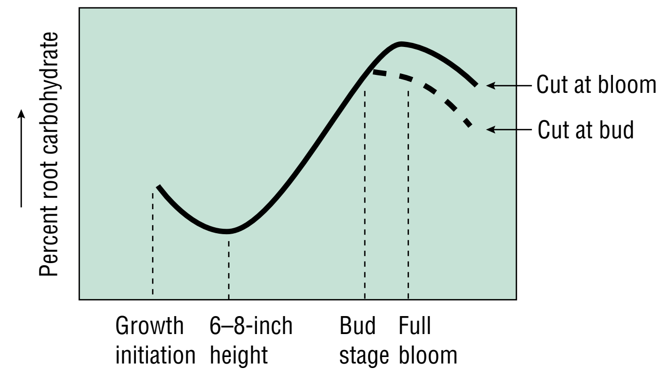


Figure 11.2. Cutting and growth stage affect the carbohydrate content of alfalfa roots.

In the Intermountain Region, as alfalfa matures from prebud to full bloom, total digestible nutrients (TDN) of a first cutting decline about 1 percentage point for every 4-day delay in harvest (that is, a decline of 0.25 percentage points per day). The amount of crude protein decreases approximately 1 percentage point every 5 days.

As mentioned, selecting the proper cutting time involves a compromise between top quality and maximum yield. Longer cutting intervals (that allow the crop to mature up to 50-percent bloom) generally result in higher tonnage and longer stand life but lower-quality hay. Conversely, very high-quality hay but short stand life and lower tonnage usually result from shorter cutting intervals (cutting alfalfa in the early-bud or prebud stage). In the Intermountain Region, it takes 3 to 4 weeks to restore root reserves and another 7 to 10 days to add surplus carbohydrates to the roots so the plant is ready for another cutting. Thus, under optimum conditions, the minimum

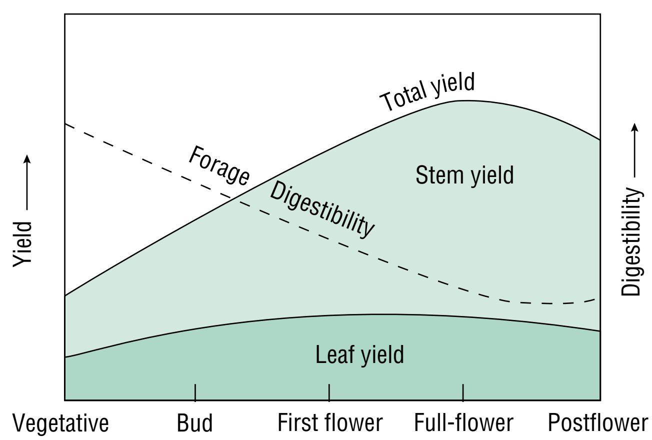


Figure 11.3. Forage yield relative to quality at different alfalfa growth stages.

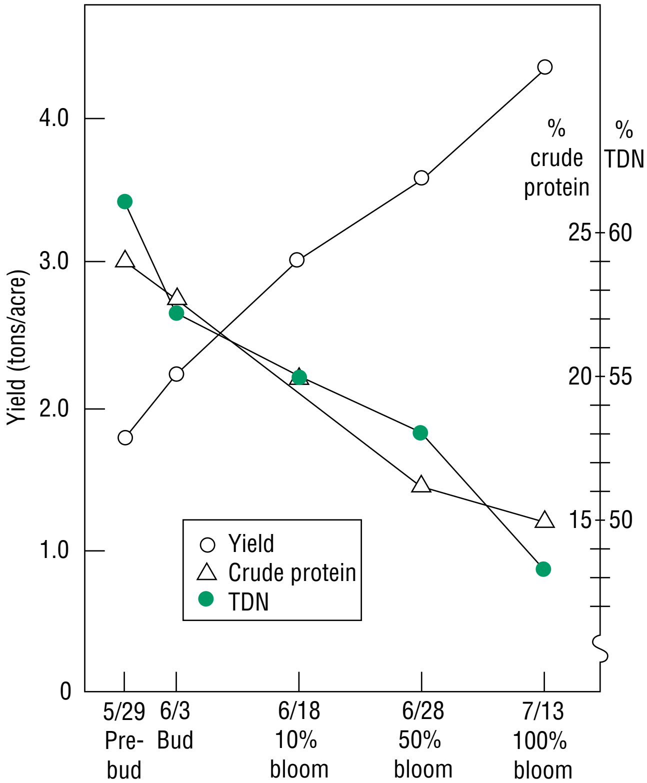


Figure 11.4. Yield and quality trade-off. As the date of first cutting is delayed, yield increases dramatically but total digestible nutrients (TDN) and crude protein decrease. (Data were gathered at McArthur, Shasta County, 1966–69.)

Table 11.1. Relative proportions of leaves and stems of alfalfa at three growth stages.

GROWTH STAGE	PERCENTAGE OF LEAVES	PERCENTAGE OF STEMS
Bud stage	63	37
1/10 bloom	48	52
½ bloom	46	54

Source: Meyer and Jones (1962)

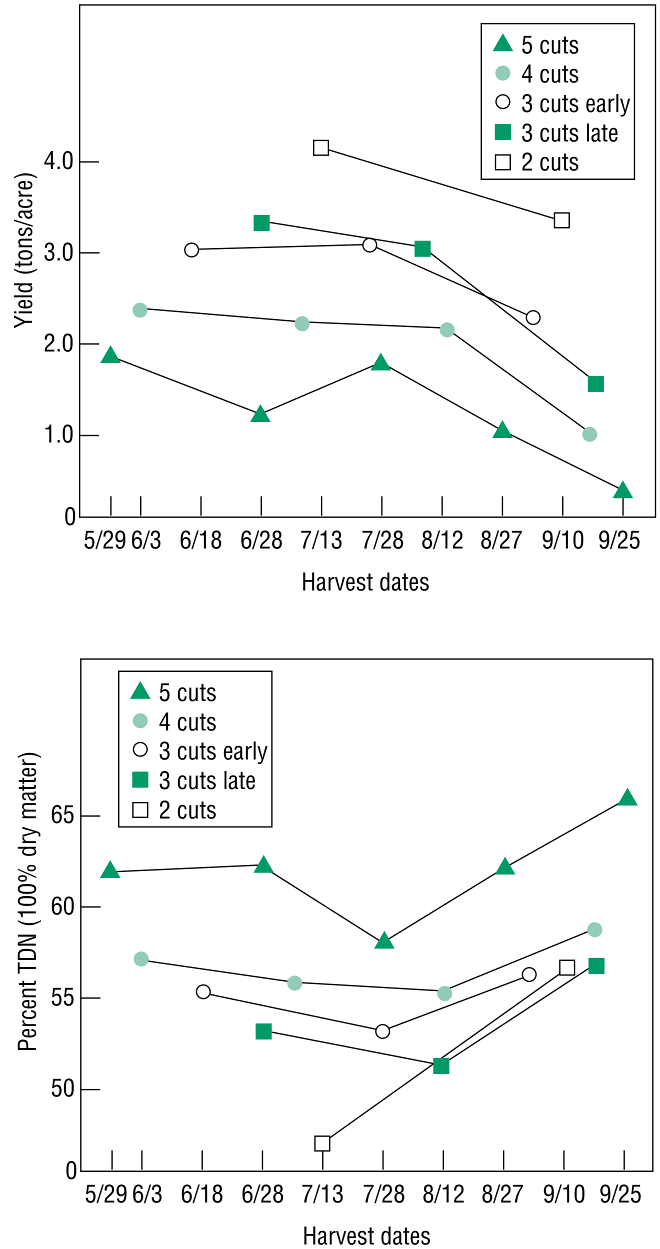


Figure 11.5. Seasonal variation in yield and TDN as they relate to cutting frequency at McArthur, Shasta County, 1966–69.

interval between first and second cuttings, or second and third cuttings, is 30 to 50 days. The time depends on weather and alfalfa variety. Regardless of variety, alfalfa will be weakened before the end of the first growing season if cut at intervals of less than 30 days. Too-frequent cutting results in reduced vigor and, often, weed infestation (because root reserves are depleted, alfalfa plants are less able to compete with unwanted vegetation).

In addition to time of harvest, seasonal changes in temperature and photoperiod (day length) impact forage yields and quality. In general, first-cutting forage yields tend to be higher than those of subsequent cuttings, regardless of the total number of cuttings per season (Figure 11.5). However, when the first cutting is taken at a very early growth stage (early-bud or sooner), second-cutting yields may be higher. The final cutting of the season, in the fall, yields less than previous cuttings because the alfalfa growth rate has slowed in response to cooler nighttime temperatures and shorter day lengths. In contrast to yield, the nutritional quality of the fall cutting is typically the highest of the season. Alfalfa harvested in the spring and fall has higher TDN than alfalfa cut at the same growth stage in midsummer. Therefore, to achieve dairy-quality hay, alfalfa must be cut at a less mature stage in midsummer than in spring or fall. The yield sacrifice associated with such early cutting may be significant, encouraging many growers to delay harvest and produce beef or horse hay in midsummer.

SELECTION OF A CUTTING SCHEDULE

There is no optimum cutting schedule for all growers in all locations in the Intermountain Region. Several factors should influence the selection of a cutting schedule. These include the quality of the hay desired, weather conditions, the anticipated length of the growing season, harvest costs, desired stand life, and the alfalfa market.

The purpose of producing high-quality alfalfa hay is to take greatest advantage of the plant's nutrient potential as a livestock feed. Therefore, hay intended for use as a maintenance feed for beef cows or for "hobby" horses can be of much lower quality than that sold to dairies or used to grow weaner calves or yearlings. Hence, the growth stage at which alfalfa is cut should reflect the intended use for the hay. The dairy industry is demanding higher and higher quality. At one time premium hay had 54 percent TDN; the dairy market is now insisting on 55 or even 56 percent TDN (90% dry matter basis). Hay intended for this market must be cut early (late-bud stage at the latest) for the necessary quality to be achieved. Conversely, hay intended for beef cattle or horses can be cut later, at 10- to 30-percent bloom, to maximize yields with acceptable quality for these classes of livestock.

Alfalfa fields are sometimes harvested on a calendar basis, using a fixed interval and a fixed number of cuttings per season. The advantage of this method is that the number of cuttings per season is predetermined. This facilitates planning—it allows advance scheduling of irrigation, the cutting of other fields, and other activities. The problem with this method is that it does not account for weather or dormancy differences among alfalfa cultivars. Weather, primarily temperature, has a significant effect on alfalfa development and will cause plant maturity on a given date to vary from year to year. The dormancy of a variety also influences its development. In general, a less dormant variety matures more rapidly than a dormant variety. Also, plants from different dormancy classes respond differently to temperature and photoperiod. Dormant varieties are more responsive to photoperiod than are less dormant varieties.

Another method of scheduling alfalfa harvests uses the growth stage of alfalfa to indicate the appropriate time to cut and the number of cuttings per season. The grower selects a specific alfalfa growth stage (such as bud, late-bud, 10-percent bloom, etc.) at which harvest will begin. This method takes into account the effects of environmental and varietal differences and results in more consistent, predictable forage yield and quality than when harvesting on a calendar basis. In some areas, the alfalfa growth stage at harvest is based on the appearance of bud or bloom; in others, regrowth from crown buds is used to indicate the proper time to cut. The regrowth method is less reliable with the dormant cultivars produced in the Intermountain Region. The primary drawback to cutting based on stage of development is that the number of cuttings per season is not defined—a partial cutting may remain at the end of the season. Unless grazing or green chopping is an option, there is little a grower can do when 0.50 to 0.75 ton of forage per acre remains in the field at the end of the growing season.

Much of the yield increase after bud stage can be attributed to increased stem weight not increased leaf weight.

The relatively short growing season in the Intermountain Region restricts the harvest schedule. Therefore, consider both calendar date and stage of growth when deciding on a harvest strategy. Modify harvest timing to fit three or four cuttings into the season. Four cuttings are often appropriate in the lower-elevation valleys and where dairy-quality alfalfa is desired for all cuttings. However, the harvest costs imposed by a fourth cutting must be weighed against any price premiums that may be received for this top-quality alfalfa. A three-cut schedule is usually preferred when at least one cutting is used for beef cattle or horses.

Base the timing of the first cutting on the growth stage of the alfalfa. Cut alfalfa at the growth stage that will most likely result in the quality and yield desired. For example, cut at early-bud stage for a 1.5 to 2.5 ton per acre yield of dairy-quality hay, but cut at early-bloom stage for a 2.5 to 3.5 ton per acre yield of hay suitable for nonlactating dairy cows or beef cattle. If the date of the first harvest is very early or very late, regardless of the stage of development of the alfalfa, the calendar date will impact the timing of other cuttings; the total number of cuttings per season may then need to be adjusted. Likewise, consider the growth stage of the alfalfa and the calendar date when adjusting the date of cutting to accommodate variation in weather.

In valleys over 4,800 feet in elevation, the choice is normally between two and three cuttings. Research has shown that producers obtain equal yields by making three cuttings instead of two. However, by making three cuttings, they greatly improve forage quality and marketability.

CUTTING HEIGHT

Leave a stubble height of 3 to 4 inches when cutting alfalfa. Studies from the central and northern United States have shown that average annual yields of dry matter, protein, and digestible dry matter decrease as cutting height increases from 3 to 9 inches. Maximum yields were obtained at the 3-inch cutting height. Raising the cutting height did increase forage quality, but it caused a significant decrease in production that more than offset the slight increase in quality.

FALL HARVEST MANAGEMENT

The decision about when to begin the final alfalfa harvest of the season deserves considerable attention. Although weather conditions and their suitability for making hay are important, they are not the only criteria. Keep in mind the effect of fall harvest management on stand life and vigor. Fall harvest management can also influence winter weed infestation, especially infestation by downy brome (cheatgrass) or hare barley (foxtail).

As mentioned, stored carbohydrates provide the energy for regrowth after cutting and initial regrowth in spring. You must allow the alfalfa sufficient time to replenish root reserves before cutting it. In addition to spring regrowth, root reserves are needed for winter hardiness. Insufficient root reserves going into the winter can result in reduced vigor, stand loss, and lower yields the following spring. Therefore, the last harvest of the growing season should occur 4 to 6 weeks before the first killing frost. (A killing frost is generally believed to be 25° to 26°F, or –4° to –3°C.) Cutting after a killing frost does not deplete root reserves. Consequently, a late harvest or grazing can be made during late October or early November if field conditions permit and growth is sufficient for a profitable crop. Unfortunately, curing conditions are seldom favorable at this time, so grazing or silage is usually the only option.

The last harvest . . . should occur 4 to 6 weeks before the first killing frost.

Predicting when a killing frost is likely to occur can be difficult. A grower can only rely on experience and historical weather data to time final cuttings. When a grower has numerous fields, cutting them all at the optimum time may be impossible. Fields cut too close to the first killing frost (mid-September to mid-October) should be allowed to grow to a late stage of development before the first cutting is made the following spring. The consequence of not doing so is reduced subsequent yields.

Most alfalfa growers in the Intermountain Region have few alternative cash crops and want alfalfa stands to produce for 6 to 8 years or longer. For these growers, fall harvest management is critical. However, if profitable rotation crops are available and a stand life of only 3 to 4 years is desired, fall harvest management is much less important.

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CHAPTER TWELVE

HAY CURING, BALING, AND STORAGE

Steve B. Orloff

Significant yield and quality losses occur when alfalfa is not harvested correctly. The goals of harvesting are to cut alfalfa at the growth stage that provides the optimum combination of yield and quality and to maintain quality and minimize losses through rapid curing and timely raking and baling. There is increasing interest in maximizing hay quality through variety selection and management. These efforts are nullified if the high-quality alfalfa is not harvested and stored properly.

Nearly all alfalfa in the Intermountain Region is harvested for hay, so this chapter emphasizes hay-making practices rather than those used when making green chop or silage. The hay-making procedure most commonly used in the Intermountain Region is a four-step process. It begins with cutting the alfalfa, which is usually done with a 12- or 14-foot self-propelled swather. After a few days the partially dried, or cured, hay is raked to turn the windrow, and two windrows are combined or laid side by side. This hastens the curing process and improves the efficiency of the baling operation. After the hay has dried sufficiently, it is baled. Finally, it is roadsided by a self-propelled bale wagon.

HAY CURING

One of the most critical aspects of harvesting is drying cut alfalfa to a point where it can be safely baled. This is especially true in the Intermountain Region, where thunderstorms pose a significant and continual threat. Rapid, uniform curing of alfalfa is highly desired. It minimizes quality losses due to bleaching, respiration, leaf loss, and rain damage and improves subsequent yields by reducing the effect of windrow shading, lessening traffic damage to regrowth buds, and allowing timely irrigation after cutting.

The moisture content of alfalfa growing in the field is generally between 75 and 80 percent. The drying rate of cut alfalfa depends upon several environmental variables. These include solar radiation, temperature, relative humidity, soil moisture, and wind velocity. Research in Michigan and California indicates that solar radiation is by far the most significant environmental factor influencing drying rate.

The objective of the hay producer is to utilize management practices that accelerate the drying rate within the confines of uncontrollable environmental conditions. To determine which management practices would be most effective, it is helpful to understand the alfalfa drying process.

The drying process of alfalfa occurs in two phases. The drying rate during each phase is governed by the resistance to water loss from the plant (Figure 12.1 explains various resistances to moisture loss). The first phase, or rapid drying phase, accounts for approximately 75 percent of the moisture loss that occurs during the curing process and requires only 20 percent of the total drying time. The stomata (leaf pores) are wide open, and moisture loss occurs from leaves through these openings and from water transfer from the stems through the leaves. Some water also departs through the cut ends of stems and through bruised tissue. The main limiting factor to drying during the first phase is boundary layer resistance, the resistance offered by the layer of still moist air around the plant. Wind moving over and through the windrow can accelerate drying by replacing the moist air in the boundary layer with drier air. The first phase is usually complete before the end of the first day after cutting. The second phase, the slow drying phase, commences at about 40 percent moisture content, when the pores of the leaf and stem close. Stomatal resistance increases immensely and drying rate depends on cuticular resistance. Compared to moisture loss in the initial phase, moisture loss is extremely slow in this phase. In fact, the drying rate in this phase is $\frac{1}{100}$ the initial drying rate.

Figure 12.1 Resistances to water loss from alfalfa.

- Boundary layer resistance: resistance related to the layer of still moist air close to the plant surface
- Cuticular resistance: the resistance of the plant surface to water movement
- Stomatal resistance: resistance that is controlled by the pores on the surfaces of leaves and stems

Wide windrows often dry one day faster than narrow windrows . . . more of the alfalfa is exposed to radiant solar energy.

Mechanical Conditioning

To accelerate curing, many growers mechanically condition or crimp the alfalfa as they cut it. In fact, mechanical conditioning has become a widely accepted practice. Most conditioners lightly crush the forage between intermeshing rollers located behind the header of the swather. The primary rationale for crimping is to crush and break the stems, which dry more slowly than leaves, thus facilitating water loss and bringing the drying rate of stems more in line with that of leaves. Mechanical conditioning affects both phases of the drying process. It accelerates the rapid phase by crushing stems, and it accelerates the slower phase by breaking the cuticle. Sometimes growers question the effectiveness of mechanical conditioning and wonder if the cutting operation could be simplified if the conditioning rollers were removed. Research has shown that mechanical conditioning hastens the drying process by as much as 30 percent. Drying time saved by mechanical conditioning can vary considerably, however, depending on weather conditions and alfalfa yield. Conditioners should be set so that stems are cracked and crushed but not cut or severely macerated. Consult the owner's manual for proper conditioner adjustment.

Chemical Conditioning

Chemical conditioning involves the use of a drying agent, usually potassium carbonate or a mixture of potassium and sodium carbonate. A drying agent is applied during swathing. The chemical hastens the drying process by allowing water to pass more freely through the waxy cuticle on the plant surface. Thus, drying agents affect the second, or slow, phase of the drying process. These agents are most effective when the weather is warm and sunny. Under poor curing conditions or when there is rain during drying, drying agents present no advantage. Drying agents have not become popular in the Intermountain Region (or in California as a whole) because of their cost, the need to haul large volumes of water to and through the field to apply them, and the good curing conditions in most of California (compared to those in the Midwest). Therefore, they are not believed to be cost-effective in most situations in the Intermountain Region.

Swath Management

Wide, airy windrows dry more rapidly than conventional ones, which are narrow and dense. This has been demonstrated in several California trials and in numerous trials throughout the United States (Figure 12.2). The extent of the advantage that wide windrows offer depends on the geographic area, the time of year, and the yield level. In general, wide windrows are most beneficial in the spring, when yields are high and day length is long (that is, there is more solar radiation than in other seasons). Wide windrows often dry one day faster than narrow windrows because the forage is spread out and more of the alfalfa is exposed to radiant solar energy. Also, because they encounter less boundary layer resistance, wide windrows do not inhibit moisture movement to the degree narrow ones do. Wide windrows improve the uniformity of drying, which affects when alfalfa can be raked and baled. The start of these practices is determined not by the average windrow moisture content, but by the moisture content of the wettest portion of the windrow. Therefore, since the moisture content of wide windrows is relatively uniform, they can be raked and baled earlier. If wide windrows are not raked earlier, their advantage is lost.

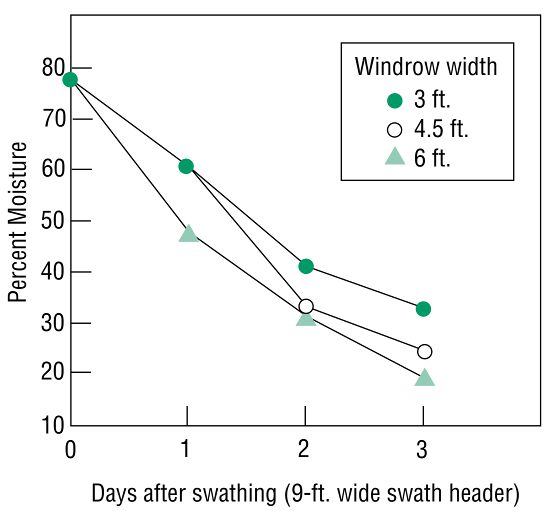


Figure 12.2. The effect of windrow width on alfalfa drying rate. (*Source:* Klamath Agricultural Experiment Station, Oregon State University.)

Some growers are reluctant to switch to wide windrows; they fear that, because wide windrows expose more surface area to the elements, color loss from bleaching will result. However, researchers who have compared alfalfa from wide and narrow windrows have not observed any significant color difference. Although wide windrows do expose more alfalfa, they usually can be raked and baled sooner, so exposure time is reduced. Also, wide windrows remain wide only until they have dried sufficiently to rake. Raking usually occurs after the first drying phase. Little bleaching occurs during the initial phase, because the waxy cuticle of the plant is largely intact. During the final curing phase, when most bleaching occurs, wide windrows have been raked and combined so they are no wider than raked conventional windrows.

Many growers have not switched to wide windrows because of equipment limitations; the width of conditioning rollers and windrow baffles determines windrow width. Some new swather designs have conditioners nearly as wide as the swather header, so growers can alter windrow width with a simple adjustment of a lever. Fortunately, inexpensive windrow conditioner shields have been developed that modify traditional swathers so they can spread windrows.

Because of their width, wide windrows must be raked prior to baling and cannot be baled directly out of the swath. Obviously, this is not a problem in areas where windrows are always raked. Also, windrow width should not be greater than that which can be easily managed with available rakes.

Raking

The purpose of raking is to expedite the drying process by transferring the alfalfa to drier soil and inverting the windrow. Inversion exposes alfalfa on the bottom of the windrow, which at this point has a higher moisture content than that at the top. Also, raking usually combines two windrows, thus facilitating baling and roadsiding. Raking is very effective, but it must be done at the proper moisture content; otherwise, excessive yield and quality losses will occur (Figure 12.3). Many growers rake alfalfa when it is too dry.

The optimum moisture content for raking is 35 to 40 percent. At this moisture content, a significant increase in drying rate is achieved while severe leaf loss is avoided. Raking at too high a moisture content may twist (commonly referred to as rope) rather than invert the hay and can actually slow drying rate. Leaf loss associated with raking hay too dry is significant. When raking hay at 20 percent moisture content, 21 percent of leaves are lost; when raking at 50 percent moisture, only 5 percent are lost (Table 12.1). Therefore, hay raked just prior to baling will be too dry. The greatest loss is in the leaf fraction. Such loss significantly reduces the quality of the hay, since leaves are its most nutritious component. Research has shown that raking alfalfa hay that is too dry is more detrimental to hay quality than baling when too dry. In one study, late raking resulted in a 25 percent loss in yield and a 2- to 4-percentage unit reduction in total digestible nutrients (TDN). (Baling when too dry resulted in a 5-percent loss.) If alfalfa was both raked and baled too dry, the loss increased 10 percent over the raking loss.

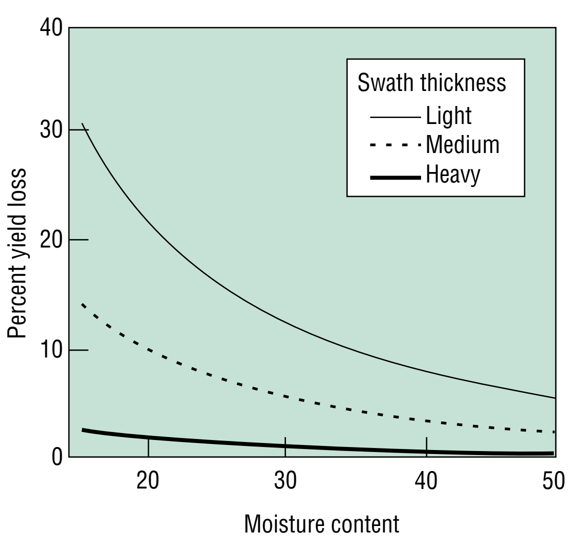


Figure 12.3. The effect of moisture content and swath thickness on dry-matter losses during raking. (*Source:* C. A. Rotz, Michigan State University.)

BALING AND STORAGE

Alfalfa must be baled within a relatively narrow range of moisture content to avoid losses in yield and quality. Whenever possible, refrain from baling hay that is below 12 percent moisture, because leaf shatter and loss will be excessive. Hay baled at too high a moisture content is subject to problems with mold and discoloration. The maximum moisture content for baling depends on bale size and density. In general, bale small two-tie bales at less than 20 percent moisture, larger and denser three-tie bales at less than 17 percent, and 1-ton bales at less than 14 percent. The source of moisture within the bale affects the upper moisture limit for safe baling. Hay can be baled at a higher moisture content when the moisture source is free moisture (dew) than when it is moisture trapped inside the stem (stem moisture). Free moisture is more readily dissipated than stem moisture.

Moisture Content Estimates

A simple and practical method to determine if alfalfa hay can be safely baled is to grab a handful of alfalfa with both hands and twist it by rotating your wrists in opposite directions. If the stems crack and break, the hay is usually dry enough to bale. The thumbnail test is an even better method. Scrape an alfalfa stem with your thumbnail. If the epidermis, or outside layer, cannot be peeled back, the hay has dried sufficiently (Figure 12.4). A moisture meter is a valuable tool to evaluate the moisture content of hay. Resistance-type moisture meters are used as hand probes or mounted on the baler chamber for on-the-go moisture monitoring. How dependable are readings from moisture meters? Researchers have tested their accuracy and found that their readings were within 2.6 percentage points of actual moisture content. Generally, meters indicate a moisture content that is slightly higher than

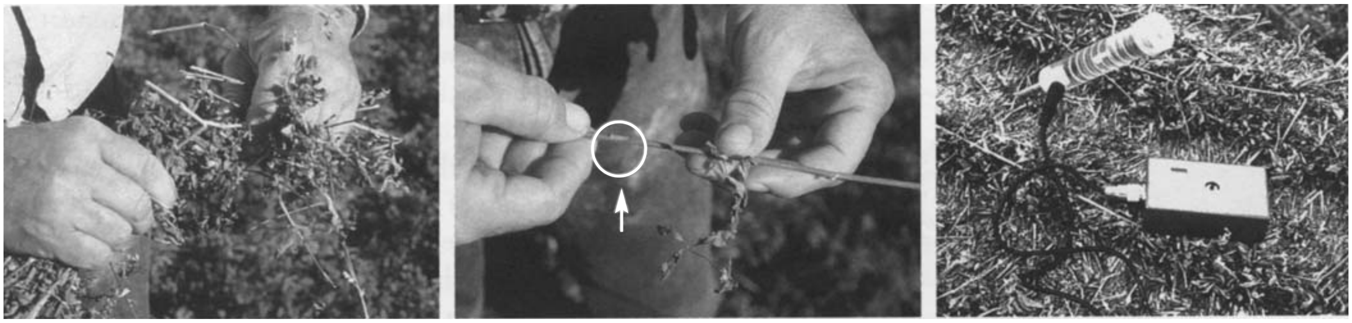


Figure 12.4. Three methods to evaluate the moisture content of alfalfa hay. (A) The twist method: Grab a handful of alfalfa with both hands and twist it by rotating your wrists in opposite directions. If the stems crack and break, the hay is dry enough to bale. (B) The thumbnail test: Scrape an alfalfa stem with your thumbnail. If the epidermis, or outside layer, cannot be peeled back, the hay has dried sufficiently. (C) Resistance moisture meters: Probe the bale several times and read the meter to learn the moisture content.

the actual content. They measure stem moisture less accurately than they measure dew moisture.

Moisture for Baling

After alfalfa is fully cured, dew or high relative humidity must soften the leaves. Otherwise, excessive leaf loss will occur during baling. Sometimes, mostly in midsummer, dew or humidity is insufficient for this purpose. Delaying the baling operation to wait for dew is undesirable—yield declines and leaf loss increases the longer hay is left in the windrow. The chance of rain damage also increases proportionately. Additionally, waiting for dew postpones other necessary operations (such as irrigation and cutting of other fields), thus disrupting the cutting cycle and possibly reducing yield and quality.

Windrows can be sprayed with water to compensate for a lack of dew or on days when humidity is insufficient to permit baling. A three-tier boom setup with seven hollow cone nozzles is an effective spray system (Figure 12.5). Two adjustable hollow cone nozzles are mounted on each of the two leading booms. The spray angle of these adjustable nozzles is narrowed to promote water penetration into the windrow. Three standard hollow cone nozzles are mounted on the trailing boom to mist over the entire windrow. Water is sprayed on the windrow at the rate of 40 to 50 gallons per acre. Depending on weather conditions, allow 10 to 30 minutes between water application and baling; this time allows the water to penetrate and soften the leaves. This practice is often an acceptable substitute for natural dew, or it can be used to extend the baling period on days with marginal humidity. However, applying water to windrows does not make midday baling possible. The high evaporation rate at this time negates the effectiveness of spraying.

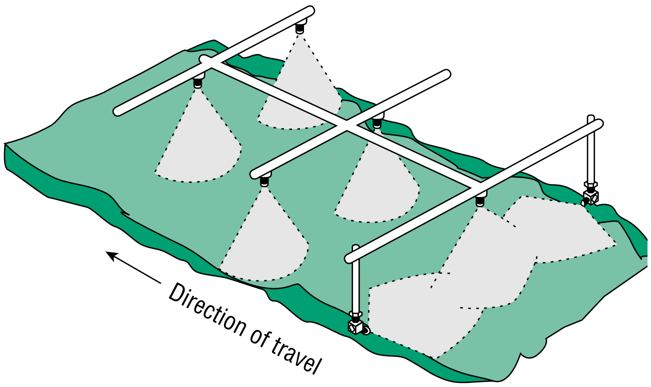
Table 12.1 Yield and leaf loss during harvest operations.

OPERATION	YIELD LOSS[1] (%)	LEAF LOSS (%)
Mowing and conditioning	2	3
Raking		
At 60% moisture	2	3
At 50% moisture	3	5
At 33% moisture	7	12
At 20% moisture	12	21
Baling, pickup and chamber		
At 25% moisture	3	4
At 20% moisture	6	4
At 12% moisture	6	8

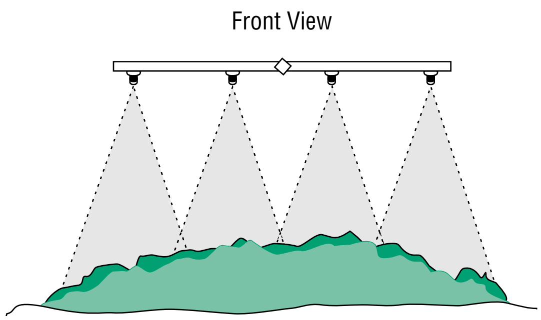
Source: Pitt, R. E. 1990. Silage and hay preservation. Ithaca, NY.
1. Reported on a 100% dry-matter basis.

Moisture Content for Safe Storage

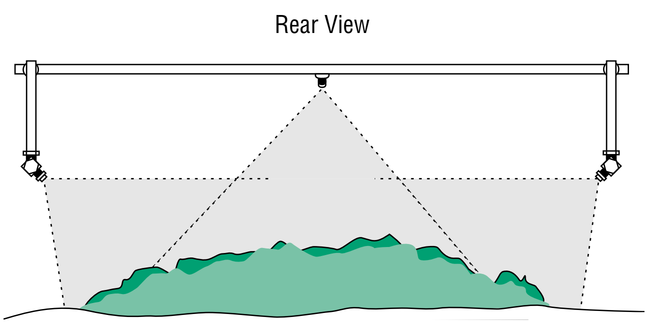
The maximum moisture content for safe hay storage is influenced by the uniformity of moisture within bales, climatic conditions during storage, and ventilation at the storage site. The moisture content of high-moisture bales can be reduced somewhat by allowing them to remain in the field until late afternoon; then road-



(A)



(B)



(C)

Figure 12.5. (A) This figure shows a three-tier spray boom configuration for adding moisture to windrows. Two adjustable hollow cone nozzles are mounted on each of the two leading booms. Only two nozzles are mounted on each boom so that the sprays do not intersect and deposit an excessive amount of water where the patterns overlap. Three standard hollow cone nozzles are mounted on the third boom. (B) As the front-view illustration shows, the boom setup contains a total of four adjustable hollow cone nozzles. Their spray angle is narrowed to promote water penetration into the windrow. (C) The three standard hollow cone nozzles on the trailing boom mist over the entire windrow. As the rear-view illustration shows, the two outer nozzles are mounted on drops, with swivels. The swivels are angled in, toward the windrow.

side them. Another way to reduce moisture content is to position balewagon loads outside with a gap between the stacks before storing the bales in a barn. Unfortunately, these methods are only partially effective; neither method can dissipate moisture deep within the interior of bales.

Significant yield and quality losses can occur during storage. Studies have indicated dry-matter losses of 1 percentage point for each percentage of moisture above 10 percent. Quality losses can take several forms. Molds may develop in hay stored at a moisture content greater than 20 percent. Molds can produce toxins that reduce palatability and are hazardous to livestock. Mold respiration causes heating, and, when hay temperatures exceed 100°F (38°C), browning reactions begin. Reactions that occur during browning, coupled with heating from mold growth, can cause temperatures to increase further. Heating may reduce the protein and energy available to the animal that consumes the hay (Table 12.2). When bale temperatures exceed 150°F (66°C), spontaneous combustion can occur. This is most likely in hay with a moisture content over 30 percent.

Heating during the first month actually helps dry hay; hence, after the first month, hay has usually dried to a moisture content where it is stable and can be stored safely. Therefore, any problems that result from storing hay with an excessive moisture content are most likely to occur during the first month of storage. Although the majority of dry-matter losses during storage occur in the first month, Rotz (1994) and others

Table 12.2. Problems associated with hay heating.

TEMPERATURE	PROBLEM
115°–125°F (46°–52°C)	When coupled with high moisture, molds and odors develop and decrease palatability.
> 120°F (49°C)	Heating reduces digestibility of protein, fiber, and carbohydrate compounds.
130°–140°F (54°–60°C)	Hay is brown and very palatable because of the carmelization of sugars; unfortunately, nutritional value is reduced.
>150°F (66°C)	Hay may turn black and spontaneous combustion is possible.

Source: V. L. Marble

When bale temperatures exceed 150°F, spontaneous combustion can occur. This is most likely in hay with a moisture content over 30 percent.

found that losses continue at a rate of about 0.5 percent per month for the remainder of the storage period.

Bale Ventilators

A bale ventilator creates a hole through the center of a standard rectangular two- or three-tie bale. The hole is formed by a spear, 8 to 10 inches long, that is mounted on the center of the baler plunger face. The spear produces a 2-inch-diameter hole through the entire bale as the hay is compressed in the chamber. Theoretically, the hole facilitates the dissipation of moisture from the bale, preventing spoilage of high-moisture hay (hay with a moisture content up to 25 percent). However, tests conducted at Michigan State University showed no benefit from using a bale ventilator. The bale ventilator did not reduce hay temperature, dry-matter loss, or moldiness, nor did it improve hay quality or color.

Preservatives

Preservatives are intended to allow storage of alfalfa hay baled at moisture contents higher than would ordinarily be considered safe. They are used on hay baled between 20 and 30 percent moisture. The advantages of baling at higher moisture contents are reduced leaf loss and reduced field curing time, which may help avoid rain damage.

Hay preservatives are usually applied at baling. Organic acids, primarily propionic acid or propionic-acetic acid blends, are the most common preservatives. They prevent mold growth and heating losses by lowering alfalfa pH and retarding the growth of microorganisms that cause hay spoilage. One disadvantage of preservative use is cost. The required application rate for propionic acid is 10 pounds per ton for hay with a moisture content of 24 percent or less. For hay with a moisture content from 25 to 30 percent, the rate is 20 to 25 pounds per ton. These application rates lead to relatively high expenses. What is more, preservatives are seldom 100 percent effective. The causes of erratic effectiveness are uneven application and areas of high moisture content within a bale. (An area of a bale with high moisture content is commonly called a slug.) In addition, propionic acid is hazardous to skin and eyes and corrosive to farm equipment. Alternatives to propionic acid include microbial inoculants and enzymatic products, but their results have been unsatisfactory in most university-sponsored tests. Most researchers conclude that using a preservative to reduce leaf loss is not usually cost-effective. Preservative use may be justified only if the product can be used selectively, when rain is imminent. But, as everyone knows, predicting rain can be very difficult.

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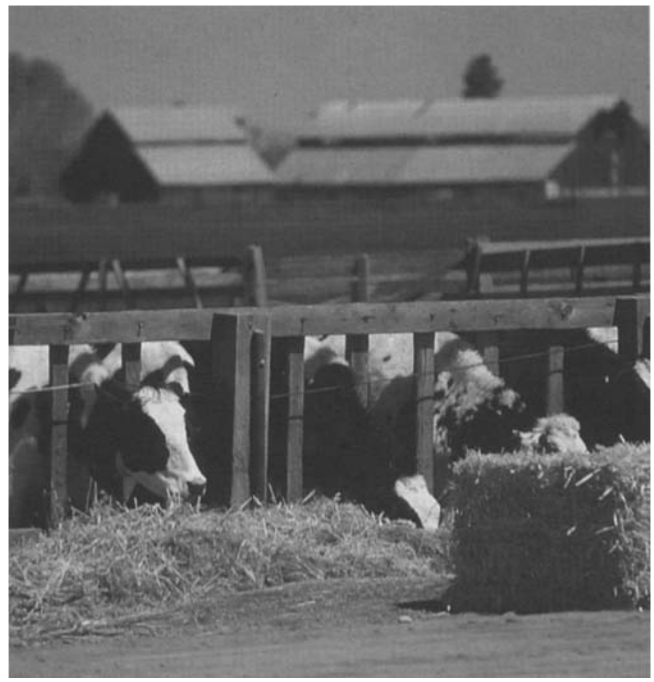
CHAPTER THIRTEEN

QUALITY AND QUALITY TESTING

Steve B. Orloff and Vern L. Marble



Alfalfa hay grown in the Intermountain Region has a well-deserved reputation for high quality. It is marketed locally and throughout much of California, in other states, and internationally. Producers recognize the importance of growing high-quality hay. Quality has a profound effect on animal performance and milk production and, consequently, the value and price of alfalfa hay.

WHAT IS QUALITY?

Forage quality is a relative term. What is considered high-quality alfalfa depends on one's perspective (whether one is the buyer or seller), on current market conditions, and, most importantly, on the intended use for the alfalfa. From a nutrition perspective, forage quality relates to the feeding value of the hay, or the ability to convert hay into milk, meat, and fat. Forage quality is a function of both forage intake and digestibility. As forage quality increases, feed intake and digestibility increase.

Like all living organisms, alfalfa plants are composed of cells (Figure 13.1). Alfalfa cells consist of the soluble and highly digestible contents of the cell (protein, sugars, fats, starch, and pectins) and the less digestible, structural parts of the cell wall (cellulose, hemicellulose, and lignin). Cell wall content is the most important factor affecting forage utilization and, thus, forage quality. Fiber analyses can indicate the cell wall content of alfalfa hay (fiber analyses are discussed later in this chapter).

Low-quality alfalfa has a high proportion of cell wall material, and the cell walls are composed of a relatively large amount of indigestible compounds, such as lignin. Lignification of the cell wall, which occurs as alfalfa plants mature, is the primary factor limiting forage digestibility. High-quality alfalfa, in contrast to low-quality alfalfa, has less cell wall material, and the cell walls are thinner and contain less cellulose and lignin. Not only is high-quality alfalfa more nutritious, but it is also more palatable and digestible. Therefore, animals consume it in larger quantities.

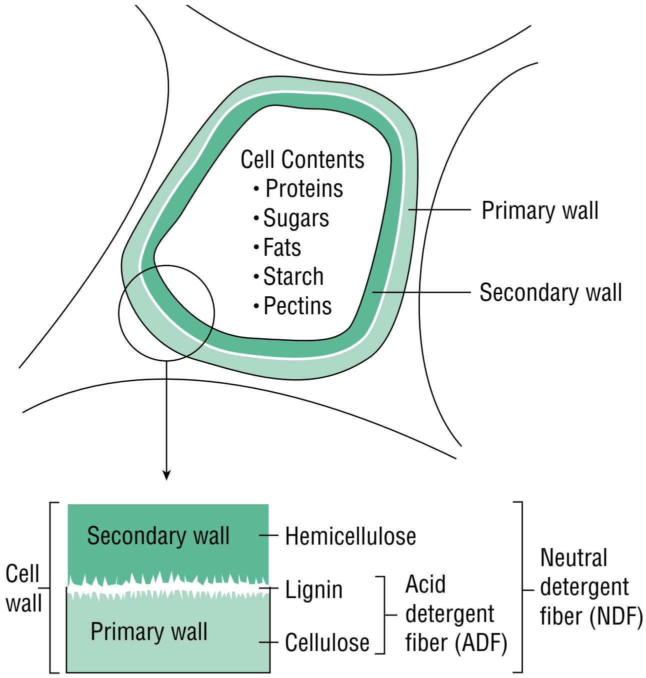


Figure 13.1. Diagram of a plant cell showing cell wall structure and cell components. (Courtesy Pioneer Hi-Bred International, Inc.)

QUALITY REQUIREMENTS

Forage quality needs depend on livestock class—that is, whether the consumers are high- or low-producing dairy cows, or beef cattle, or ruminant versus non-ruminant animals. High-producing dairy cows require highly digestible, high-energy, high-protein forage. Milk output from dairy cows fed low-quality alfalfa hay will never equal milk output from cows fed high-quality hay. Compared to high-quality alfalfa, low-quality alfalfa remains in the ruminant digestive tract longer; this results in decreased intake and animal productivity. Supplements can only partially compensate for low-quality hay in the diet. Compared to high-producing dairy cows, low-producing cows, nonlactating cows (dry cows), and beef cattle have lower nutrition requirements; they do not require top-quality alfalfa. Similarly, horses (especially inactive "hobby horses") have lower energy requirements than do lactating dairy cows. In fact, horses can become colicky when fed alfalfa of too high a quality. Unlike ruminants, horses can respond to eating low-quality hay by increasing their consumption of it and passing it through their digestive system more rapidly; this response compensates for the low quality. The primary criterion when judging alfalfa hay for horses is not its energy value but its condition. Hay for horses should be free of dust, mold, and weeds.

FACTORS AFFECTING QUALITY

Numerous factors, both controllable management factors and uncontrollable environmental factors, influence alfalfa hay quality. Unfortunately, alfalfa quality and yield are usually inversely related. In other words, factors that result in high yields usually result in decreased forage quality; conversely, factors that decrease yield increase forage quality.

Harvest management and variety selection

Stage of maturity at the time of cutting is the most important controllable factor (see chapter 11). Quality declines with advancing alfalfa maturity. However, yields increase with advancing maturity, so harvest management is a compromise between maximum yields and maximum quality. Alfalfa variety selection influences forage quality (chapter 3), as do hay-making practices (chapter 12). Raking or baling when the hay is too dry results in excessive leaf shatter and reduced quality. Heating and mold growth occurs in hay that is baled too wet. Although quality differences among alfalfa varieties are not great compared with differences in other characteristics, most alfalfa seed companies are making a major effort to improve forage quality through breeding. When available, varieties that are higher in quality may increase management options, but they will not replace the need for sound cultural practices.

Seasonal effects

Seasonal variations in light, moisture, temperature, and photoperiod (day length) all affect forage quality. Alfalfa harvested in the spring, or late summer or fall, has a higher leaf and protein content than summer-produced alfalfa of the same maturity. Therefore, the quality of the last hay cutting (third or fourth) is typically the highest of the year. The first cutting produces higher quality than midsummer hay cutting(s).

Soil moisture

Either too much or too little water can impact yield and quality; however, the relationship is not clear-cut. The usual effect of drought stress is a stunted plant that, compared to unstressed plants, is leafier, has finer stems, and less fiber, and is more digestible. However, the effect of drought stress on forage quality may depend on the severity and timing of the stress. Severe stress may result in leaf loss and a reduction in quality. At any rate, the yield reduction incurred from moisture stress (see chapter 4) is too great a price to pay for high-quality hay. Soil type also affects forage quality, but it is difficult to distinguish the effects of soil type from its indirect effect on water-holding capacity, soil aeration, and nutrient availability. In general, alfalfa produced on very fine-textured clay soils or salty soils is shorter, finer stemmed, and leafier than alfalfa grown on loam or sandy soils.

Pests

Insects, diseases, and nematodes can either increase or decrease forage quality, depending on the type of damage they inflict. Pest pressures that delay alfalfa development typically result in higher forage quality, but they reduce yields. Some diseases and nematodes may retard plant growth and yield, resulting in improved quality. On the other hand, some pests cause a reduction in the leaf-to-stem ratio, an increase in fiber concentration, or a reduction in protein concentration. All these changes lower feeding value. For example, leaf and quality loss is often associated with insect feeding and disease pressure. The presence of weeds in alfalfa hay almost always reduces forage quality because most weeds are less palatable and nutritious than alfalfa.

Rainfall

Like environmental factors, weather conditions after alfalfa is cut influence quality. Rain is a continual threat in the Intermountain Region. Rainfall can decrease forage quality considerably—it can shatter and destroy leaves, leach soluble nutrients, and prolong respiration. The force of raindrops hitting drying alfalfa disconnects leaves from the stem. The wetting and drying process increases the potential for leaf shatter. Rain-damaged alfalfa can be brittle after drying, so it is more susceptible to loss during raking or baling. Extra operations may also be necessary to dry the rewetted alfalfa, and these may increase mechanical losses and reduce forage quality.

Leaching of soluble nutrients is the primary cause of quality loss. Rain leaches the more soluble, highly digestible nutrients from alfalfa. It leaches some of the soluble protein and reduces the digestibility of the remaining protein. As a result, rain damage decreases digestibility and increases fiber concentration. Rainfall can cause additional losses by prolonging respiration. After it is cut, alfalfa continues to respire until its moisture content drops to less than 40 percent. Rain rewets the forage and allows respiration to continue.

Sampling . . . is the primary factor affecting the accuracy of quality analysis.

The effect of rain on alfalfa quality depends on the amount, intensity, and duration of the rain as well as the moisture content of the alfalfa at the time of rainfall. Leaching losses increase as the amount and duration of rainfall increase. An intense rain for a short time has less effect on forage quality than the same amount of rain over a longer duration. Both leaching and leaf loss are greater with drier alfalfa than with that which is freshly cut. Rain early in the drying process causes little loss: The cuticle, or outer coating on the plant surface, is largely intact soon after cutting and is believed to shed water better at that point than when the forage has dried.

Because of these variables, it is difficult to predict the quality of rain-damaged alfalfa hay. Just because rain falls on cut alfalfa does not mean that it is unsuitable for the dairy market. Rain often has a greater effect on the visual appearance of hay than on its nutritional value. Chemically analyze rain-damaged hay to determine its suitability for dairy cows; do not rely on its visual appearance.

HAY EVALUATION

The ultimate test of hay quality is animal performance. However, an estimate of alfalfa forage quality is usually needed before hay is sold or used as feed. Therefore, alfalfa hay quality is estimated using sensory or laboratory analysis. Laboratory evaluation may include either chemical analysis ("wet" chemistry) or near-infrared reflectance spectroscopy (NIRS). Often, both sensory and laboratory analyses are used to evaluate alfalfa hay quality.

Sensory Analysis

The visual and physical properties used to evaluate alfalfa hay quality include stage of maturity, leafiness, presence of foreign material, condition, odor, color, and texture.

Maturity

As mentioned in the chapter on harvest management (chapter 11), the stage of maturity when alfalfa is cut is probably the single most important determinant of quality. However, it is difficult for a buyer or broker to determine the maturity of alfalfa once it has been baled. Usually only the presence or absence of bloom can be determined, and this is an inadequate means by which to assess maturity.

Leafiness

Visual inspection involves estimating the leafiness of hay. This is important because leaves are the hay's most nutritious component. On a 100-percent dry-matter basis, leaves contain 27 percent protein and 70 percent total digestible nutrients (TDN); stems at the 10 percent bloom stage contain only 13 percent protein and 45 percent TDN. Leafiness is a function of the alfalfa maturity, variety, weather, and conditions when the hay was raked and baled.

Foreign Material

A sensory inspection involves assessing the presence and amount of foreign material. Foreign material may be weeds, straw, soil, wire, or anything other than alfalfa. Foreign material may be unpalatable or even physically damaging or toxic to livestock. Pay particular attention to unpalatable or toxic weeds (such as foxtails, yellow starthistle, and fiddleneck), since standard laboratory tests do not detect them.

Condition and odor

Dusty hay with excessive leaf shatter results from baling with too little moisture. If hay is moldy, or off-color or has an objectionable odor, its moisture content was too high for baling.

ADF and TDN values presented on a laboratory report should not be considered separately; TDN is calculated from ADF.

Color

Many people judge alfalfa hay based on its color. The greener it is, they think, the higher its quality. These people give color too much importance; it is not a good indicator of digestibility. Color merely indicates the curing conditions and whether the hay was put up properly.

Texture

Some hay is excessively rough, or "pokey"; other hay is soft and fine textured. Rough-textured hay can be unpalatable and cause intake problems. In severe cases, it can even cause mouth lesions (particularly in horses).

A visual analysis consists of looking at a whole bale or pulling apart a bale and examining hay flakes. Both visual and laboratory evaluation of hay quality are important (Table 13.1) and should be used in combination. Visual inspection is especially useful to detect weeds, mold, and foreign material—all of which cannot be accurately assessed by chemical analyses. Visual inspection is particularly important when purchasing horse hay, since horses are especially sensitive to mold and dust.

Table 13.1. Relative reliability of visual inspection and chemical analysis for evaluating alfalfa quality.

	RELATIVE RELIABILITY	
QUALITY FACTOR	VISUAL INSPECTION	CHEMICAL ANALYSIS
Stage of maturity	Poor	Excellent
Leafiness	Fair	Excellent
Foreign material	Excellent	Poor
Condition	Excellent	Poor
Green color	Excellent	Poor
Texture	Excellent	Poor

Although visual evaluation is useful for describing the physical attributes of alfalfa hay, it cannot be used to estimate the feeding value. Chemical analysis can provide the information necessary for balancing rations and predicting animal performance.

Laboratory Analysis

Much of the alfalfa hay produced in the Intermountain Region undergoes laboratory analysis to estimate its nutritional quality prior to being sold. Values obtained from laboratory analyses are often used to set the price of alfalfa hay. The price differential between "dairy-test" hay and "nontest" hay is usually significant. Therefore, results from quality analyses are extremely important to both the dairy and the hay producer.

Sample Collection

The first step in laboratory analysis is collecting a representative sample. The importance of proper sampling cannot be overemphasized, since it is the primary factor affecting the accuracy of quality analysis. The validity of the testing program rests on obtaining a representative sample that accurately reflects the quality of the entire lot of alfalfa hay.

Quality differences should not result from differences in sampling methods. When sampling, use a coring device rather than an entire flake of hay or a "grab sample." Several core samplers are available for alfalfa hay (Figure 13.2). The inside diameter of the coring device must be no less than ⅜ inch and no more than ¾ inch. The shaft must be long enough to sample at least 12 to 18 inches into the bale. The complexity of coring devices varies widely. A sampler can be a simple shaft,

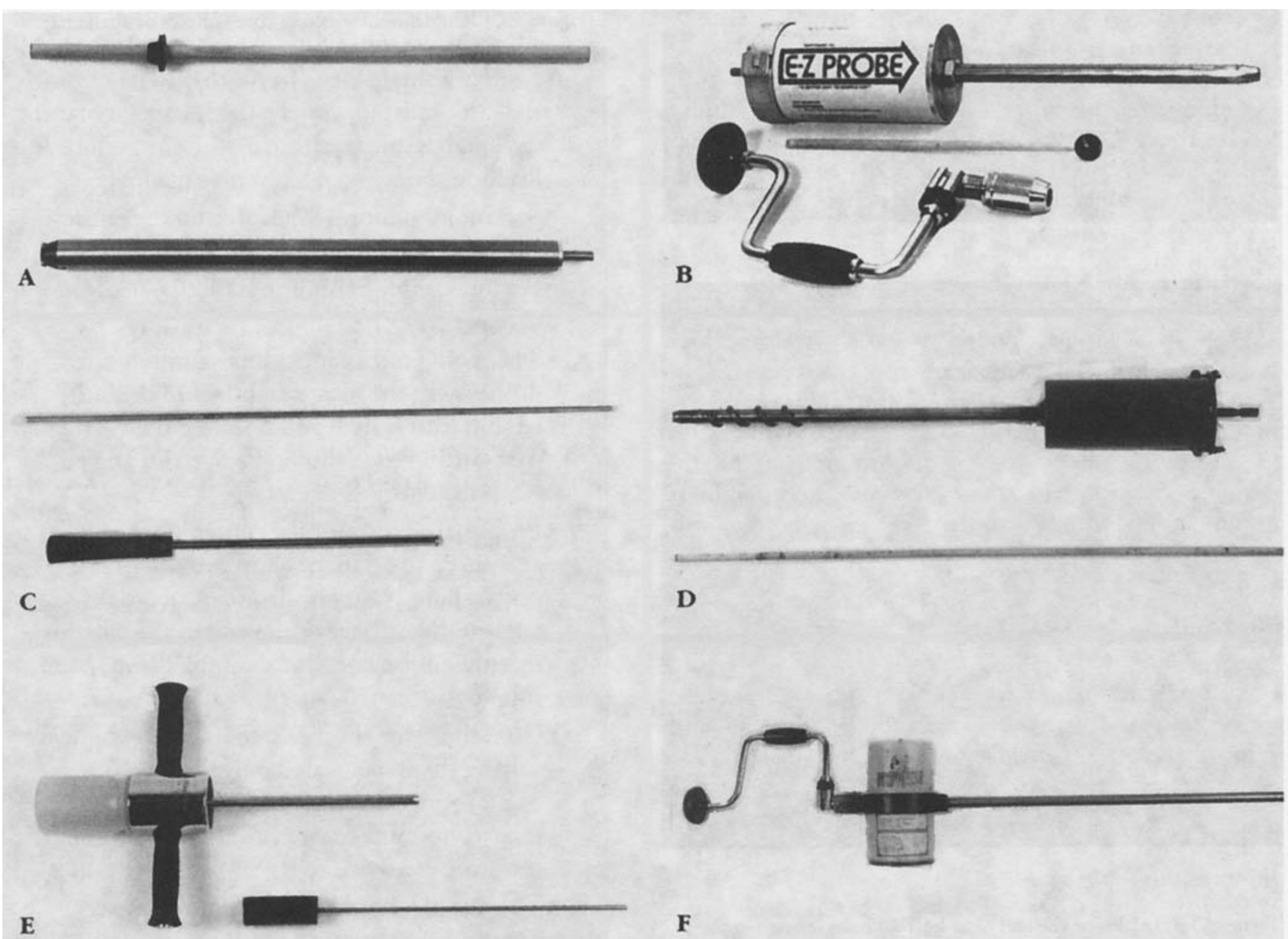


Figure 13.2. Representative coring devices for sampling alfalfa hay bales: (A) Penn State forage sampler, (B) Techni-Serv E-Z Probe, (C) sharpened golf club shaft, (D) Utah hay sampler, (E) Hay Chec hay sampler, and (F) Forageurs hay sampler.

such as a segment of a golf club or ski pole, or a sophisticated device with a sample collection box. (If you use a golf club or ski pole as a sampler, be certain the inside diameter of the shaft is no less than ⅜ inch; many are narrower.) A list of commercially available samplers, their descriptions, and the address of the manufacturer can be found in University of California (UC) Leaflet 21457, *Testing Alfalfa for Its Feeding Value.*

In a test of sampler effectiveness, hay from the same lot was sampled with three different sampling devices. The resulting analyses showed no difference in dry matter or fiber content. The consistency of the findings indicated that none of the three sampling devices over- or underselected any component of the hay. Similarly, a recent test in the Intermountain Region indicated that a sharpened golf club shaft, a Penn State forage sampler, and a Utah hay sampler were equally effective at providing representative samples. However, an auger, or corkscrew-type coring device, selectively sampled leaves over stems. This resulted in analysis of TDN that averaged three percentage points higher than analysis of samples taken by other coring devices. A large quantity of fines in the sample bag usually indicates that the coring device selectively samples leaves.

Quality can vary considerably from bale to bale and even within the same bale. Therefore, to obtain a representative sample, core a minimum of 20 randomly chosen bales per lot—coring 30 to 40 bales would be

(A)

(B)

Figure 13.3. (A) Probe the end of at least 20 bales, centering the coring device in each one. Insert the probe horizontally, 12 to 18 inches deep. (B) Store the entire sample in a sealed polyethylene freezer bag so the laboratory can determine the "as received" moisture content.

Figure 13.4. Guidelines for taking core samples of alfalfa hay.

- Sample a single lot of hay—that is, hay from the same cutting, variety, field, stage of maturity, and harvested within a 48-hour period. A lot should not exceed 200 tons of alfalfa.
- Sample at random. Walk around the entire stack and sample bales at various heights.
- Per lot, sample a minimum of 20 bales (one core per bale).
- The coring device must be a sampling tube, or probe, with the inside diameter of the cutting edge at least ⅜ inch and no more than ¾ inch. The cutting edge should be flat, not angled. Keep the cutting edge sharp.
- Probe bale ends near the center, horizontally, at least 12 to 18 inches into the bale. The probe should enter horizontally at a right angle to the surface of the end of the bale. Be sure the probe does not slant up, down, or sideways.
- Combine core samples into a single sample by storing them in a sealed polyethylene freezer bag. Storing them in plastic will allow laboratory technicians to determine the "as received" moisture content.
- The sample should weigh approximately ½ pound.
- Do not expose the sample to heat or direct sunlight and send to a lab as soon as possible.

better. Probe the stack or lot at various heights and locations around the stack. Probe a bale near the center from either end, inserting the probe horizontally and perpendicular to the surface of the bale (Figure 13.3). Place all samples into one polyethylene freezer bag and seal it so laboratory technicians can determine the "as received" moisture content. Do not divide or subsample prior to grinding; doing so could bias the results if the subsample is taken from the top (where there may be fewer leaves) or bottom (where leaf pieces may settle). Take care not to leave the samples on the dash of your pickup or any other place where they might be subjected to heat or direct sunlight. Send samples to the lab as soon as possible after collection. Figure 13.4 summarizes sampling guidelines.

Testing

Forage quality can be determined either by chemical analyses or by near-infrared reflectance spectroscopy (NIRS). Remember, both methods are only tools to predict animal performance. NIRS is gaining popularity because it is fast and accurate. In chemical analysis, or "wet" chemistry, the alfalfa sample is treated with various chemicals to destroy or isolate certain plant constituents. The remaining plant residues are quantified and used to estimate the feeding value of the alfalfa. The relationship between chemical analysis and animal performance has been established through years of animal-feeding trials.

Figure 13.5 lists the various laboratory analyses that are often performed on alfalfa hay. In addition, the figure describes values used to determine quality. The analyses normally conducted to evaluate alfalfa quality in California include moisture, crude protein (CP), and acid detergent fiber (ADF) tests. Total digestible nutrients (TDN) and other predictions of energy are calculated by using the ADF value. Many nutritionists are increasingly interested in neutral detergent fiber (NDF) analysis, which is useful for predicting intake.

MOISTURE The water content of hay can vary considerably, depending on the environment and the length of time since harvest. Moisture content can have a significant effect on the economic value of the hay on a per-pound basis. The price of hay with a high moisture content should be discounted accordingly. To prevent confusion, laboratories usually report the quality of the hay on an "as received" basis

Figure 13.5. Laboratory analyses to determine the quality of alfalfa.

Crude protein (CP) Estimate of protein based on measurement of both protein and nonprotein nitrogen.

ADF-nitrogen (ADF-N) When alfalfa is damaged by excessive heating, a portion of the crude protein becomes bound and is not available to the animal. The bound protein, calculated from ADF-nitrogen, can be subtracted from the crude protein to estimate the amount of available protein.

Acid detergent fiber (ADF) Measurement of the plant fiber that remains (cellulose and lignin) after an acidic detergent removes more digestible cell components. As ADF increases, the digestibility of alfalfa decreases. ADF is used to calculate many of the energy values that appear in hay analysis reports (TDN, DDM, NEL).

Total digestible nutrients (TDN) Calculated from ADF and used to estimate the energy value of forage. Sum of all digestible organic nutrients (proteins, fiber, fat, nitrogen-free extract). TDN is the most extensively used forage quality value in California for hay-marketing purposes.

Digestible dry matter (DDM) Similar to TDN. DDM is another value calculated from ADF and is an estimate of the energy available in forages. It is used to formulate rations.

Net energy for lactation (NEL) The net energy for lactation is now used more commonly than TDN in dairy ration formulation. It is calculated directly from ADF.

Neutral Detergent Fiber (NDF) This is the fiber that remains after using a neutral detergent to remove the cell contents and pectin. NDF value differs from ADF value in that it includes hemicellulose. NDF analysis is considered to be more useful for predicting intake; the higher the NDF, the lower the intake.

Relative feed value (RFV) Estimates overall forage quality, combining estimates of both digestibility and intake (ADF and NDF). This value is not commonly used in the West.

Calcium (Ca) and phosphorus (P) The quantity of Ca and P, as well as the Ca:P ratio, is important in dairy rations. Alfalfa is a good source of Ca but a rather poor source of P. Knowing the Ca and P concentration in the hay can assist in proper ration formulation.

as well as on a 90- and 100-percent dry-matter basis (Figure 13.6).

CRUDE PROTEIN CP is measured by determining the concentration of nitrogen in the forage sample and converting this figure to protein by multiplying by a factor of 6.25 (the factor derives from the fact that plant protein is generally 16 percent nitrogen). Therefore, CP is not just a measurement of protein—it reflects the presence of other nitrogen-containing compounds, such as amino acids and chlorophyll. Although some laboratories calculate a CP value based on the fiber content of the hay, fiber concentration is a poor indicator of CP. It should not be used in place of the standard method: determining the nitrogen concentration. When alfalfa has been baled with excessive moisture and heat damage occurs, some of the protein may become chemically bound and unavailable. In this case, an analysis for crude protein would overestimate the amount of available protein. An ADF-N analysis (see Figure 13.5) is needed to determine the protein that is unavailable for digestion.

ACID DETERGENT FIBER The energy value of alfalfa hay must be determined indirectly, from its fiber content. Therefore, the ADF and TDN values presented on a laboratory report should not be considered separately; TDN is calculated from ADF. The higher the fiber, the lower the energy value. The most common fiber test is ADF analysis, which has largely replaced the modified crude fiber (MCF) method formerly used in California. The ADF test is preferred over the MCF method because it is faster, easier to run in the laboratory, as accurate as MCF for predicting TDN, and more accurate than MCF for predicting the quality of alfalfa-grass mixtures. The ADF test is the method approved by the National Forage Testing Association. ADF can be converted to TDN by using Table 13.2 or the following equation:

$$\text{TDN \%} = 82.38 - (0.7515 \times \text{ADF \%})$$

In this equation, all constituents are expressed on a 100-percent dry-matter basis. The results of a test can be expressed as the percentage of dry matter in the sample—90 percent or 100 percent, whichever is desired. However, the percentage must be specified to avoid confusion. To convert TDN at 100 percent dry matter to TDN at 90 percent dry matter, multiply by 0.90. Conversely, to convert TDN at 90 percent dry matter to TDN at 100 percent dry matter, divide by 0.90 (or multiply by 1.11).

At 20 core samples per lot, the standard error is typically one percentage point of TDN.

Consistency of Results

Growers, brokers, and dairy producers have been frustrated by variability in laboratory results. Confusion has arisen due to different analysis procedures among regions, states, and individual laboratories. TDN values have varied, although the digestibility of the forage has been the same. Some states and laboratories have used different procedures to determine ADF and

Table 13.2. Relationship between acid detergent fiber (ADF) and total digestible nutrients (TDN) at 100 and 90 percent dry matter (DM).

% ADF		% TDN	
100% DM	90% DM	100% DM	90% DM
20.0	18.0	67.4	60.7
21.0	18.9	66.6	59.9
22.0	19.8	65.8	59.2
23.0	20.7	65.1	58.6
24.0	21.6	64.3	57.9
25.0	22.5	63.6	57.2
26.0	23.4	62.8	56.5
27.0	24.3	62.1	55.9
28.0	25.2	61.3	55.2
29.0	26.1	60.6	54.5
30.0	27.0	59.8	53.8
31.0	27.9	59.1	53.2
32.0	28.8	58.3	52.5
33.0	29.7	57.6	51.8
34.0	30.6	56.8	51.1
35.0	31.5	56.1	50.5
36.0	32.4	55.3	49.8
37.0	33.3	54.6	49.1
38.0	34.2	53.8	48.4
39.0	35.1	53.1	47.8
40.0	36.0	52.3	47.1

Lab Name
Address

Sample No.: 0106
Date received: 6/10/94
Date sampled: 6/7/94
Date reported: 6/13/94

Name: John Haygrower
Address: 2215 Ranch Lane
High Mountain, CA

Lot I.D.: Field 4B
Lot size: 120 tons
Cutting number: One

		Dry Matter Basis	
I. Laboratory Analyses:	As received	90% DM	100% DM
Dry matter (DM), %	85.5	90.0	100.0
Acid detergent fiber (ADF), %	24.7	26.0	28.9
Crude protein (CP), %	18.6	19.6	21.8
II. Estimated Energy Values (calculated from ADF)			
Total digestible nutrients (TDN), %	51.9	54.6	60.7
Net energy for lactation (NEL), Mcal/lb	0.530	0.558	0.620
Digestible dry matter (DDM),%	56.8	59.8	66.4

III. Hay Quality Rating for This Sample (ADF values on a 100% DM basis)

- [x] Premium (29.0% ADF or less)
- [ ] Fair (32.1 to 37% ADF)
- [ ] Good (29.1 to 32% ADF
- [ ] Low (more than 37% ADF)

Figure 13.6. A hay quality analysis form as provided by a laboratory.

even different mathematical equations to predict TDN from ADF. TDN values reported from laboratories using different methods are not interchangeable. Details of the recommended system for California are printed in UC Leaflet 21457, *Testing Alfalfa for Its Feeding Value.* Confusion has also occurred because forage quality values have been reported at different percentages of dry matter. Some of this confusion can be avoided if the alfalfa industry focuses on the ADF value rather than the predicted TDN and if labs report results on an "as received" 90-percent and 100-percent dry-matter basis.

Differences among laboratories do exist, but these can be minimized by following standard sampling and laboratory procedures. Remember, when splitting a sample to send to two laboratories, grind and mix the sample prior to dividing.

The National Forage Testing Association (NFTA), composed of researchers, extension specialists, hay dealers, and commercial forage-testing laboratories, sponsors a voluntary laboratory certification program to improve the consistency of laboratory results and reduce discrepancies that occur between laboratories. Guidelines for standardized sampling, analysis, and reporting are available. Participating laboratories receive a ground alfalfa sample for analysis once every 3 months. A laboratory is certified when its results fall within an acceptable range for three out of the four annual samples. Using a certified laboratory can help ensure the reliability of the forage quality analysis.

What are typical forage quality values? Table 13.3 lists expected ranges of alfalfa forage quality. Knowing expected ranges of CP, ADF, and TDN for alfalfa at different maturity levels helps a grower assess the credibility of laboratory results. If reported values fall too far from anticipated values, consider disregarding the

Table 13.3. Expected ranges of alfalfa forage quality at various growth stages.[1]

		100% DRY MATTER			90% DRY MATTER		
GROWTH STAGE	DESCRIPTION	% CP	% ADF	% TDN	% CP	% ADF	% TDN
Prebud	>12 in. long, no buds or flowers	25.0–29.0	21.0–25.0	63.5–66.5	22.5–26.0	19.0–22.5	57.0–60.0
Early bud	1–2 nodes with buds, no flowers	22.5–26.0	24.5–28.5	61.0–64.0	20.0–23.5	22.5–25.5	55.0–57.5
Late bud	>3 nodes with buds, no flowers	20.5–24.0	27.0–30.5	59.5–62.0	18.5–21.5	24.5–27.5	53.5–56.0
Early bloom	1–15% bloom	18.0–22.0	29.0–35.0	56.0–60.5	16.0–20.0	26.0–31.5	50.5–54.5
Midbloom	16–85% bloom	15.5–20.0	34.0–37.5	54.0–57.0	14.0–18.0	30.5–34.0	49.0–51.0
Full bloom	86–100% bloom	14.0–17.0	36.5–40.0	52.5–55.0	12.5–15.5	33.0–36.0	47.0–49.5

1. Values are rounded to the nearest 0.5 percent.

results or resubmitting samples for another analysis at the same or a different laboratory.

Limitations of Laboratory Testing

Growers, brokers, and dairy producers should be aware of the limitations on the degree of accuracy that can be achieved with hay quality analysis and not put too much weight on absolute values. For example, there is probably no difference in quality between hay that tests 54.7 and 55.2 percent TDN. Analytical methods are not accurate enough to detect such small differences. Variability exists in the lab results, both with "wet" chemistry and with NIRS analysis; however, the greatest loss in accuracy occurs with sampling. The issue is how well a sample represents the entire lot of hay. At 20 core samples per lot, the standard error is typically one percentage point of TDN. If fewer samples are taken, the error is considerably more. This underscores the need to obtain a representative sample.

Quality testing for forage has advanced significantly in the last decade, and quality analysis is a useful tool for determining the nutrition quality of alfalfa hay and assessing its value. However, growers, brokers, and dairy producers must realize the limitations of forage analysis. Whenever possible, they should assess the value of hay by judging its effect on animal performance, as well as using sensory and chemical tests.

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CHAPTER FOURTEEN

GRAZING MANAGEMENT

Rhonda R. Gildersleeve

COURTESY AMERICA'S ALFALFA

Grazing, as an alternative to hay or silage production, has not been widely promoted in the United States until recent years. Generally, alfalfa does not persist well under continuous grazing conditions. Although using alfalfa as pasturage results in high gains per animal and per acre, owners feared animal losses due to bloat. Despite these disadvantages, alfalfa fits well in controlled grazing systems, providing a high-quality pasture with excellent drought tolerance. Widespread availability of the antibloat supplement poloxalene, electric fencing, increased harvest costs, and grazing management techniques capable of maintaining alfalfa stands have led to greater interest in grazing alfalfa. Recent plant-breeding efforts suggest that cultivars with low bloat potential and more persistence under grazing are possible and should further increase the use of alfalfa in pastures.

Effective grazing management requires some knowledge of how animals graze and make use of forage. Under pasture conditions, animals tend to select, of the plants available, those of higher nutritional quality. Chemical analysis of forage samples indicates that they choose mainly the soft leaves and stems as they graze. Voluntary intake of alfalfa is higher than that of other pasture species. Alfalfa is a highly digestible, nutritious forage whose dietary potential can be maximized by rotational grazing. Grazed alfalfa supplies all livestock protein needs. Much of the protein will be degraded to ammonia in the rumen and converted to amino acids by rumen microbes, which are then absorbed in the animal's hindgut. Dietary energy supplementation may help maximize gain. For example, high-producing dairy cows that graze alfalfa may benefit from rumen-degraded protein supplements.

In the Intermountain Region, options for grazing alfalfa include the following:

- dormant-season grazing of alfalfa stubble
- grazing as a substitute for an early- or late-season cutting
- rotational grazing of alfalfa during the growing season

This chapter will describe each of these options and outline grazing management strategies to optimize animal production without sacrificing alfalfa vigor and stand life. It will also discuss the health problems that are most often associated with alfalfa pasturage.

Alfalfa is a highly digestible, nutritious forage whose dietary potential can be maximized by rotational grazing.

DORMANT-SEASON GRAZING

Of the three alternatives listed, dormant-season grazing of alfalfa is the most widely used in California at present. This option utilizes, as cattle or sheep feed, the forage produced between the final harvest and the first killing frost. Dormant-season grazing—that is, grazing during the early winter months—often meshes well with the lambing season.

Recent studies have shown that dormant-season grazing may be an effective integrated pest management (IPM) strategy because it reduces weed and insect pests. In Oklahoma, cattle grazing during dormancy reduced the number of overwintering alfalfa weevil eggs by 60 percent and reduced the population of the weevil parasite *Bathyplectes curculionis* by less than 12 percent. New Zealand researchers reported that, during dormant-season grazing, the number of overwintering blue alfalfa aphids decreased from 220 to 2.5 per stem. Dormant-season grazing may reduce rodent populations because it decreases winter cover.

In many areas of California, dormant-season grazing occurs during periods of wet weather. This raises concerns about soil compaction from trampling, increased crown damage or disease, and reduced stand densities. Studies at the University of California, Davis, and in the southern San Joaquin Valley revealed that dormant-season grazing caused no change in either soil bulk densities or alfalfa stand density. Other researchers reported that trampling caused few detrimental effects. Animal holding areas apart from the alfalfa field can minimize damage, especially in areas with heavy clay soils and in wet weather.

Several management tactics can optimize dormant-season grazing. Nevada guidelines recommend initiating grazing soon after a killing frost, to maximize forage quantity and quality before shattering and leaching losses occur. To avoid bloat, wait until leaves turn brown. (Bloat is discussed later in this chapter.) In areas where snow cover occurs, leave a 3-inch stubble to catch snow—this will decrease frost heaving and reduce cover for overwintering mice. In milder climates, hold animals in the field until they completely consume the old stems. Getting rid of these will improve the quality of the first cutting. Growers can expect that grazing animals will remove about 0.5 ton forage per acre during the winter period. To prevent yield loss, remove animals before spring growth begins.

GRAZING AS A SUBSTITUTE FOR CUTTING

This option is most often used in spring or fall, before the first or last cutting, when inclement weather threatens the ability to harvest a quality hay crop (Figure 14.1.). In general, spring grazing delays the next harvest by the approximate length of the grazing period. Spring grazing does not affect the yield of subsequent cuttings. With sound management, substituting grazing for harvesting has no detrimental impact on the alfalfa stand.

For early spring grazing, turn animals into the pasture when alfalfa is approximately 4 inches high. Use rotational grazing to manage animal pressure so that average plant height does not exceed 5 to 7 inches (this will help maintain some leaf area). If the pasture

Figure 14.1. Grazing often substitutes for a fourth cutting when weather conditions make it difficult to properly cure a hay crop.

will be cut later, for hay, allow a recovery period of at least 40 days before harvesting the crop.

If more than one grazing is substituted for cutting during the growing season, follow these guidelines:

- Make one or two cuttings between the grazing cycles.
- Allow regrowth to go into the bloom stage before animals are permitted to graze.
- Maintain a short grazing period.

With the onset of cold, wet fall weather, grazing may be an alternative to a fourth cutting. Grazing may allow you to retrieve an additional 0.5 to 1.0 ton per acre of fall growth. Allow the alfalfa to reach bloom stage before grazing begins. This enables plants to store adequate root carbohydrates prior to frost. This approach is similar to that for dormant-season grazing.

VERN MARBLE

Figure 14.2. Advances in electric fencing have facilitated rotational grazing of alfalfa and other forages. Electric fences are a psychological barrier, not a physical barrier (like a barbed-wire fence). A few cattle may not adapt to electric fences and have to be removed from the herd so that producers can effectively manage the remainder of the cattle.

ROTATIONAL GRAZING DURING THE GROWING SEASON

Rotational grazing of alfalfa during the growing season offers much potential for high gain per animal and per acre. In humid regions, owners of beef steer and market lamb have realized liveweight gains of 1,000 and 900 pounds per acre, respectively. Rotational grazing is preferable to continuous grazing because it maintains stand vigor and maximizes production.

Do not allow animals to graze before alfalfa reaches early flowering stages. This ensures that root carbohydrate reserves are not depleted, and it decreases the potential for bloat. Grazing periods less than 2 weeks long prevent animals from grazing regrowth; sheep should have a shorter rotation schedule than cattle because they graze more closely. Most experts suggest a period of 28 to 42 days for recovery following grazing, or approximately the length of the usual hay harvest during the growing season. Divide the alfalfa field into a number of paddocks (generally four to nine), and rotate the animals through the paddocks as they graze the alfalfa. During periods of peak alfalfa production, some paddocks may be cut for hay instead of being grazed. Also establish a separate loafing area for watering and mineral supplementation.

Grazing management is the key to maximizing livestock gains without detriment to the alfalfa stand. Advances in electric fencing have made labor and management aspects of rotational grazing of alfalfa and other forage crops simpler and more cost-effective (Figure 14.2). Different classes of livestock may require somewhat different rotational grazing schemes. To maintain a percentage of leaf in the diet that will maximize gains, allow market lambs a shorter grazing period than other animals.

To maintain high quality, graze alfalfa closely to remove older, lignified stems. Recommended stubble heights as animals leave the field range from 4 to 5 inches to 6 to 8 inches, or when new crown shoots appear. This may be accomplished by using a leader-follower system, whereby animals on a high-nutrition regime rotate into a new paddock several days ahead of "cleanup" animals, whose nutritional needs can be met with the lower-quality feed left behind. A leader-follower system might be used for stocker steers followed by dry mature cows, for example. Another alternative is creep grazing, whereby young calves are allowed into new paddocks through fence gaps. They are then followed by their dams, who rotate into the "creep" paddock after they graze down the present one.

Stocking rates on alfalfa should be based on the following factors:

- forage production (estimated from previous hay yields)
- nutrition needs and estimated intake of the class of livestock
- percentage of forage utilized (Use 50-percent utilization as a rule of thumb.)

Be conservative in your estimates and flexible in adjusting the stocking rate.

AGRONOMIC PRACTICES

Procedures for stand establishment (see chapter 2), irrigation (see chapter 4), and fertilization (see chapter 5) of alfalfa for pasturage are the same as those for alfalfa hay or silage. Schedule irrigation for periods when animals are not grazing the paddock. Since animals return some nutrients to the soil, via urine and fecal material, use soil or plant tissue tests to determine the need for fertilizers (see chapter 5).

ANIMAL MANAGEMENT CONCERNS

Frothy Bloat

The potential for livestock death due to frothy bloat has been a major obstacle to widespread use of alfalfa as pasturage. Bloat results when ruminant animals retain the gases produced during microbial fermentation of forage in the rumen. A stable foam develops, and it prevents the escape of gases through eructation. The rumen swells into the abdominal cavity, where it interferes with body processes and may cause death. Symptoms of bloat include frequent urination and defecation, arched back, labored breathing, and lolling of the tongue. Economic ramifications include reduced weight gains and feed efficiency, lower milk production, and increased veterinary and labor costs.

Occurrence of bloat is linked to periods of lush, rapid growth of certain forages, including alfalfa. Typical suspect species are high-nitrogen, easily digested forages with low dry-matter and fiber contents. Individual animals can be particularly susceptible to frothy bloat. Once identified, chronic bloaters should be permanently removed from the pasture.

Several management strategies can help decrease the incidence of bloat caused by grazing alfalfa. Beginning 5 to 7 days before alfalfa grazing starts, give animals a daily dose of 1 to 2 grams poloxalene per 100 pounds body weight. This antifoaming agent is available in block, liquid, or pellet form. If fed in block form, it should be the only source of salt and minerals. To increase the likelihood of consumption by all animals, place the poloxalene near loafing and watering areas. Monensin and other ionophore supplements also appear to decrease bloat incidence.

Alfalfa is most likely to cause frothy bloat during vegetative growth. Do not let animals graze until after flowering begins. Prior to initial turnout, fill the animals up on grassy or stemmy hay, and, if possible, leave all animals on the alfalfa pasture continuously. When rotating between pastures, move cattle in late morning through the afternoon, after they have grazed. Never move very hungry animals to new pastures. Regular supplementation with dry hay may be necessary.

A compatible grass—such as ryegrass, orchardgrass, or bromegrass—planted with alfalfa can decrease bloating. Animals tend to graze the grass first, which may decrease gains somewhat compared to those realized from a pure alfalfa pasture. Because the severity of bloat increases when alfalfa is irrigated while animals graze, do not irrigate when animals are present. Cool, wet, cloudy weather may also increase chances of bloat. By applying the management practices this section recommends, you can reduce losses due to bloat to less than 5 percent.

Plant breeders in Canada began trying to develop a bloat-safe alfalfa in 1970. They recognized that rapid initial digestion is a major contributor to bloat, so their efforts have included the attempt to produce an alfalfa cultivar that is digested slowly. Researchers caution that it may be some time before such a cultivar is commercially available.

The potential for livestock death due to frothy bloat has been a major obstacle to widespread use of alfalfa as pasturage.

Estrogen Problems in Sheep

Sheep are especially susceptible to phytoestrogens, plant-produced compounds that mimic estrogen when ingested by ruminants. Alfalfa and certain *Trifolium* species (notably subterranean clover) can induce infertility in sheep because these plants contain phytoestrogenic compounds. To avoid fertility problems, do not allow sheep to graze alfalfa for 2 weeks prior to breeding and until 2 weeks after conception.

Other Health Problems

Enterotoxemia, overeating, and clostridium C & D are three causes of sudden death whose symptoms mimic those of frothy bloat. Minimize the potential for the spread of disease by ensuring that all animals on alfalfa pasture receive vaccinations for infectious diseases at intervals recommended by a veterinarian. Make adequate water and trace minerals (including salt) available on a free-choice basis. Check animals once or twice each day so that any appearing injured, bloated, or distressed can receive care promptly.

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CHAPTER FIFTEEN

MANAGEMENT AND REPLACEMENT OF DEPLETED STANDS

Steve B. Orloff and Daniel H. Putnam

The rate of decline of an existing stand can be slowed by selecting an adapted variety with persistence and by practicing good management. Inevitably, however, the stand will thin due to diseases, winter injury, and other factors, including mismanagement. Yield, quality, and profit will fall to a point where a decision regarding the fate of an older stand must be made.

This decision is greatly influenced by the profitability of available rotation crops. Unfortunately, the short growing season and cool climate in the Intermountain Region limit rotation crop options. For most of the region, rotation crops (primarily cereals) are less profitable than alfalfa. Furthermore, establishing a new stand of alfalfa is expensive—cash costs for establishing a stand are over $200 per acre. This chapter will discuss methods to evaluate old stands, management options for thin stands, and techniques for removing old alfalfa stands.

EVALUATING OLD STANDS

Calculate Stand Density

Both forage yield and quality are directly related to stand density. Traditionally, alfalfa stands are evaluated by using plant counts to determine the number of plants per square foot (Table 15.1). Based on this method, stand densities below three to five plants per square foot should be replaced (Figure 15.1) because these stands usually yield less than 4 tons per acre (actual yield varies depending on production area). Furthermore, forage quality declines as weeds invade open spaces between plants.

The problem with using plant counts to assess stands is that all crowns are counted equally. However, a small weakened plant is not nearly as productive as a large healthy plant. Research in Wisconsin has demonstrated that the number of stems per square foot is a better reflection of productivity than is the number of plants. Results showed that fields with 55 or more stems per square foot (measured at 6 inches of regrowth) produced maximum yields and that fields with fewer than 40 stems per square foot were not profitable and warranted replacement.

Analyze the Economics of Stand Removal

The matter of when to remove an alfalfa field is primarily an economic decision. The anticipated yield, quality, and price of alfalfa produced from a new field must be compared with that of the existing stand. Remove a stand when its productivity has declined to such a degree that net profits would be greater if the alfalfa were removed and a new crop established.

Unfortunately, the economics of stand removal are not simple; a grower must consider several factors in addition to productivity and forage quality (Figure 15.2). Rotation requirements, the income or loss that occurs with rotation crops, the amount of forage needed, the strength of the alfalfa market, and the opportunity cost of money spent on stand establishment (that is, what else could you do with the money) all enter into the decision. Any of these factors can reverse a decision based on production alone. In addition, pest pressures may dictate that an alfalfa stand be replaced before its production level indicates it is necessary. Diseased fields may need to be removed early due to rapid stand decline or to prevent diseases (such as verticillium wilt) from spreading to healthy fields. Severe infestations of unpalatable or perennial weeds may require that an alfalfa field be plowed out. Similarly, stand removal may be the only economical means of dealing with serious outbreaks of rodent pests.

Table 15.1. Minimum stand densities for different production years.

END OF PRODUCTION YEAR	STAND DENSITY (NO. OF PLANTS/ FT^2)
1	10–20
2	8–12
3	6–9
Any year	3–5—Replace stand

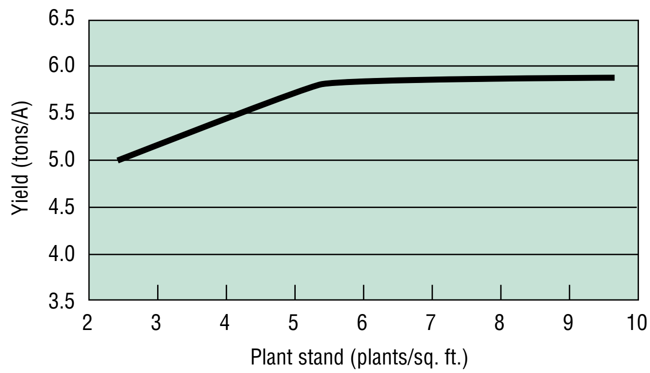

Figure 15.1. Alfalfa stands below five plants per square foot result in lost yield. (Data obtained from fifth-year stands in a 1985 variety trial, Tulelake, California.)

UNDERSTANDING MANAGEMENT OPTIONS

When faced with a depleted alfalfa stand, growers have two options: stand extension and stand replacement. The next two lists present the alternatives associated with each choice.

Stand extension
- Continue to harvest a poor alfalfa stand.
- Interseed another forage plant.
- Overseed with alfalfa.

Stand replacement
- Replant alfalfa after removing old stand (produce back-to-back alfalfa).
- Remove stand and rotate to another crop.

Factors to be considered when deciding which option to pursue include pressure from diseases, pests, and weeds; rotation requirements; total acreage and type of forage desired; and the projected status of the alfalfa hay market. Prolonging stand life is unwise if disease pressure is severe. Likewise, if fields are heavily infested with rodents or difficult-to-control perennial weeds, remove the stand. If you have insufficient forage acreage, consider interseeding, overseeding, or replanting alfalfa after alfalfa. High hay prices are another incentive for extending stand life. However, continuing to harvest a poor alfalfa stand is not usually a viable option. In general, intermountain alfalfa stands remain in production for too many years rather than too few.

STAND EXTENSION

Interseeding

The costs of interseeding poor stands with grasses are comparable to those of herbicide application. Interseeding may preclude the need for an herbicide and alfalfa weevil treatment. Also, yields of mixed alfalfa-grass fields are frequently over 1 ton higher than those of older, pure-alfalfa stands. The economics of interseeding are market related and depend on the price differential between pure alfalfa and an alfalfa-grass mixture. The market for mixed hay is primarily for horses, but mixed hay is also fed to cattle and dry cows. The price difference between pure alfalfa and alfalfa-grass mixtures depends on the visual appearance of the hay and the strength of the horse hay or stock hay market. Alfalfa-grass hay sometimes sells for as much as pure alfalfa hay in areas that have developed a strong horse hay market.

Figure 15.2. Factors to consider when deciding whether to replace an alfalfa stand.

- Estimated annual yield of old versus new stand
- Production costs of old versus new stand
- Comparison of quality, marketability, and price of hay from old and new stands
- Anticipated strength of hay market
- New stand establishment expenses
- Expected new stand life
- Profitability of rotation crops
- Rotation crop requirements
- Quantity of forage desired
- Pest problems (diseases, weeds, rodents)
- Opportunity for other investments

Stand densities below three to five plants per square foot should be replaced.

Many alfalfa growers target the dairy market and strive to produce top-quality "high-test" hay. However, with a large acreage, maintaining dairy quality on all fields is difficult because of the time required to swath, cure, and bale numerous fields. To maximize quality when growing several fields, cut young high-producing fields first and manage them to produce hay of high nutritional quality. Interseed fields of older, thinner alfalfa stands to prolong stand life and maintain yields. Cut these fields last with the goal of maximum yield in mind, and market the hay for horse and other nondairy use.

Interseeding annuals

It is a common practice in some areas to interseed oats or, less frequently, awnless (beardless) barley or wheat into a thin stand of alfalfa. This usually improves first cutting yield—a 4-ton yield is common. Herbicides are not needed, and interseeding often reduces the alfalfa weevil population. To interseed, first cultivate with a harrow or disc in late winter or early spring. This kills emerged weeds and prepares a suitable seedbed. The interseeded species is usually planted by drilling, but it could be broadcast and harrowed (Figure 15.3). The preferred seeding rate depends on the alfalfa stand density (higher seeding rates for thinner stands), but 50 to 75 pounds of oat seed per acre has produced maximum yields in most research trials. The amount of nitrogen fertilizer to apply varies depending on soil type and fertility. Most tests have indicated that 40 to 60 pounds of nitrogen per acre is adequate to supplement the nitrogen that is supplied by the alfalfa crop. The forage produced is not suitable for milking dairy cows, but it is widely accepted for other classes of livestock, particularly horses. Researchers continue to search for alternative annuals for interseeding, such as beseem clover, which has forage quality nearly equal to that of alfalfa.

The drawback of interseeding oats or other cereals is that they are usually headed-out when harvested and do not recover after cutting. Therefore, they do not contribute to increased yields in subsequent cuttings. In fact, second cutting yields from fields interseeded with oats are often slightly lower than fields not interseeded. This is most likely the result of damage to the alfalfa during cultivation for interseeding and of competition from the interseeded crop. The alfalfa usually recovers, and yields of later cuttings are comparable to those of pure alfalfa stands. Nonetheless, most growers harvest only one cutting when interseeding cereals into alfalfa. After one harvest, they remove the alfalfa and rotate to a different crop.

Interseeding perennials

Perennial grasses interseeded in alfalfa contribute forage beyond the first cutting and may extend stand life for several years (Figure 15.4). Researchers have evaluated the suitability of several grass species for interseeding. These include perennial ryegrass, tall fescue, kemal festulolium (ryegrass x tall fescue), orchardgrass, timothy, and matua prairiegrass. Orchardgrass appears to be the species best suited for interseeding. It is high yielding, very palatable, and compatible with alfalfa. Some dairies accept alfalfa-orchardgrass, and it is highly desired by many retail feed stores for pleasure-horse hay. Tall fescue is high yielding but extremely aggressive; over time, it chokes out alfalfa. Ryegrass is high yielding for the first cutting, but it also tends to be very competitive with alfalfa. Also, ryegrass has not persisted well in some parts of the Intermountain Region. Matua prairiegrass, like orchardgrass, is highly palatable, but it is less competitive; unfortunately, yields of fields interseeded with matua grass were lower than those with orchardgrass in initial tests. Alfalfa-timothy interseedings are highly desirable because of their potential marketability to the horse industry, but to date alfalfa-timothy hay has not received a premium higher than that for other alfalfa-grass hays. Timothy does not compete well, so stand establishment can be slow and difficult, particularly when interseeding. Nevada growers have had success killing alfalfa in strips by using glyphosate (Roundup) prior to interseeding timothy. Tests have shown that timothy does not yield well the first year after seeding, but it performs well in later years if planted on proper soil types (medium- to fine-textured soils).

Methods for interseeding perennial grasses are similar to those for interseeding cereals. Fields are cultivated with a harrow or disc in the late winter or early spring (this kills emerged weeds and prepares a seedbed). Fall seedings, after the last alfalfa cutting of the season, are possible, but weed infestations may be severe. Winter annual weeds emerge with the interseeded crop, and most available herbicides cannot control them.

The interseeded perennial grass is usually drilled using the small-seed attachment of a grain drill. No-till drills can be used for seeding, but tillage is usually beneficial to control emerged weeds. Seed can be broadcast and incorporated with a ringroller or culti-

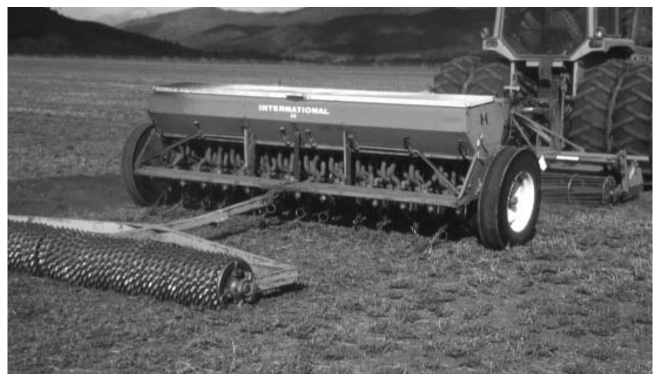

Figure 15.3. Use of a stand grain drill to interseed forage grasses into a thin alfalfa stand.

Figure 15.4. Timothy interseeded into a depleted alfalfa stand.

packer; if you do so, increase seeding rates slightly. Seeding rates, per acre, depend on the seed size of the interseeded species: 5 pounds timothy; 10 to 12 pounds orchardgrass, ryegrass, or tall fescue; or 30 pounds matua grass. Perennial grasses are slow to become established and should be interseeded before the alfalfa stand becomes too thin (this is especially true for timothy). Perennial grasses can be interseeded along with a low rate of oats (50 pounds per acre or less) to improve yields in the first cutting after interseeding. This practice may slow the growth of the perennial grasses, however. Unlike pure-alfalfa stands, apply nitrogen to alfalfa-grass mixtures annually (approximately 50 to 75 pounds nitrogen per acre is sufficient).

Overseeding with Alfalfa

It is tempting to thicken an old stand by overseeding with alfalfa. Conceptually, overseeding should substantially reduce the costs associated with establishing a new stand. Unfortunately, successful overseeding is difficult at best. Seedling emergence following overseeding is often adequate, but most seedlings fail to survive. As a result, only the original stand remains.

Several explanations account for overseeding failures. First, diseases, and insect and nematode populations frequently increase in established stands. The older plants can withstand them, but they destroy vulnerable seedlings. The second reason involves competition. Alfalfa seedlings grow slowly and are not very competitive. They have to compete for light, water, and nutrients with other alfalfa plants and weeds that may be hundreds of times their size. Competition for light and water is usually the most severe. After surface water is depleted, seedlings may succumb to drought stress, whereas deeper-rooted older plants thrive. Large, vigorously growing plants shade seedlings, further reducing top and root growth and water uptake. Third, germinating alfalfa seeds may be exposed to autotoxic compounds. Autotoxic compounds are naturally occurring chemicals that are released from leaves, stems, and roots of older alfalfa plants (but are concentrated in leaves). These compounds reduce germination and retard seedling development. Lastly, after many years of producing a perennial crop under irrigation, the seedbed surface is not usually ideal.

Orchardgrass appears to be the species best suited for interseeding.

Despite these obstacles, some growers claim success at thickening alfalfa fields by overseeding. These successes may be highly specific to site—especially to soil and weather conditions. At best, consider overseeding a risky practice. Growers who attempt overseeding should pay particular attention to these factors:

- **Weed and insect control:** Many insects feed on young plants.
- **Irrigation:** Seedlings compete poorly for moisture, so you should irrigate frequently. Consider a 4-day irrigation cycle to provide adequate moisture for germination and establishment.
- **Time of seeding:** Seed when competition from established plants is minimal—perhaps in early fall or between second and third cuttings.
- **Seeding technique:** Plant ¼ to ⅜ inch deep. Planting too deep will increase the probability of failure.

STAND REPLACEMENT

Stand Removal Practices

Alfalfa can be remarkably difficult to kill. Both mechanical and chemical methods are employed to remove old stands. Mechanical techniques include plowing, rototilling, multiple discings, and undercutting with wide sweeps. A rotary tiller is the most effective implement for removing alfalfa, but it is expensive and time-consuming to operate. Plowing is perhaps the most common method of stand removal, but plowing is often undesirable in rocky or shallow soils. Several passes are normally required when ripping or discing an old stand.

Herbicides are useful to remove alfalfa on rocky or erodable soils. Roundup (glyphosate) is the most frequently used product for this purpose. However, high rates or retreatment may be needed because alfalfa is comparatively tolerant to Roundup. Dicamba (Banvel) or 2,4-D (several products) can be used alone or in combination with Roundup, provided no crops sensitive to growth regulator-type herbicides are near treated fields. Herbicides may need to be combined with tillage for complete control. Regardless of the method used, alfalfa crowns must be desiccated (completely dried) to reduce the possibility of regrowing.

Back-to-Back Alfalfa

In areas where rotation crops are more profitable than alfalfa, these rotation crops often dictate when and how often fields are planted to alfalfa. However, as stated earlier, few profitable rotation crops exist for much of the Intermountain Region. Growers who do not have alternative crop options or who are experiencing extreme market forces or on-farm needs generally plant alfalfa directly after alfalfa.

Planting alfalfa back to back is fraught with many of the problems associated with overseeding alfalfa into an existing stand. Even if chemicals or tillage creates a non-competitive environment for young seedlings, the seedlings must still contend with autotoxic compounds, diseases, and pests. The effect of autotoxic compounds probably dissipates within 2 to 3 weeks following stand removal, but diseases and pests persist much longer. Rotation to another crop for one year usually allows enough time for diseases and pests to dissipate.

Crop Rotation

The many benefits of crop rotation are well established, and most agronomists recommend crop rotation, rather than continuous cropping, for almost all species. Alfalfa is highly valued for its contribution to other crop species in a rotation. Benefits derived by subsequent crops include nitrogen (which is biologically fixed by the bacteria associated with alfalfa), greater water infiltration, and improved tilth. In turn, crop rotation benefits alfalfa. Rotation can break disease and insect cycles and improve weed control and soil fertility.

ADDITIONAL READING

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KEY TO PLANT SYMPTOMS

How to use this key: Find the symptom in the left column, below. Read across to find the identifying code(s) of the possible problem(s). Use the codes to identify probable causes in the column at right.

SYMPTOMS

Leaves	Problem
Skeletonized	I1, I5
Chewed	I4, I5, I6, I7
Curled and sticky	I2, I3
Yellow (veinal)	H7
Yellow between veins (interveinal)	E4, H6, H8
General yellowing of plant	F1, F4, F6, D10
V-shaped yellow or dead tip	D12
Small brown/black spots	D9
Yellow to pale green underside	D8
Tan marginal lesions	D5
White marginal spots	F3
Red underside	F5
Dark bluish/green	E1, E3, F2, D2
Crinkled	H9, I8
Narrowed (strapped)	H3
Clasped, or stuck together	H1
Burned (necrotic)	E1, E2, E3, H4, H5
Darkened, water-soaked	E2
Flagging and white	D1
Roots	
Taproot rotted	D3, D4
Tan or black root lesions	D6
Vascular tissue red	D11, D12
Vascular tissue yellow/tan	D4, D10
Chewed	V1, V4
Cavities along sides	I6
Galls on lateral roots	D2
Stubby roots	H2
Crowns	
Bluish/black dry rot	D7
Orange/red flecks	D5
Brown/yellow lesions	D6
Shoots	
Stem and leaves eaten	I7, V2, V3, V4, V5
Wilting/flagging	D4, D7, D12
Stunted and yellow	D10
Dead stem buds, swollen internodes	D1
Shortened internodes	F5, D1, D12
Plant wilt, green stem	D12

PROBABLE CAUSES

Problem		Color Photo
	ENVIRONMENTAL FACTORS	
E1	Salt	
E2	Frost	3.1
E3	Moisture stress	
E4	Abiotic/nonpathogenic	
	FERTILITY	
F1	Nitrogen	5.3
F2	Phosphorus	5.1
F3	Potassium	5.6
F4	Sulfur	5.4
F5	Boron	5.7
F6	Molybdenum	5.5
	HERBICIDE INJURY	
H1	Eptam	6.1
H2	Balan	
H3	2,4-DB	6.2
H4	Buctril	6.3
H5	Gramoxone	
H6	Velpar	6.4
H7	Karmex	
H8	Sencor	
H9	Roundup	6.5
	INSECTS	
I1	Alfalfa weevil	7.1–7.3
I2	Pea aphid	7.4
I3	Blue alfalfa aphid	7.4
I4	Alfalfa caterpillar	
I5	Armyworm	
I6	Clover root curculio	7.5
I7	Grasshoppers	
I8	Thrips	7.6
	DISEASES AND NEMATODES	
D1	Stem nematode	8.1–8.3
D2	Root-knot nematode	8.4
D3	Pythium	9.1
D4	Phytophthora root rot	9.2
D5	Stagonospora crown/root rot	
D6	Rhizoctonia root canker	
D7	Anthracnose	9.3
D8	Downy mildew	9.4
D9	Common leaf spot	
D10	Bacterial wilt	9.5
D11	Fusarium wilt	9.6
D12	Verticillium wilt	9.7–9.9
	VERTEBRATES	
V1	Gophers	10.1
V2	Squirrels	10.3
V3	Rabbits	
V4	Meadow mice	10.4
V5	Deer	

Adapted by Steve B. Orloff from Canevari, W. M. 1993. Diagnosing field problems. *Proceedings, 23rd California Alfalfa Symposium,* 124–27. December 8–9, Visalia, CA.

CHAPTER 3

A

B

3.1. Frost can be a problem almost anytime during the growing season, but it is most common in early spring. (A) Within hours after a hard frost, leaves darken and appear water-soaked; stems may bend over.

(B) After a day, leaves—or parts of leaves—may become yellow or white. Typically, affected leaves fall from the stem a few days later. Severe frost may kill entire shoots.

CHAPTER 5

5.1. Phosphorus deficiency, although characterized by stunted plants with small leaves, is difficult—if not impossible—to identify visually, because many other problems cause similar symptoms. Contrast the phosphorus-deficient plants (left) with those that received phosphorus fertilizer (right).

5.3. Nitrogen deficiency is evident soon after planting, when seedlings reach 4 to 8 inches in height. In a field with nitrogen-deficient alfalfa, stunted yellow plants are scattered among taller dark green plants. The yellow plants result from poor inoculation by Rhizobia bacteria; the dark green plants have been adequately inoculated.

5.2. Nitrogen, sulfur, and molybdenum deficiencies all cause yellowing and stunting. (A, B, C) These photos illustrate the progressive development of the deficiency and chlorotic leaf symptoms (left) versus healthy leaves (right).

A

B

C

JACK CLARK (3.1A, 5.2 A, B, C), STEVE ORLOFF (3.1B), ROLAND MEYER (5.1, 5.3)

5.4. Sulfur deficiency can occur at any time or growth stage, but it is most common in spring, when alfalfa starts growing and soils are cold or wet. Contrast the yellow sulfur-deficient plants with the green normal growth where sulfur was applied.

5.5. Molybdenum deficiency generally occurs after the first or perhaps second cutting. Regrowth of molybdenum-deficient alfalfa, like that of alfalfa deficient in sulfur, may be extremely yellow and stunted. This photo shows a strip of yellow plants between green plants; the green plants received an application of molybdenum.

A

B

C

D

5.6. (A) The upper portion of this alfalfa stem exhibits potassium-deficiency symptoms. (B) The first symptoms to appear are yellow or white spots, each about the size of a pinhead, near the margins of upper leaves. (C and D) As the plant becomes more deficient, leaf tips and margins become more chlorotic. When leaves mature, the yellow tissue dies and turns brown.

ROLAND MEYER (5.4, 5.5), JACK CLARK (5.6A, B, C, D)

A

B

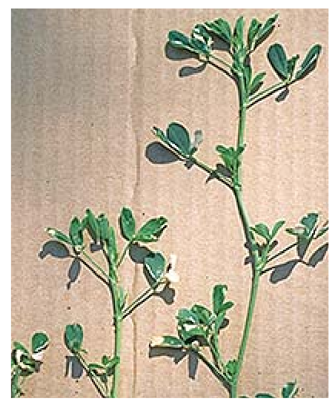
C

5.7. (A) The yellow and reddish chlorotic leaf tips and margins associated with boron deficiency are somewhat similar to potassium-deficiency symptoms. (B) Leaves of boron-deficient alfalfa are reddish purple on the underside, and sometimes on the top. (C) After an irrigation, or when regrowth occurs, a new stem may initiate at the base of the third or fourth leaf from the top of the plant. The new stem appears normal at first, but the internodes (stem segments between leaves) become increasingly shorter. Later, the leaves of the new stem also exhibit boron-deficiency symptoms—yellow on top and reddish purple on the underside.

CHAPTER 6

6.1. The preplant herbicide Eptam may stunt seedlings and cause cupped and clasped leaves, especially when it is applied to sandy soils.

6.2. Narrowed (strapped) leaflets can be a sign of injury by the herbicide 2,4-DB. Such leaves often become evident when rain or sprinkler irrigation occurs too soon after herbicide application.



6.3. Buctril can cause necrotic lesions (dead spots) on plants, especially if applied when weather is above 80°F.

6.4. Herbicides that are photosynthetic-inhibitors (Velpar, Karmex, and Sencor) can cause chlorosis, or yellowing, when applied after alfalfa resumes growth in spring. (This photo shows Velpar injury.)

6.5. Actively growing alfalfa plants treated with Roundup become stunted and have small crinkled leaves.

JACK CLARK (5.7A, B, C), BILL FISCHER (6.1, 6.4, 6.5) STEVE ORLOFF (6.2), CHARLES HICKS (6.3)

CHAPTER 7

7.1. (A) First- and second-instar larvae of the alfalfa weevil feed on the tightly folded young leaves at the end of shoots. (B) Larger larvae feed on older leaves, giving them a (C) skeletonized appearance.

A

B

C

7.2. Once alfalfa weevil larvae complete their growth, they spin silken cocoons on leaves or in debris on the soil surface.

7.3. The adult alfalfa weevil is dark gray to brown, with a dark brown stripe on its back, and has the distinctive weevil snout. The weevil can be seen for a short time before it enters a resting stage, which it spends in weedy areas near the field or in field trash.

A

B

7.4. Both blue alfalfa aphids and pea aphids infest intermountain alfalfa fields. (A) Blue alfalfa aphid causes significantly more stunting, but (B) pea aphid is more common in the Intermountain Region. The two aphids can be distinguished by examining their antennae through a hand lens. Blue alfalfa aphid antennae are uniformly dark; those of the pea aphid have dark bands on light green antennae. The pea aphid on the right has been parasitized by a wasp of the genus *Aphidius.*

A

B

7.5 (A) White larval forms of the clover root curculio (8X magnification) begin feeding on fibrous roots. (B) They subsequently chew large cavities along the sides of taproots.

7.6. Feeding by thrips causes wrinkled and distorted leaves.

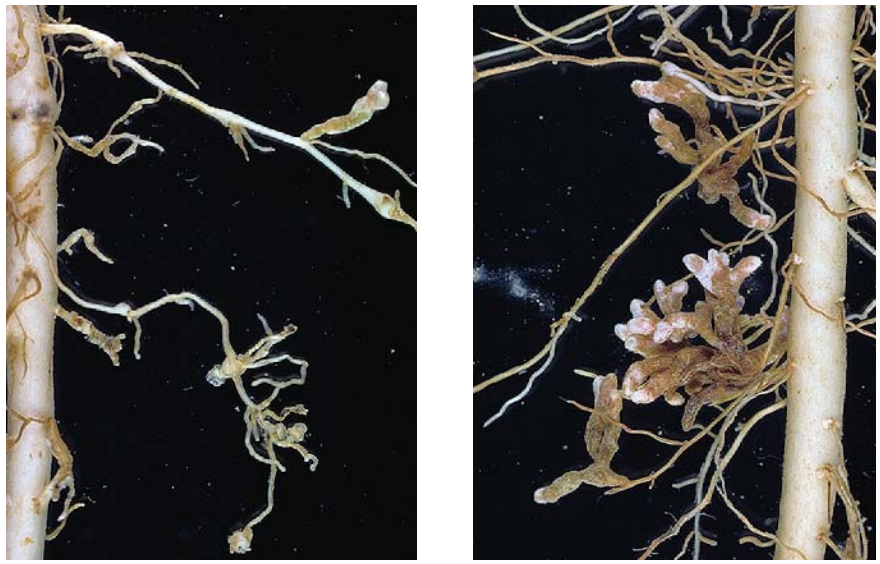
JACK CLARK (7.1A, B, C, 7.2, 7.3, 7.4A, B, 7.5A), LARRY GODFREY (7.B), STEVE ORLOFF (7.6)

CHAPTER 8

8.1 Stem nematode-infested plants have dead stem buds and short, swollen internodes. The shoots on the right are normal.

8.2 Shoots that are slightly smaller than normal and completely white are symptomatic of a stem-nematode infestation. Such shoots are most prominent after the first cutting.

8.3. Stem-nematode infestation typically occurs in patches of the field in spring, when weather is cool and wet.



8.4. (A) Root-knot nematode causes galls on lateral roots. (B) Unlike galls, nitrogen-fixing nodules are pinkish and easily dislodged by rubbing.

CHAPTER 9

9.1. The seedling on the left is healthy; the other three show different symptoms of seedling disease. The second seedling has a brown lesion and an abnormally thick root below it. The root of the third seedling has the pinched-off look typical of plants infected by Pythium fungi. By growing new roots, the seedling on the right has recovered from an earlier infection.

A

B

9.2. (A) Phytophthora root rot lesions are yellow-brown to black and eventually girdle the taproot. The taproot usually rots where water drainage is impeded. (B) When a phytophthora-infected root is sliced vertically, red-orange to yellow streaks, which spread up several inches from the rotten root tip, become visible.

STEVE ORLOFF (8.1, 8.3), VERN MARBLE (8.2, 9.2A, B), JACK CLARK (8.4A, B, 9.1)

9.3. (A) Symptoms of anthracnose include dead straw-colored stems that are bent and sometimes scattered through fields. (B) Straw-colored oval or diamond-shaped lesions with a brown border are found on stems of infected plants. (C) When diseased stems are removed from the crown, a blue-black crown rot is visible.

A B C

A

9.4. (A) Light green to yellow patches on leaflets are characteristic of downy mildew (a foliar disease common to intermountain alfalfa). (B) On the underside of leaves infected with downy mildew is a fine grayish growth of spore-bearing structures.

B

9.5. The small, yellowish plant in the foreground has bacterial wilt. Severely infected plants are stunted and have spindly stems and small, distorted leaflets.

9.6. A longitudinal cross section of a fusarium wilt-infected root reveals a dark reddish brown discoloration in the stele, or center, of the root.

9.7. Foliar symptoms of verticillium wilt are similar to those caused by gopher feeding. However, the stems of plants infected with the disease do not wilt and usually retain their green color. Near the top of shoots, the stems between the leaves (internodes) are short, and the plant cannot be pulled out of the ground easily.

JACK CLARK (9.3A, B, 9.4B), STEVE ORLOFF (9.4A), VERN MARBLE (9.3C, 9.5), DONALD BARNES (9.6), RICHARD PEADEN (9.7)

9.8. V-shaped yellowing, or chlorosis, of leaflets is a diagnostic symptom of verticillium wilt.

9.9. Rolled leaflets are characteristic of verticillium wilt.

CHAPTER 10

10.1. Pocket gophers are rarely seen above ground, as in this photo; you may know they are present only by seeing the damage they cause—crescent-shaped mounds and scattered dead plants.

A

B

10.2. (A) A tractor-drawn mechanical bait applicator is useful for large areas. (B) It constructs an artificial burrow and deposits poison grain at preset intervals.

A

B

10.3. (A) The California ground squirrel has a flecked coat and long bushy tail. It is found along field edges and fence lines. (B) In contrast, the Belding ground squirrel is solid brown with a short, flat tail. It inhabits alfalfa fields.

10.4. A series of trails (about 2 in. wide) that lead to numerous short, moundless entrance holes indicates an infestation by meadow mice.

RICHARD PEADEN (9.8, 9.9) JACK CLARK (10.1, 10.2B), W. PAUL GORENZEL (10.2A, 10.3A), STEVE ORLOFF (10.3B, 10.4)