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*Ecology and Management of Annual Rangelands Series*

# Part 9: Vegetation Management

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*Ecology and Management of Annual Rangelands Series Technical Editor: Melvin George*

**Publications in this series:**

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Vegetation management research focused on annual range improvement to increase forage production and quality has resulted in an extensive literature. The purpose of this publication is to provide range managers and students with an overview of that research and the practices that have developed from it for brush and weed control, seeding, and fertilization. The use of grazing to manage vegetation is discussed in the eighth publication in this series, "Grazing Management."

Management of vegetation with fire, heavy equipment, herbicides, improved forage plants, and fertilizer played an important role in range improvement following World War II until the late 1970s. Increased fuel and fertilizer costs following the energy crisis of the mid-1970s, low prices for livestock in the 1980s and '90s, increased liability associated with prescribed burning, the ban from the Environmental Protection Agency (EPA) on the use of 2,4,5-T for brush control, requirements for environmental impact statements, and other economic and policy changes all conspired to reduce the economic return from many range improvement practices. In addition, low grazing land rental rates often made it more cost effective to rent another acre than to improve an acre. While these forces may have reduced the application of range improvement practices on California's rangelands for the past 30 years, vegetation management remains the only practical way to increase carrying capacity or to improve wildlife habitat. Current trends of higher lease rates and limited availability of rental property due to conversion to other uses may rejuvenate interest in these practices.

Cattle grazing on California's annual rangelands.

Vegetation management (brush and weed control, seeding, and fertilization) has been a continuing theme of research at the University of California since the late 1880s (George and Clawson 2014). Prior to the 1970s, the focus was primarily to increase carrying capacity by growing more forage and improving animal performance by increasing forage quality. Following federal and state environmental legislation in the 1970s, management for water quality, air quality, and threatened and endangered species became important management objectives on California's and the nation's rangelands. While increasing carrying capacity by producing more forage remains an important objective, ranchers and public agencies also manage for fire hazard reduction, improved water quality, air quality, and biodiversity. Suppressing introduced species and restoring native species has become a major theme among conservation organizations and some government agencies.

In this publication, we will first identify practices that reduce seasonal gaps in forage availability and quality. Then we will discuss the economics of vegetation management. Finally, we will review brush and weed control, rangeland seeding, and rangeland fertilization practices, emphasizing the findings and recommendations of the University of California and other researchers as they have been the main source of what is known about rangeland improvement on annual rangelands.

## ANNUAL RANGELAND FORAGE SYSTEMS

Most ranches in California combine irrigated and dryland hay and pasture with the rangeland forage base in an integrated forage system. These additional forages are complementary to the rangeland forage base, and they increase the carrying capacity of the ranch or improve forage quality. Annual rangeland ranches depend on numerous complementary forages and feed sources to provide adequate nutrients for beef cattle and sheep production enterprises. Several common and uncommon sources of feed and forage are described below for different seasons of the year. The productive potential and feasibility of each of these sources must be adapted to the forage plant and livestock requirements, and these are dependent on the ranch's natural, managerial, and financial resources.

### Seasonal Forage Production and Quality

In this section, we will discuss the influence of vegetation management practices on seasonal forage production, forage quality, and animal performance. The range improvement practice alternatives are often applied in combination with weed and brush control to increase carrying capacity while mitigating seasonal forage gaps. For a thorough discussion of seasonal forage productivity including examples of seasonal and annual production, see the first publication in this series, "Mediterranean Climate," and Becchetti et al. (2015). The seventh publication in this series, "Livestock Production," discusses seasonal forage quality and animal performance.

The annual range forage year has been divided into seasons to reflect variations in productivity, quality, and animal performance. Bentley and Talbot (1951) segregated the seasons into the inadequate-green season, adequate-green season, and inadequate-dry season. George et al. (2001) and Becchetti et al. (2015) defined four seasons: fall onset of growth, winter slow growth, rapid spring growth, and summer dry. Each of these seasons has characteristic productivity limitations.

The fall season is the period between the first germinating rains and the onset of cool winter temperatures. This season can be quite short to several weeks long, depending on the timing of fall precipitation and the onset of cool temperatures. During this period, the dry residual forage that was produced the previous season provides low-quality dry matter for grazing. As germination and seedling establishment progresses, the amount of new green forage increases. This new forage is high in protein and energy, but high water content may limit nutrient intake. During winter, new forage continues to grow slowly, and residual dry forage disappears due to grazing and decomposition. During the fall-winter period, low forage levels can limit intake of dry matter, energy, protein, and other nutrients. Supplementation, seeding, and fertilization can improve animal performance during the fall and winter period.

Rapid spring growth begins with rising spring temperatures. During this portion of the growing season, forage quantity and quality are usually adequate for rapid livestock gains. Forage level increases rapidly and frequently outproduces the livestock's ability to consume it. Unused forage at the end of this season remains as low-quality dry residue. Forage production and quality during this period are increased by seeding legumes and fertilization. Although not common, excess forage can be conserved as high-quality hay for future use if properly timed. Conservation of forage avoids risk associated with uncertain weather conditions, and it may increase market flexibility. However, required equipment increases overhead costs.

Forage maturity and moisture loss precede the summer dry season. Standing dry forage gradually shatters and decomposes, resulting in continued decline in forage quality through the summer season. This forage provides energy to grazing stock but frequently is of

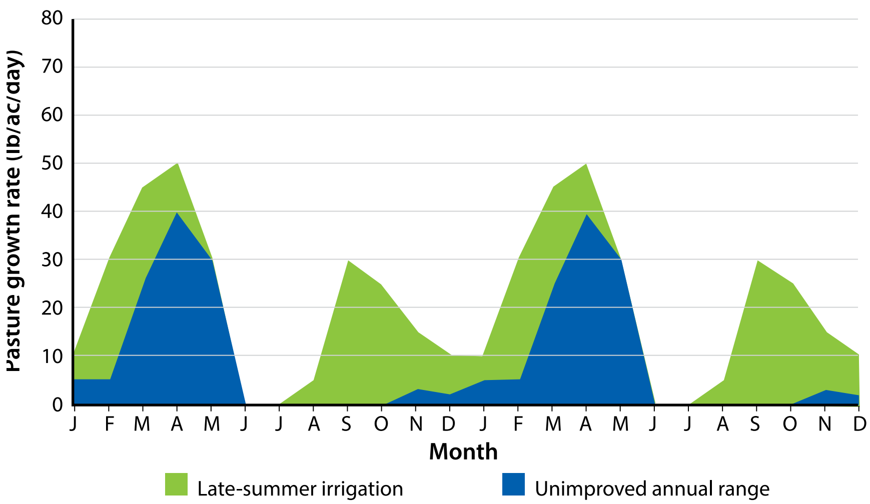


**Figure 1.** Comparison of seasonal productivity with and without late-summer irrigation.

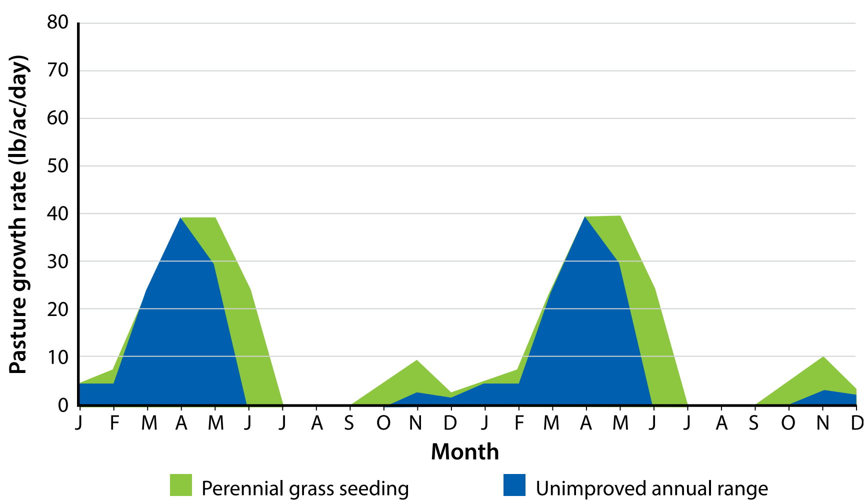


**Figure 2.** Comparison of seasonal productivity with and without a perennial grass seeding.

inadequate quality to meet other nutrient requirements. Intake of this forage is limited by its quality. It is common practice to move stock to higher elevations and irrigated pasture or provide protein and mineral supplements during this season. Strategic use of appropriate legumes can increase the quality of this dry forage.

The following seasonal forage and grazing management practices can provide solutions to limitations in forage production, quality, and utilization that are manifested as inadequate animal production per acre. Controlling medusahead, goatgrass, yellow starthistle and other weeds, in combination with the seeding and fertilization that may be desirable during this season, can increase carrying capacity of annual rangeland and forage quality.

**Season 1 (onset of green season, fall):** The timing and amount of annual range forage productivity is highly variable and may require feed from other sources to provide adequate dry matter or protein. Protein supplements are commonly used. Development of complementary forages such as the following alternatives may be desirable where they are cost effective.

1. Early fall green feed (fig. 1) can be produced by supplemental irrigation of annual ryegrass *(Lolium multiflorum),* winter cereals, or subterranean clover *(Trifolium subterraneum).* In this uncommon alternative, annual rangeland seeded with ryegrass, winter cereals, or subterranean clover can be irrigated in mid- to late summer to stimulate early germination and early start of the green season (Taggard et al. 1976).
2. Seed summer-dormant perennials such as perlagrass *(Phalaris tuberosa),* Hardinggrass *(Phalaris aquatic),* or Berber or Palestine orchard grass *(Dactylis glomerata)* for early fall green feed (fig. 2). Non-native perennial grasses have been successfully seeded in annual rangeland soils that have sufficient depth and adequate rainfall. This practice was most common along the north and central coast and along the Sierra Nevada foothills south to Mariposa County. Other regions are commonly too dry to support successful perennial grass seedings.
3. Stay on summer pasture into the fall months to save annual range for late fall and winter use. Grazing mountain meadows and high-elevation rangeland is a common means of providing summer green forage to beef cattle herds and sheep flocks. However, cold weather may restrict this option, and some operations leave high-elevation rangeland before hunting season begins. Seasonal productivity of mountain meadows is described in Season 4 below.
4. Graze alfalfa *(Medicago sativa)* fields in the fall or winter. Central Valley alfalfa fields

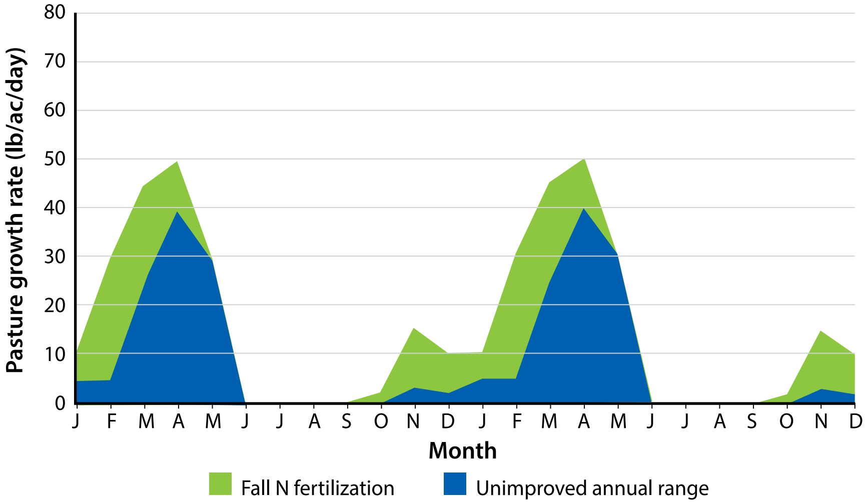


**Figure 3.** Comparison of seasonal productivity with and without nitrogen fertilization.

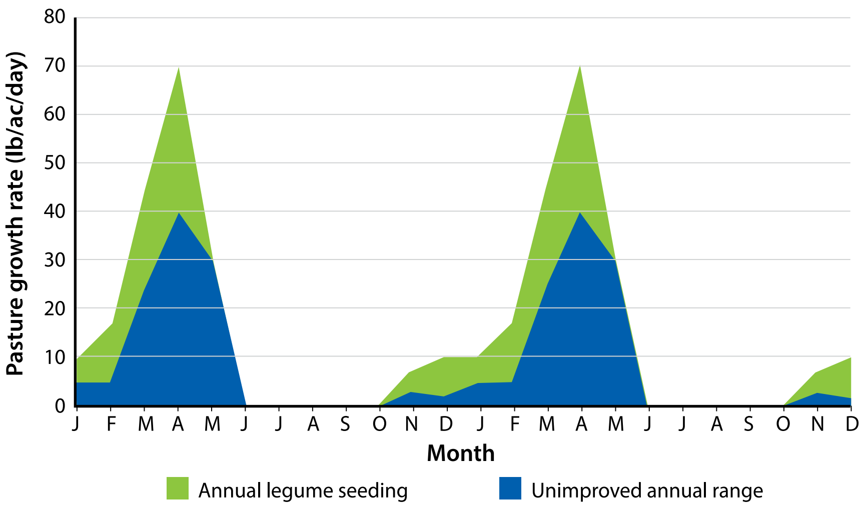


**Figure 4.** Comparison of seasonal productivity with and without an annual legume seeding.

are often used by sheep operations as a fall forage source.

5. Provide protein supplements and graze unused dry residue from previous growing season. "Livestock Production," the seventh publication in this series, describes potential gaps in forage quality and discusses beef cattle supplementation practices.
6. Provide energy supplements during the inadequate-green season (fall/early winter). The "Livestock Production" publication in this series describes energy supplementation needs and practices.

**Season 2 (winter season):** Following fall growth, annual range productivity usually stagnates due to cold winter weather. During this period, protein supplementation may be unnecessary, but inadequate dry matter intake may require feeding of hay. Complementary forages may improve winter feed.

1. Nitrogen fertilization of annual range can increase winter feed (fig. 3). Fall application of nitrogen can increase range forage productivity, permitting increased stocking rates and improved animal performance. Annual rangeland nitrogen fertilization practices are discussed later in this publication.
2. Annual legumes increase winter forage productivity and quality if properly managed (fig. 4). Annual legumes such as subterranean clover, rose clover *(Trifolium hirtum)*, and the annual medics (*Medicago* spp.) increase forage quality and productivity, resulting in improved animal performance.
3. Alternatives 1, 2, 4, and 6 in Season 1, above, can also provide feed during this season.

**Season 3 (rapid spring growth, adequate-green season):** Forage production on annual range during the spring season usually is not limiting. However, weed invasions can reduce carrying capacity. The time of warming temperatures and the amount and timing of spring rains largely determine the length of this season.

1. Alternative 2 in Season 1 and alternatives 1 and 2 in Season 2, above, can increase feed during this period.
2. Controlling medusahead *(Taeniatherum caput-medusae)*, goatgrass *(Aegilops triuncialis)*, yellow starthistle *(Centaurea solstitialis)*, and other weeds during this season can increase carrying capacity of annual rangeland and may be used in combination with alternative 1.
3. Cool-season irrigated pasture can provide high-quality feed during this period (figs. 5 and 6). Irrigated pasture is a common forage source for annual rangeland livestock operations. Some ranches own

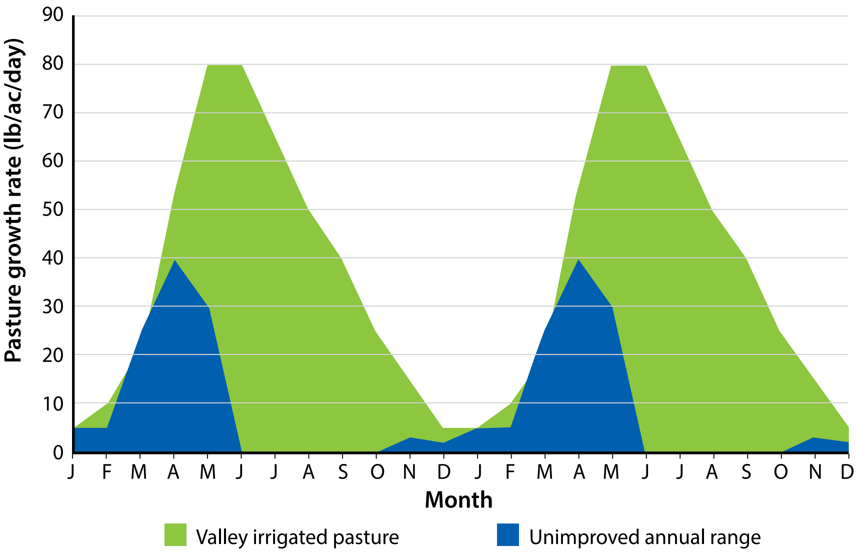


**Figure 5.** Comparison of unimproved annual range and valley irrigated pasture seasonal productivity.

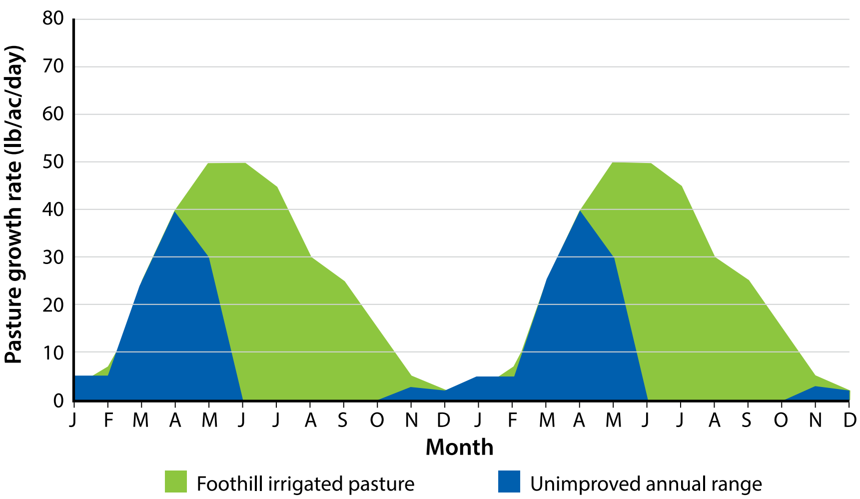


**Figure 6.** Comparison of unimproved annual range and foothill irrigated pasture seasonal productivity.

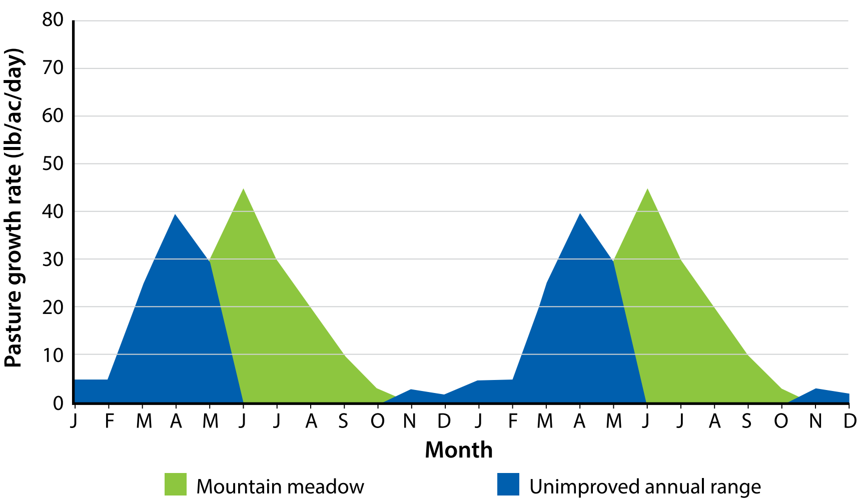


**Figure 7.** Comparison of unimproved annual range and mountain meadow seasonal productivity.

irrigated pastures while others lease pasture.

4. Production of winter cereals or ryegrass can provide extra feed or hay during this season. Although this is not a common practice, it has been used in the past and can provide additional spring forage.

**Season 4 (dry season, inadequate-dry):** The dry season starts as soon as soil moisture is depleted following the end of the rainy season. The dry feed is low in protein and other nutrients. The following complementary forages can provide summer grazing.

1. Rotation of livestock from dry range to irrigated pasture can be a cost-effective method of providing adequate protein and dry matter in summer.
2. Travel to high-elevation range and mountain meadows is a common practice (fig. 7). Grazing management of these forage sources should follow established guidelines for perennial range and pastures.
3. Produce sudangrass *(Sorghum bicolor)* for pasture or hay production.
4. Annual legumes such as rose clover, Lana vetch *(Vicia dasycarpa),* and annual medics can raise the quality of dry annual range feed for all or part of the summer season.
5. Crop residue such as winter cereal stubble can provide dry matter. Shattered grain may improve the quality of this feed source.

While vegetation management practices and development of complementary forages can mitigate gaps in forage quantity and quality, grazing management practices (discussed in "Grazing Management," the eighth publication in this series) can reduce over- and underutilization of forage due to terrain and distance to water and plant preferences exhibited by grazing livestock. The use of pasture subdivision and controlled grazing systems can increase utilization and enhance animal management, but less expensive methods such as salt, water, and supplement placement, herding, and selective fertilization should be given equal consideration to fencing. New fencing methods and materials make permanent and temporary pasture subdivision more cost effective than traditional fencing. Grazing management of annual range should emphasize maintenance of adequate residue and efficient utilization of forage.

## ECONOMICS OF RANGE IMPROVEMENT

In California the cost of improving an acre of rangeland has always had to compete with the cost of renting an acre of grazing land. Often it has been cheaper to increase carrying capacity by renting another acre rather than paying the per-acre cost of range improvement. However, as it becomes harder to find grazing land to lease, range improvement may become more important. Brush control is one of the oldest and quickest ways to increase carrying capacity for livestock production, but the economics of this and other range improvement practices have changed. Before the energy crisis of the 1970s, it was less costly to use fossil fuels and fertilizers that are fossil fuel based in range improvement. Following the increase in fuel costs, brush control practices (especially mechanical methods) became more costly, as did the cost of planting seed and applying fertilizer. Beginning in the 1950s, ranchers, in collaboration with the university and several government agencies, planned and conducted burns to control brush. By the 1970s, subdivisions and single-family homes had moved into the state's range and forestlands, creating a huge liability for burning. Prescribed burning is still economical in many instances, but the liability risk, air quality concerns, and cost has resulted in a decrease in burning.

The decision to improve rangelands depends on several factors, including (1) financial returns from the improvement, (2) risk of failure, (3) government subsidies, (4) financial returns from alternative practices, (5) effects on vegetation, including recovery following treatment, and (6) current and projected livestock prices and ranch costs. Costs and returns to vegetation management vary with many factors. Differences in site potential and prevailing weather conditions influence the success of vegetation management. Livestock prices, as well as fuel and labor costs, are important influences that vary over time. Availability of equipment such as special seeders can also influence costs and practice success. While costs and returns have been reported in budgets in the past, today this information is scarce and highly site-specific. Consequently, we will not attempt to generalize about costs and returns of vegetation management practices.

Unlike range improvement to increase ranch profit, reducing fire hazard and restoration of native plants to rangelands are not constrained by profit goals. Consequently, restoration projects often operate under a different set of economic rules than those that guide ranchers. Fuel reduction and restoration of native plants to public and private lands are often subsidized by government programs or by funds from conservation organizations. Creating a profit is seldom an objective. Instead, managing vegetation to reduce fire hazard holds the promise of reducing fire suppression costs and economic losses to catastrophic fires. But realization of the promise will require long-term and permanent investment in vegetation management practices.

## BRUSH AND WEED CONTROL

### Woody Plant Management

Historically, oak and shrub removal has been recommended to increase forage production in oak woodlands. From the 1940s to the 1980s, mechanical and chemical tree and shrub control and prescribed burning were often used to selectively thin oak woodlands (Love et al. 1952). In some cases, all trees and shrubs in chaparral and oak woodlands were controlled, resulting in a type-conversion to annual grassland (fig. 8). Seeding and fertilization often accompanied tree and shrub control.

On sites where oak trees are dense and canopy cover is high, forage productivity can be increased by oak tree thinning (Kay 1986; Kay and Leonard 1979). On sites where tree density is sparse, such as the oak savannas of the central and southern Sierra Nevada foothills, forage productivity and quality are greater under the trees and oak removal may decrease

**Figure 8.** Aerial view of a Sierra foothill oak woodland that has been cleared of all woody vegetation, thinned to decrease canopy cover, or untreated to maintain natural canopy cover.

forage production (Holland 1979). In most cases the removal of blue oaks (deciduous) to less than 25 percent canopy cover resulted in increased forage production. In general, live oak (evergreen) stands with greater than 25 percent canopy cover will have less forage growth than cleared areas (Kay 1986; Kay and Leonard 1979).

### *Fire*

Landowners, state agencies, and the University of California have a long history of collaboration on brush control, including prescribed burning (George and Clawson 2014). Consequently, there is an extensive literature on prescribed burning and fire effects on woody plants in California's annual rangelands (e.g., Emrick and Adams 1977; Green 1981; Biswell 1999; McCreary 2004). Control of woody plants in oak woodland and chaparral ecosystems has been a major theme of ranchers and fire control agencies. Fire was the earliest form of brush and weed control in California's annual rangelands. Native Americans used fire as a management tool to enhance habitat and to manage food and fiber plants. McClaran (1986) and McClaran and Bartolome (1989) estimated fire return intervals of about 25 years in oak woodlands prior to European settlement. After settlement, the return interval was around 7 years, due to more frequent burning by settlers. In the 1940s, Sampson (1940) estimated that oak woodland burning by ranchers resulted in return intervals of 8 to 15 years. Beginning in the 1940s, County Range Improvement Associations, in collaboration with the University of California and the California Department of Forestry (Cal Fire), conducted prescribed burns to increase forage production and decrease fire hazard. From 1945 to 1975, more than 9,000 burning permits were used to burn more than 2.5 million acres of California rangeland. While prescribed burning continues today, urbanization and air quality concerns have reduced the use of fire as a management tool. Today, fire frequency is more likely to be on the order of 25 to 50 years or longer. Thus, while prescribed burning and mechanical and chemical brush control were frequently used to remove or reduce the shrub and tree layers in oak woodlands and chaparral (Murphy and Crampton 1964; Murphy and Berry 1973), since the beginning of the twenty-first century they have been used less frequently.

While fire was the first method of brush control, over the years mechanical and chemical methods have also been important. Often fire has been used in combination with mechanical, biological, and chemical methods. Partnering with government agencies such as Cal Fire may provide avenues for mitigating liability for controlled burning on private lands through programs such as the Vegetation Management Program (VMP). On public lands, the USDA Forest Service and the Bureau of Land Management are potential partners. These programs usually require the landowner to prepare for the fire by constructing fuel breaks, though the burn itself is conducted by the government agency (Green 1981; California Air Resources Board 2003; McCreary 2004).

### *Herbicides*

In the 1950s and 60s, effective tree-thinning practices were developed in oak woodlands. These included basal frilling with the application of 2,4-D and/or 2,4,5-T or tree cutting (cut stump) followed by 2,4-D or 2,4,5-T application to the cut surface. These practices were used to type-convert chaparral and oak woodlands to annual grasslands (Leonard et al. 1956; Leonard 1959). In the 1980s, the EPA banned the use of 2,4,5-T because it frequently contained dioxin as a synthesis contaminant. Triclopyr, 2,4-D, imazapyr, and glyphosate are currently used for woody plant control. Glyphosate is a postemergent, nonselective herbicide that is most effective when applied to live tissue. Triclopyr and 2,4-D are postemergent herbicides that are selective for broadleaf plants. Imazapyr is a nonselective post- and pre-emergent herbicide. Depending on the compound, these chemicals can be used as a cut stump treatment, stem injection, or foliar spray. Additional information on chemical control is available on the University of California IPM website, http://www.ipm.ucdavis.edu/PMG/PESTNOTES/pn74142.html. Because regulations and chemical recommendations are subject to change, current herbicide recommendations and regulations should be reviewed with the county agricultural commissioner before purchase and application.

### *Biological*

Biological control has been defined simply as the utilization of natural enemies to reduce the damage caused by noxious organisms to tolerable levels (DeBach and Rosen 1991). One approach to biological control has been termed *classical biological control*; it involves the discovery, importation, and establishment of exotic natural enemies, with the hope that they will suppress a particular organism's population. This approach has been most successful in situations in which an organism moves or has been transported to a new environment, usually without the natural enemies that have regulated its population and prevented major outbreaks. There are few examples of classical biological control agents for woody plants on rangelands. Tamarisk beetles have shown some effect on saltcedar (*Tamarix* spp.) along rangeland riparian areas. Biological control of Klamath weed *(Hypericum perforatum)*, a nonwoody plant, is discussed in a later section.

Weed scientists consider the use of grazing or browsing by domestic animals to be a cultural practice rather than a classical biological control. Goat browsing has been used successfully in California's oak woodlands and chaparral (Spurlock et al. 1978). While browsing is not an effective means of reducing well-established brush stands, it is useful in managing resprouting and reestablishment following fire and other methods of control. Targeted grazing for managing vegetation is covered in the eighth publication in this series, "Grazing Management."

### *Mechanical*

Mechanical methods (Roby and Green 1976) are often used in the control of woody plants. For example, heavy equipment such as bull dozer blades with brush rakes or heavy-duty disks can be used to remove small shrubs, and anchor chains pulled between two bull dozers can uproot larger shrubs. In past years, the ball and chain method was used to layover and uproot brush on steep slopes. Adams (1976a, 1976b, 1976c, 1976d) reviewed the use of these mechanical methods.

### *Combining Practices*

Because no single method of control is effective in all situations, biological, cultural, mechanical, and chemical methods are often used in combinations to achieve the best control. Use of prescribed fire is often preceded by mechanical or chemical treatments that allow the brush to dry for several months. Herbicides may be used to kill brush before application of fire or mechanical methods. Chemicals may be applied to clean up after large-scale application of fire or mechanical control. Chemicals or goats can be used following fire to suppress reemerging vegetation. Often seeding of desired species follows control of brush and other weeds to stabilize soil, improve forage production and quality, reduce fire hazard, and improve habitat.

### *Oak Conservation*

In the 1980s, concern about poor oak regeneration, combined with firewood harvesting and permanent conversion to other uses, led to a University of California and state agency cooperative program to improve oak regeneration. Regeneration of blue oaks was of particular concern because they are weak resprouters on some dry sites and because of a number of factors that limit seed germination, seedling establishment, and survival to the tree stage (McCreary et al. 2011). In the past 30 years, researchers in the University of California Division of Agriculture and Natural Resources developed successful restoration methods of planting acorns and transplanting seedlings and protecting naturally produced seedlings and saplings (McCreary et al. 2011). They developed site/habitat-specific practices to improve oak regeneration (e.g., McCreary 2001); identified grazing practices that could protect oaks (McCreary and George 2005); studied oak woodland habitat values (e.g., Block et al. 1994); documented and classified oaks and oak woodlands (e.g., Allen et al. 1991); and investigated landowner attitudes about oaks and oak woodlands (e.g., Huntsinger et al. 1997). Extensive information on oak conservation can be found at the UC Oaks website, https://oaks.cnr.berkeley.edu/.

Before it was recognized that blue oaks and other oak species were not regenerating on some sites, it was a common practice to remove live oaks, and in some places blue oaks, to increase forage production. Following oak removal, increased light, moisture, heat, and soil nutrients contributed to increased forage production compared to that of natural grassland patches that occur in a mosaic pattern with oak woodlands. But three reports (Kay and Leonard 1979; Kay 1986; Dahlgren et al. 1997) have shown that about 15 years after oak removal, forage production where oaks had been removed was similar to forage production in the natural grassland patches. They attribute this to gradual depletion of the nutrients that had accumulated under the oak canopy.

On blue oak sites where regeneration was poor, firewood cutting and removal of oaks have decreased. Raguse et al. (1986) developed guidelines for oak woodland range improvement. They recommended leaving woody vegetation along riparian zones and other drainage ways to reduce erosion and also on rocky outcrops and shallow soils where opportunities for increased forage production are low. They also recommended leaving trees on slopes exceeding 30 to 40 percent and leaving scattered groups or corridors of trees of different age classes for wildlife habitat and to maintain an aesthetic viewscape. They suggested that seeding of improved forage species only in cleared areas could be used to fill gaps in the ranch's forage sources.

## Weed Management

Annual rangeland grazing or carrying capacity is severely reduced by weed infestations. While the annual rangelands are largely populated by introduced annual plants, some are the target of weed control efforts to improve forage quantity and quality and to improve native grass and forb restoration. Yellow starthistle *(Centaurea solstitialis)*, medusahead *(Taeniatherum caput-medusae)*, and barb goatgrass *(Aegilops truncialis)* are the focus of most rangeland weed control programs, but control of various other thistles, perennial pepperweed *(Lepidium latifolium)*, and certain poisonous plants remains locally important. Fire has proven useful for managing many of these weeds, but concerns about liability and air pollution limit the use of prescribed burning. DiTomaso (2000) reviewed the impact and management of invasive weeds on rangelands and called for integrated approaches to rangeland weed management. He concluded that successful management of noxious weeds on rangelands will require the development of a long-term strategic plan incorporating prevention programs, education materials and activities, and economical and sustainable multiyear, integrated approaches that improve degraded rangeland communities, enhance the utility of the ecosystem, and prevent reinvasion or encroachment by other noxious weed species. Guidelines for controlling many of these weeds, as well as discussions of their biology, are available on the UC Weed Research and Information Center's website, http://wric.ucdavis.edu/. Here, we will review three rangeland weeds that currently receive the most attention and one weed that was successfully controlled using biological methods.

### *Yellow Starthistle*

DiTomaso et al. (2006) published a management guide for yellow starthistle that addresses the introduction and spread of yellow starthistle as well as its biology, ecology, and control methods, including strategic planning of control programs. Tillage, mowing, and hand removal are among the mechanical methods reviewed in this guide.

Prescribed burning and targeted grazing can be valuable tools in an integrated management program. Herbicides, both pre-emergent and postemergent, can also successfully control yellow starthistle. In particular, clopyralid, aminopyralid, and aminocyclopyrachlor provide excellent control at low rates. All three of these compounds have both pre- and postemergence activity. A combination of a spring burn followed by a pre-emergent herbicide application in the following growing season has been found to be one of the most successful strategies for yellow starthistle control. The burn suppresses current plants and acts to stimulate germination of much of the remaining seed bank the next fall, which the herbicide then controls. Biological control has primarily focused on insects that attack the flower heads. Only two insects have proven somewhat effective, including the hairy weevil *(Eustenopus villosus)* and the false peacock fly *(Chaetorellia succinea)*, having been reported to reduce seed production (DiTomaso et al. 2006). Revegetation with native or introduced grasses, legumes, or other forbs is an important component of long-term yellow starthistle management.

### *Medusahead*

Methods for controlling medusahead have been studied and implemented since the 1950s with the goal of reducing thatch buildup and reducing flowering and seed production. Control approaches have often targeted windows for burning when medusahead is still growing but when most associated species are mature and dry (Kyser et al. 2008; Murphy and Lusk 1961; McKell et al. 1962). Grazing management approaches have successfully reduced flowering on a small scale by targeting a narrow period just before the flower emerges in April or May (DiTomaso et al. 2008). On a large scale, grazing has been less successful because of management challenges, including availability and distribution of water and availability of sufficient cattle numbers for targeted grazing in later spring and early summer (Davy et al. 2015). Glyphosate can be an effective control method when applied in early spring to young medusahead plants. However, it is nonselective and can damage desirable broadleaf or grass vegetation, including native perennial grasses at moderate to high rates. In the correct ecosystem, proper timing and low rates of glyphosate can control medusahead without damaging desirable perennial plants (Kyser, Creech, et al. 2012). Fall applications of aminopyralid at high rates have been shown to prevent medusahead germination throughout the season (Kyser, Peterson, et al. 2012).

### *Barb Goatgrass*

Barb goatgrass was first identified in California in the early 1900s, but it has spread rapidly in recent years. Barb goatgrass grows in dense stands supported by deep and rapidly establishing root systems that make it extremely competitive in annual rangelands. Davy et al. (2008) reviewed the biology and ecology of barb goatgrass, as well as control methods. Fire can be an effective method of control if repeated for 2 consecutive years (DiTomaso et al. 2001). While no grass-selective herbicides are registered for rangelands in California, glyphosate is a practical and effective method for controlling selected patches. Mowing and grazing can be effective if heavy defoliation is applied just prior to seed head emergence.

Invasive plants cause serious ecological damage to California's wildlands, and successfully addressing this widespread problem requires an integrated approach. Effective control will require long-term management using combinations of biological, mechanical, cultural, and chemical methods (DiTomaso 2000). Integrated management may incorporate specific sequences of practices and approaches, including targeted grazing and permanent changes in grazing practices. Successful control will also require cooperation of private landowners and public agencies working within organized weed control areas.

### *Klamath Weed*

Klamath weed is not considered a large rangeland weed problem because its control in the 1940s was so successful. The importation in 1944 of *Chrysolina quadrigemina* and its close relative, *C. hyperici*, was the first North American attempt at controlling weeds with insects. The insects are natural enemies of Klamath weed, also known as St. John's wort. This native European plant is a pest on rangelands throughout the temperate regions of the world because it displaces forage plants and is toxic to cattle and sheep. In 1943 it was estimated that 400,000 acres of California rangelands were infested with Klamath weed.

The beetles *Chrysolina hyperici* and *C. quadrigemina* were first released in 1945 and 1946, respectively. Both species became established, but *C. quadrigemina* proved especially effective for Klamath weed control. Populations of the beetles quickly grew and spread. After 5 years, millions were collected from original release sites for redistribution throughout the Pacific Northwest. Ten years after the first releases, Klamath weed populations in California were reduced to less than 1 percent of their original size (Huffaker and Kennett 1959), and the weed no longer threatens the livestock industry. From 1953 to 1959 alone, California saved an estimated $3,500,000 per year due to this biological control program (DeBach and Rosen 1991).

## Rangeland Seeding

Seeding of improved forage species has been the primary means of improving productivity of annual grasslands and cleared or thinned oak woodlands and chaparral. Introduction of annual legumes and perennial grasses from the Mediterranean region, often by way of Australian forage improvement programs, has been an integral part of range improvement programs. Subterranean clover was introduced from Australia in the 1930s. Rose clover was introduced in the 1940s by Professor R. Merton Love of the Agronomy and Range Science Department (a legacy department of the current UC Davis Plant Sciences Department). Smilograss *(Oryzopsis milliacea)*, an Asian native grass, was introduced from New Zealand by Drs. E. W. Hilgard and E. J. Wickson in 1878. Hardinggrass was introduced from Australia by Dr. P. B. Kennedy shortly after his arrival at UC Berkeley in 1912. Later, summer-dormant orchard grasses and summer-dormant tall fescue were introduced for rangeland seeding. Bur clover *(Medicago polymorpha)* is an annual medic that was introduced during European colonization of California. In the 1950s and 60s, it was joined by other annual medics (*Medicago* spp.) from Australian breeding programs. Lana vetch was introduced for rangeland seeding in the 1950s by USDA Soil Conservation Service (now USDA Natural Resources Conservation Service).

## Annual Legumes

Seeding of rose clover (fig. 9) and subterranean clover to improve productivity on Mediterranean-type rangelands began in the 1950s. The primary effect of annual legumes on annual rangeland productivity is to increase winter and spring forage production and to improve the nutritional quality of the available forage. Table 1 compares protein and crude fiber content of legumes, grasses, and other forbs. Gains of 150 to 300 pounds of beef per acre can be consistently produced on annual legume–improved ranges. In "good clover years," this type of production is possible on clover alone. However, since good clover years do not occur every year, the introduction of annual legumes, including subterranean clover, rose clover, and annual medics is recommended. Maximum profit per acre results from paying careful attention to adequate soil fertility, seeding adapted varieties, ensuring proper inoculation at planting, and providing good grazing management.

**Figure 9.** Bill Weitkamp, farm advisor, checking a rose clover seeding.

**Table 1.** Crude protein and crude fiber content of annual grasses, filaree, and bur clover at seven stages of maturity

| Stage of maturity | Crude protein (%) | | | Crude fiber % | | |
|---|---|---|---|---|---|---|
| | Annual grass | Filaree | Bur clover | Annual grass | Filaree | Bur clover |
| early vegetative | 18 | 27 | 28 | 24 | 12 | 16 |
| late vegetative | 15 | 25 | 27 | 25 | 14 | 17 |
| early flowering | 15 | 22 | 26 | 26 | 16 | 19 |
| late flowering | 10 | 16 | 22 | 29 | 21 | 23 |
| mature | 6 | 10 | 19 | 33 | 26 | 26 |
| dry | 5 | 7 | 18 | 34 | 28 | 28 |
| dry, leached | 3 | 5 | 17 | 35 | 30 | 29 |

### *Adaptation*

Subterranean clover, rose clover, lana vetch, and the annual medics are adapted to annual rangelands where elevations are below 3,000 feet and rainfall exceeds 15 inches. Rose and subterranean clover are most commonly used and grow well together on neutral to acid soils. The annual medics tend to be best adapted to neutral to basic soils. Several varieties of annual clovers and annual medics mature over a wide range of dates from very early to very late spring (table 2). Some subclovers are adapted to wet or poorly drained soils. Most fields to be seeded contain a variety of soils, so the seeding mixture should contain several varieties and types of clover. It should include both early- and late-maturing varieties that are adapted to a variety of sites to ensure good forage growth during very dry winters or springs, as well as under "normal" conditions. Following is an example of a seeding recommendation from Tehama County in 2013:

| Variety of clover | Seeding rate (lb/ac) |
|---|---|
| Hykon rose clover | 3–4 |
| Losa subterranean clover | 3–4 |
| Campeda subterranean clover | 3–4 |
| Antas subterranean clover | 3–4 |
| Total | 12–16 |

## Ewe Fertility and Subterranean Clover

Certain subclover varieties have high estrogen concentrations. Estrogen compounds (especially formononetin) in the leaves reduce the fertility of ewes grazing this forage. Most of the varieties currently used in California are low in estrogen (see table 2) Large amounts of estrogen in the forage may be harmful to sheep, but cattle and goats seem unaffected by these estrogenic compounds.

## Subterranean Clover Flowering Dates

Subclover selection and breeding programs in Australia have produced a wide selection of varieties. One of the main differences between strains is the length of time required for the plant to produce seed, which may be as much as 60 days between the earliest and latest strains. This makes it possible to find strains adapted to a wide range of rainfall zones. Early-flowering varieties are adapted to low-rainfall zones with short growing seasons, and they can be used across a range of rainfall amounts and season lengths. Later-flowering varieties require a longer growing season and may not do well in low-rainfall zones with short growing seasons.

**Table 2.** Annual legumes recommended for seeding on annual rangelands

**Subterranean clovers**

| Variety | Minimum rainfall *inches* | Flower date | Estrogen level | Hard seed content | Number of seeds *per lb (1,000)* |
|---|---|---|---|---|---|
| **Early season varieties** | | | | | |
| Losa | 10 | early March | low | high | 65 |
| Nungarin | 10 | late February | low | very high | 65 |
| Northam | 10 | early March | low | high | 70 |
| Geraldton | 10 | early March | high | medium | 85 |
| **Early midseason varieties** | | | | | |
| Daliak | 12 | mid-March | low | medium | 80 |
| Yarloop | 18 | mid-March | very high | medium | 60 |
| Seaton Park | 18 | mid-March | low | medium | 65 |
| Trikkala | 18 | mid-March | low | low | 50 |
| **Midseason varieties** | | | | | |
| Antas | 18 | early April | low | moderate | 50 |
| Campeda | 20 | early April | low | high | 55–60 |
| Dinniup | 18 | late March | very high | high | 85 |
| Esperance | 20 | early April | low | medium | 70 |
| Woogenellup | 20 | early April | low | low | 60 |
| Howard | 20 | early April | high | low | 60–80 |
| Clare | 20 | early April | low | very low | 70 |
| **Late season varieties** | | | | | |
| Mt Barker | 25 | late April | low | very low | 70 |
| Larissa | 25 | late April | low | low | 60 |
| Nangella | 30 | late April | low | very low | 70 |
| Tallarook | 35 | early May | high | very low | 60 |

**Annual medics**

| Variety | Minimum rainfall *inches* | Flower date | Estrogen level | Hard seed content | Number of seeds *per lb (1,000)* |
|---|---|---|---|---|---|
| Bur | 10 | February | N/A | high | 145 |
| Harbinger | 10 | January | N/A | high | 190 |
| Hannaford | 10 | February | N/A | high | 110 |
| Jemalong | 10 | February | N/A | high | 110 |

**Rose clovers**

| Variety | Minimum rainfall *inches* | Flower date | Estrogen level | Hard seed content | Number of seeds *per lb (1,000)* |
|---|---|---|---|---|---|
| Olympus | 10 | February | low | very high | 155 |
| Hykon | 12 | February | low | very high | 135 |
| Kondinin | 12 | March | low | very high | 165 |
| Wilton | 15 | April | low | very high | 160 |

**Crimson clover**

| Variety | Minimum rainfall *inches* | Flower date | Estrogen level | Hard seed content | Number of seeds *per lb (1,000)* |
|---|---|---|---|---|---|
| Crimson clover | 15 | March | N/A | high | 140 |

### *Seeding and Fertilization*

Murphy et al. (1973) published guidelines for planting and managing annual legume seedings. Most lands planted to annual legumes are deficient in either sulfur or phosphorus, or both, so that adequate amounts are required to produce a good initial stand and to maintain maximum forage and seed production. While there may be a carryover effect the year after fertilization, especially from phosphorus applications, maintenance fertilization is necessary to maintain clover stands and productivity.

Clovers need to grow in association with certain soil bacteria *(Rhizobium)* to provide the nitrogen they need for growth (Holland et al. 1969). In most areas these required strains of bacteria are not present in the soil and must be furnished by inoculating the seed with the right bacteria at seeding time. Well-inoculated clovers supply extra nitrogen to make the associated grasses more productive. The pellet method of inoculation is recommended.

Some seedbed preparation is often necessary to reduce competition, ensure the survival of rhizobium bacteria, and provide for seed coverage; however, direct seeding in low residue has been successful in many locations. Seed can be broadcast or drilled, but it should be covered by about 0.5 inch of soil. Seeds may not emerge if they are placed deeper. Seeding rates are often around 10 to 20 pounds/acre. A broadcast seeding should be lightly covered by ring rolling or harrowing. Broadcast seedings that are not covered are highly susceptible to failure in marginal rainfall areas. Range drills (fig. 10) are sometimes available from area seed companies. Seeding should be done as close to the first fall rain as possible and before cold weather. Fall seedings in October and early November are much more successful than December seedings. If germinating rains do not come before cold weather, delay seeding until the following year.

**Figure 10.** A rangeland drill seeding in an oak woodland following woody plant control.

### *Grazing Management*

Legumes stimulate the early growth of grasses and filaree. In the winter and early spring, seeded ranges should be grazed to use the grass and prevent nonlegumes from crowding the clovers. Reducing grazing while clover is blooming will allow an adequate seed set. Stands should be heavily grazed during the summer and fall to make use of the dry feed and to trample the seed into the ground. More stands of clovers have been lost by grazing too light than by heavy grazing.

## Annual Grasses

Annual ryegrass is the main improved annual forage grass used on annual rangelands. With proper fertilization it can provide high-quality forage during the growing season, and it remains an important species for improving forage quantity and quality. Annual ryegrass germinates rapidly and is able to quickly stabilize soils following burns and other disturbances. Unfortunately, this characteristic also makes annual ryegrass a strong competitor to native species. Consequently, it has been listed as an invasive non-native plant that threatens wildlands by the California Invasive Species Council. If your goal is to maintain and increase native grasses and forbs, excluding annual ryegrass is a legitimate management practice. However, if you need to stabilize soil quickly or you are seeking improved forage, seeding annual ryegrass remains an important agricultural practice.

Like annual legumes, annual grasses should be seeded just prior to the fall rains. Annual grass seeds are small and should not be buried too deep when seeding. Seed can be broadcast or drilled, but it should be covered by about 0.5 inch of soil. Seeds may not emerge if they are placed deeper. It has generally been recommended that seed be drilled with a grassland or rangeland drill into existing but closely grazed stubble from the previous growing season. If a drill is not available, the soil should be lightly disked or harrowed to loosen the top 1 inch of soil and seed broadcast on the soil surface. Broadcasting should be followed by light rolling or dragging to cover the seed. Annual grass seeding rates are frequently about 5 to 10 pounds/acre.

Blando brome (soft chess brome, *Bromus hordeaceus*) and Zorro fescue (annual fescue, *Vulpia myuros*) are also available for seeding for erosion control. Soft chess brome is a desirable forage species that is naturalized and widespread on annual rangelands. Annual fescue is widespread but not desirable for improving forage. Both of these grasses were selected from wild populations and developed into commercial varieties by the USDA NRCS Plant Materials Center.

### Perennial Grasses

Seeding native or introduced perennial grasses into annual rangelands has always been challenging, with failure being more frequent than success. Competition from annual grasses and forbs during seedling establishment is a major source of failure, but improper grazing of successful seedings has also been a source of stand loss. The primary reasons that ranchers have seeded perennial grasses on annual rangelands is to provide a higher amount of winter feed and green feed several weeks later in the season than the naturalized annual grasses and forbs. Hardinggrass and some other perennial grasses have the ability to break summer dormancy and begin growth before the first fall rains and remain green until after seed has matured in early summer. This can add several weeks to the green forage season. However, when seedings are successful, establishment sometimes takes 3 to 5 years before perennial grasses are able to compete with annual grasses. Consequently, perennial grass seedings have not been widespread on annual rangelands, with most success being along the high-rainfall north coast.

From 1937 to 1951, the University of California Extension Service and Agricultural Experiment Station planted thousands of test plots to determine what grasses were adapted to seeding following brush burns and other woody plant control. Planting methods and seeding recommendations were developed for the annual rangelands and intermountain areas where rainfall exceeded 10 inches (Love et al. 1952). Hardinggrass was seeded in many counties, and remnants of those plantings can still be found. However, McKell et al. (1966) found that grazing during active growth reduced yields and increased mortality. Likewise, ranch managers have reported low persistence of grazed stands in all but the very best soils. Kay (1960) found that Hardinggrass tolerates fire, making it a good candidate for erosion control. However, the California Invasive Plant Council has listed Hardinggrass as an invasive, non-native plant that threatens wildlands. In the 1960s, summer-dormant orchard grass did well in many test plots around the state and became part of perennial grass seeding recommendations. Several other grasses, including smilograss, tall wheatgrass *(Agropyron elongatum)*, and mission veldtgrass *(Ehrharta calycina)*, were also recommended. Recent releases of summer-dormant tall fescue varieties are currently showing promise as a companion with summer-dormant orchard grass.

Except for poor rainfall years, weed management prior to sowing perennial grasses is the greatest factor for successful establishment. Annual grass competition during establishment of perennial grasses can cause complete failures of perennial grass seedings. Following is an example of a timeline for seeding perennial grasses and managing established stands on soils that are not highly compacted and do not require deep tillage:

1. Apply a nonselective herbicide such as glyphosate in early spring the year before planting to control all weeds.
2. Wait for the first fall germination, and again spray a nonselective herbicide such as glyphosate.
3. Drill seed immediately after spraying in the fall at less than ¼ inch in depth.
4. Using a broadleaf selective herbicide such as 2,4-D, control broadleaf weeds in early spring after planting.
5. Defer grazing until the new seeding is fully established and cannot be pulled from the ground, which is usually the second or third year after planting, depending on rainfall during establishment.

6. Planting annual legumes in the same manner as described above, once the perennial grasses are established, can be used as a long-term method of providing nitrogen.
7. To maintain the established stand, grazing is best deferred in the fall, grazed from winter to midspring, deferred from grazing in late spring, and grazed again in the summer. As with perennial grasses in irrigated pastures, plants should not be grazed to a height low enough to damage the crown, as this will limit future production and stand life.

Native grasses, especially California needlegrass *(Nasella pulchra)*, were tested along with the introduced perennial grasses and are included in the recommendations by Love et al. (1952). Restoration of native grasses has been a recurring objective of range managers on California's annual rangelands (Kay et al. 1981; George et al. 1992) since the 1940s. The goal of restoring grasslands and woodland understories to some presettlement condition has proven to be unrealistic, because not only is there uncertainty about the historical composition and extent of California native grasslands, but restoration failure is common. Rangeland and restoration scientists have tried to restore native grasses but have not found dependable native grass restoration practices for use on land that is steep, rocky, or highly eroded. Competition from naturalized annual grasses and forbs remains a major barrier to native grass restoration. Season-long heavy grazing has also resulted in poor stand survival. Proper grazing of perennial grass stands is discussed in the eighth publication of this series, "Grazing Management." On arable land, native grasses can be grown for seed and pasture following standard crop production practices. Scientists continue to seek practices to control the annuals and promote native perennials.

## FERTILIZATION OF NONSEEDED ANNUAL RANGELAND

### Why Fertilize

Annual rangeland soils without legumes are nitrogen (N) deficient (Jones 1974; Jones and Woodmansee 1979). To increase winter forage and total production, nitrogen must be added by a legume or nitrogen fertilization. Phosphorus (P) and sulfur (S) deficiencies are also widespread. In some areas, molybdenum deficiencies are quite common. Deficiencies of potassium, boron, and lime occur on acid soils but are not widespread. Usually these latter deficiencies become evident only after adequate amounts of phosphorus and sulfur have been applied on legume pastures. In the 1950s and 60s, the effects of nitrogen, phosphorus, and sulfur on forage production were estimated on several annual rangeland soil series using greenhouse pot studies (table 3) as well as field plots (tables 4 and 5). These studies showed that most soil series responded to phosphorus and/or sulfur as well as nitrogen.

**Table 3.** Yields (g) from Soil-Vegetation Project fertilizer pot studies in the 1950s and 1960s

| Soil series | County | Fertilizer treatments | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ck | S | P | PS | N | NS | NP | NPS |
| Auburn | Shasta | 5.4 | 7.2 | 8.8 | 8.6 | 9.2 | 11.0 | 24.0 | 29.8 |
| Auburn | Shasta | 7.5 | 8.8 | 11.8 | 12.0 | 14.8 | 18.2 | 34.5 | 38.8 |
| Kinman | Humboldt | 18.5 | 25.2 | 24.8 | 27.0 | 28.5 | 36.5 | 37.8 | 43.8 |
| Kneeland 1 | Humboldt | 12.7 | — | 18.7 | — | 25.2 | 25.0 | 45.0 | 51.5 |
| Kneeland 2 | Humboldt | 23.5 | — | 33.7 | — | 24.0 | 24.0 | 71.2 | 75.0 |
| Kneeland 3 | Humboldt | 16.2 | — | 18.7 | — | 36.5 | 40.0 | 37.0 | 47.7 |
| Laughlin | Mendocino | 68.8 | 37.0 | 105.5 | 115.5 | 54.8 | 38.8 | 236.8 | 259.8 |

*Notes:* Ck = no fertilizer (control)
P = 88 lb/ac of phosphorus in triple superphosphate
S = 100 lb/ac of sulfur in gypsum
N = 160 lb/ac of nitrogen in urea

*Continued on next page*

**Table 3.** Yields (g) from Soil-Vegetation Project fertilizer pot studies in the 1950s and 1960s, continued

| Soil series | County | Fertilizer treatments | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ck | S | P | PS | N | NS | NP | NPS |
| Lodo | Tehema | 10.6 | 10.8 | 12.0 | 11.6 | 32.6 | 39.2 | 45.6 | 48.8 |
| Lodo | Tehema | 10.5 | — | 11.2 | — | 28.8 | 36.8 | 29.0 | 38.0 |
| Lodo | Tehema | 7.5 | — | 8.0 | — | 27.0 | 32.2 | 26.5 | 37.5 |
| Lodo | Tehema | 4.8 | — | 4.8 | — | 17.5 | 21.0 | 22.8 | 33.2 |
| Los Gatos | Shasta | 14.0 | — | 13.8 | — | 21.5 | — | 40.3 | 51.5 |
| Mattole 1 | Humboldt | 9.8 | — | 9.5 | — | 32.8 | 30.5 | 59.8 | 56.5 |
| Mattole 2 | Humboldt | 13.0 | — | 16.0 | — | 25.8 | 20.2 | 58.8 | 58.0 |
| Mattole 3 | Humboldt | 19.2 | — | 18.5 | — | 33.2 | 33.0 | 52.2 | 56.2 |
| McMahon | Humboldt | 14.0 | — | 16.0 | — | 44.5 | 46.2 | 77.0 | 79.0 |
| McMahon | Humboldt | 19.2 | — | 34.8 | — | 26.0 | 52.0 | 53.0 | 57.0 |
| McMahon | Humboldt | 18.4 | 15.6 | 17.0 | 20.6 | 34.2 | 34.8 | 55.6 | 70.2 |
| Millsap | Glenn | 13.5 | — | 14.5 | — | 59.2 | 62.2 | 65.2 | 73.2 |
| Millsap | Glenn | 23.5 | — | 24.2 | — | 52.2 | 64.2 | 59.0 | 59.0 |
| Millsap | Glenn | 7.5 | — | 7.5 | — | 16.0 | 19.5 | 19.0 | 32.0 |
| Millsholm | Glenn | 9.7 | — | 13.5 | — | 70.0 | 78.2 | 89.8 | 81.2 |
| Millsholm | Glenn | 27.5 | 25.7 | 26.2 | 19.2 | 66.5 | 63.5 | 75.8 | 69.8 |
| Nacimiento | Tehema | 15.2 | — | 14.2 | — | 38.8 | 25.5 | 51.8 | 64.2 |
| Sehorn A | Glenn | 13.5 | 14.5 | 11.8 | 12.5 | 35.0 | 34.2 | 40.8 | 30.8 |
| Sehorn B | Glenn | 14.8 | 11.8 | 12.8 | 22.0 | 31.0 | 34.8 | 42.0 | 36.5 |
| Sierra | Shasta | 6.8 | 6.2 | 8.8 | 10.6 | 1.6 | 8.4 | 36.0 | 42.0 |
| Toomes | Tehema | 33.2 | 35.2 | 33.0 | 36.8 | 64.8 | 64.2 | 71.2 | 56.8 |
| Toomes | Tehema | 3.8 | 5.4 | 13.2 | 11.6 | 1.2 | 2.6 | 18.4 | 8.2 |
| Tyson | Humboldt | 20.2 | 27.0 | 27.0 | 26.0 | 34.2 | 45.2 | 29.2 | 57.5 |

*Notes:* Ck = no fertilizer (control)
P = 88 lb/ac of phosphorus in triple superphosphate
S = 100 lb/ac of sulfur in gypsum
N = 160 lb/ac of nitrogen in urea

**Table 4.** Yields (lb/ac) from Soil-Vegetation Project plot studies of fertilizer rates in the 1950s and 1960s

| Soil series | County | Fertilizer treatments | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N0-P0-S0 | N0-P0-S100 | N0-P200-S0 | N0-P200-S100 | N150-P0-S0 | N150-P200-S0 | N150-P0-S100 | N150-P200-S100 |
| Argonaut | Amador | 5,568 | 5,484 | 6,432 | 5,964 | 7,026 | 7,728 | 6,732 | 6,246 |
| Auburn | Butte | 2,682 | 2,562 | 3,192 | 2,832 | 3,942 | 4,818 | 4,212 | 5,220 |
| Kneeland | Humboldt | 1,536 | 1,344 | 1,632 | 1,752 | 1,560 | 1,800 | 936 | 1,752 |
| Laughlin | Humboldt | 910 | 914 | 1,346 | 1,008 | 2,995 | 2,988 | 2,954 | 3,338 |
| Millsap | Glenn | 709 | 894 | 916 | 980 | 2,951 | 4,693 | 5,368 | 5,380 |
| Millsholm | Glenn | 1,264 | 2,058 | 1,974 | 2,704 | 3,386 | 4,938 | 5,158 | 5,878 |
| Newville | Glenn | 366 | 365 | 337 | 296 | 848 | 1,050 | 1,148 | 864 |
| Sehorn | Glenn | 2,540 | 3,040 | 3,010 | 3,200 | 5,040 | 5,610 | 5,400 | 5,900 |
| Sehorn | Glenn | 2,168 | 2,992 | 3,536 | 4,704 | 4,150 | 5,786 | 5,386 | 6,342 |
| Sierra | Yuba | 1,290 | 1,338 | 1,770 | 1,506 | 2,412 | 3,384 | 2,772 | 3,492 |
| Yorkville | Humboldt | 159 | 153 | 178 | 154 | 194 | 267 | 237 | 231 |
| Yorkville | Humboldt | 1,090 | 578 | 893 | 1,358 | 2,280 | 2,035 | 2,515 | 2,654 |

**Table 5.** Yields (lb/ac) from Soil-Vegetation Project fertilizer plot studies in the 1950s and 1960s

| Soil series | County | Fertilizer treatments | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ck | S | P | PS | N | NS | NP | NPS |
| Gaviota | Shasta | 3,568 | 3,224 | 2,664 | 3,624 | 3,336 | 3,752 | 3,008 | 4,256 |
| Guenoc | Shasta | 622 | 509 | 1,315 | 1,154 | 1,142 | 1,185 | 3,379 | 3,708 |
| McMahon | Humboldt | 2,907 | 2,290 | 3,708 | 3,265 | 2,583 | 4,177 | 5,684 | 4,640 |
| Millsholm | Glenn | 1,686 | 1,498 | 1,018 | 2,214 | 1,792 | 1,904 | 2,125 | 2,214 |
| Sehorn | Glenn | 1,572 | 1,404 | 1,652 | 1,614 | 3,750 | 6,438 | 5,634 | 6,222 |
| Sehorn | Glenn | 1,597 | 2,246 | 1,814 | 2,637 | 1,709 | 2,160 | 1,709 | 2,272 |
| Sehorn | Glenn | 1,572 | 1,404 | 1,652 | 1,614 | 3,750 | 6,438 | 5,634 | 6,222 |
| Sehorn | Tehema | 2,540 | 3,040 | 3,010 | 3,200 | 5,040 | 5,400 | 5,610 | 5,900 |
| Toomes | Shasta | 462 | 696 | 828 | 426 | 1,068 | 978 | 1,386 | 1,518 |

*Notes:* Ck = no fertilizer (control) S = 100 lb/ac of sulfur in gypsum P = 88 lb/ac of phosphorus in triple superphosphate N = 160 lb/ac of nitrogen in urea

**Table 6.** Comparison of fertilizer costs and returns between 1957 and 2012

| Variables for determining profit from fertilizer use | 1957 | | 2012 | |
|---|---|---|---|---|
| | No fertilizer | N fertilizer | No fertilizer | N fertilizer |
| **Stocking rates:** | | | | |
| Stocking rate (ac/head) | 2.5 | 1.0 | 2.5 | 1.0 |
| Stocking rate (head/ac) | 0.4 | 1.0 | 0.4 | 1.0 |
| **Weight gain:** | | | | |
| Calf ending weight per acre (lb/ac) | 207 | 540 | 207 | 540 |
| Calf beginning weight per acre (lb/ac) | 147 | 370 | 147 | 370 |
| Calf gain (lb/ac) | 60 | 170 | 60 | 170 |
| **Costs:** | | | | |
| Beginning weight cost ($0.2425/lb) | $35.65 | $89.73 | $210.00 | $529.00 |
| Fertilizer cost ($) | | $13.92 | | $46.00 |
| Interest for 124 days at 4% | $0.73 | $2.11 | $2.86 | $7.82 |
| Total costs ($) | $36.37 | $105.76 | $213.07 | $582.92 |
| **Income:** | | | | |
| Ending weight gross income ($0.222/lb) | $45.95 | $120.00 | $257.00 | $670.00 |
| Net income ($/ac) | $9.58 | $14.12 | $43.61 | $86.68 |
| **Profit** | | | | |
| Average profit from fertilizer ($/ac) | | $4.54 | | $43.07 |

For about 15 years in the 1950s and 60s, University of California at Davis researchers studied the effect of nitrogen fertilization on range forage production and animal productivity on 28 ranches in 20 counties (Martin and Berry 1970). When analyzed together, fertilizer effects the first year increased carrying capacity from 38 head days per acre to 92 head days per acre and livestock gains from 60 pounds per acre to 170 pounds per acre. Greater first-year benefits were observed where nitrogen plus sulfur or nitrogen plus phosphorus were required than where only nitrogen was needed. Second-year carryover effects measured at 13 locations were much greater where nitrogen was applied with either sulfur or phosphorus than from nitrogen alone (Martin and Berry 1970; Jones 1974). Table 6 is a comparison of the 1957 costs and returns, reported by Martin and Berry in 1970, with projected costs and returns in 2012. In 2012, fertilizer costs for nitrogen, depending on the formulation, were 2 to 5 times higher than in 1957 and stocker cattle prices were 5 to 6 times higher.

In the mid-1980s, nitrogen was again shown to be beneficial in a large-scale study of the effects of fertilization and legumes on beef production at the UC Sierra Foothill Research and Extension Center, northeast of Marysville, California (Raguse et al. 1988). In this study, nitrogen was applied at 40 and 80 pounds/acre with and without phosphorus and sulfur. Phosphorus and sulfur were applied at two rates with and without nitrogen, phosphorus at 30 and 60 pounds/acre, and sulfur at 33 and 66 pounds/acre. This study showed that animal weight gains were greater with nitrogen than without and that the greatest gains resulted from application of nitrogen, phosphorus, and sulfur. This study also showed that dry matter digestibility was increased.

One of the most important benefits of nitrogen fertilization is that it can substantially increase production during the winter and early spring (fig. 11). This early feed is extremely valuable because it replaces expensive hay or other energy supplements for livestock. For ranchers dependent on annual rangeland for winter and spring feed, the onset of the green season is awaited with great urgency each year. Nitrogen fertilizer can increase winter forage production before the spring flush of growth and effectively replace 2 to 6 weeks of supplemental feeding during the winter. Nitrogen fertilization will also increase spring feed, but this is usually not a forage-short season for the range livestock producer in California.


**Figure 11.** Effect of ammonium sulfate application on annual rangeland.

The decision to apply nitrogen (N) fertilizer to rangeland is based on

- the need to extend the adequate-green forage season by increasing winter forage production
- the need to increase total production and an ability to fully utilize increased feed
- the absence of native or seeded legumes in significant amounts
- average annual rainfall of 12 to 30 inches
- expectation that the site will respond adequately to generate a return on the fertilizer investment
- the desire to invest capital in a short-term improvement or to have the flexibility of a year-to-year decision

If precipitation exceeds 30 inches, the risk of nitrogen loss by leaching is great. An annual legume seeding should be considered instead of nitrogen fertilization on high-rainfall sites. An annual legume seeding has a higher initial cost, but it is frequently less costly than nitrogen fertilization if costs are amortized over the life of the stand. Annual legumes also improve forage quality substantially.

## Weather and Site Productivity

Knowledge of range sites and their forage productivity and response to fertilization is critical in making the decision to fertilize annual rangeland. Productive sites should receive priority for fertilization. Range forage response to fertilization varies with prevailing weather patterns (fig. 12A). During a favorable weather year, above-average forage productivity is further increased by application of nitrogen (fig. 12B). Likewise, low productivity during an unfavorable year can be increased by fertilization but not to the levels expected under favorable weather conditions (fig. 12C). However, the percentage increase may be greater than in a wet year. To properly

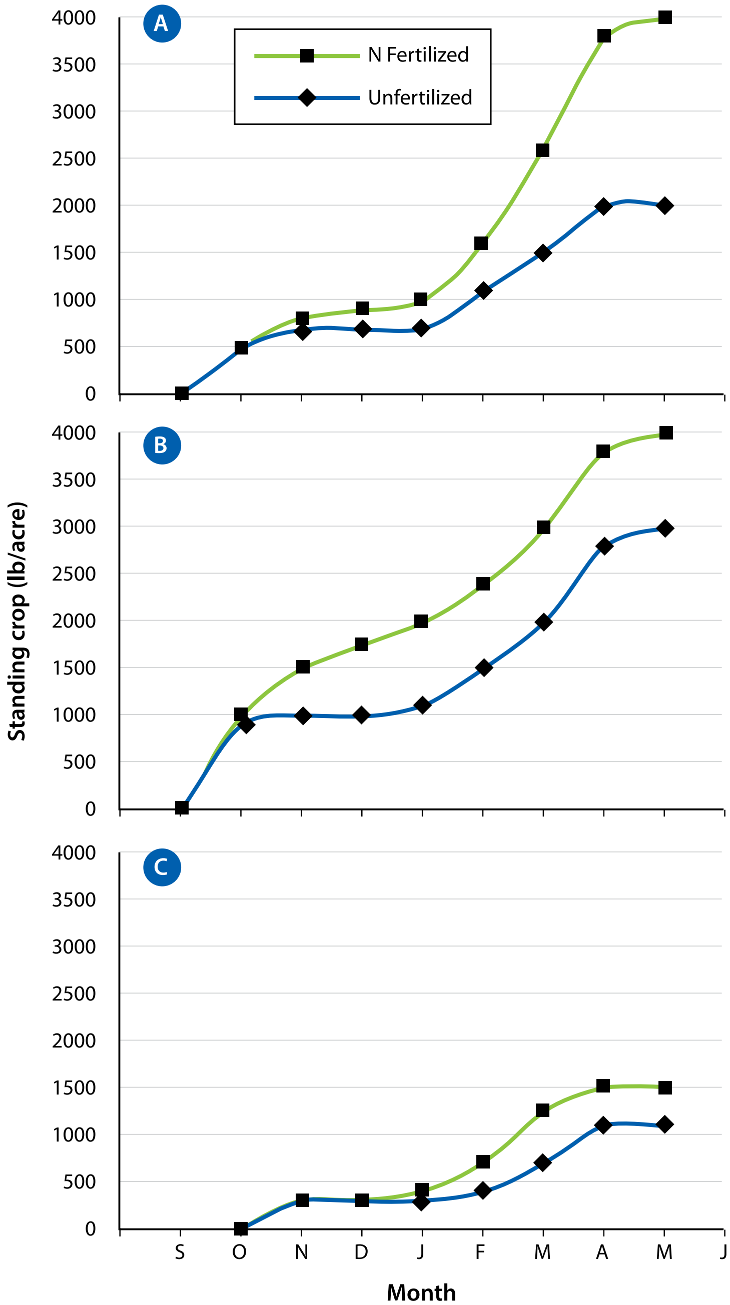


**Figure 12.** Seasonal productivity of fertilized and unfertilized annual range forage during (A) average, (B) favorable, and (C) unfavorable years. Note: These are simulated curves representing an "average range site" and are not the product of a specific study.

**Table 7.** Total forage production and estimated response to nitrogen (N) fertilization on California annual rangeland for a precipitation range of 15 to 30 inches

| Kind of year | Dry matter *(lb/ac)* | Improvement due to N fertilization | |
|---|---|---|---|
| | | Reasonable | Possible |
| Unfavorable year | 1,000 | 1–1½ X | 1½–2 X |
| Average year | 2,000 | 2X | 3–4 X |
| Favorable year | 3,000 | 1–1½ X | 3–5 X |

assess the response to fertilization on a given range site, the site's forage productivity and fertilizer response during a favorable, average, and unfavorable weather year should be estimated to allow the decision maker to better assess fertilization benefits and risks over the range of weather patterns characteristic of California's Mediterranean climate.

A favorable year in terms of forage production can result from fall rains coinciding with warm fall temperatures or from extended warm, wet spring weather. An unfavorable year results when the fall rainy season is delayed or when cold fall temperatures occur earlier than normal. Most years are intermediate to these favorable and unfavorable extremes (see the first publication in this series, "Mediterranean Climate").

Table 7 and fig. 12 illustrate the estimated annual forage production for a favorable, average, and unfavorable year on a range site of average productivity in the California annual rangeland. Included are expected and possible productivity improvements based on numerous fertilizer trials. Tables 8 and 9 show the combined results of 54 grazing trials designed to evaluate the effects of nitrogen fertilization over a 15-year period in 20 counties (Martin and Berry 1970).

Factors other than prevailing weather contribute to the inherent productivity of the range site. Those sites that have inherently low productivities may respond to range improvement, but the response may not be great enough to pay for the cost of improvement. Range fertilization frequently produces a 1½-to-2-fold increase in dry matter production. A site normally averaging 1,500 pounds of dry matter per acre will yield an additional 1,500 pounds from nitrogen fertilization and there is a reasonable chance that this improvement is economically feasible. If the average productivity is only 500 pounds per acre, then the economic feasibility of a 2-fold increase, or 500 additional pounds of forage per acre, is less likely. Range economists often advise ranchers to improve those range sites with the highest potential first. This is good advice except where the lower-potential

**Table 8.** Beef production (lb/ac) response to nitrogen (N) fertilization during wet and dry years compared to the average of 15 years of 54 trials in 20 counties

| Kind of year | Precipitation *(inches)* | Beef production *(lb/ac)* | | | |
|---|---|---|---|---|---|
| | | O | N | NP | NS |
| Unfavorable year (dry) | 12.66 | 47 | 117 | 172 | — |
| Average (1954–1968) | 21.40 | 60 | 140 | 195 | 157 |
| Favorable year (long rainy season) | 26.12 | 66 | 160 | 144 | — |

**Table 9.** Rates of beef production in relation to nitrogen (N) fertilizer applied (lb beef/lb N) during a wet and dry year compared to the average of 15 years of 54 trials in 20 counties

| Kind of year | Precipitation *(inches)* | Lb of beef/lb of N | | |
|---|---|---|---|---|
| | | N | NP | NS |
| Unfavorable year (dry) | 12.66 | 1.1 | 1.7 | — |
| Average (1954–1968) | 21.40 | 1.2 | 2.0 | 1.5 |
| Favorable year (long rainy season) | 26.12 | 1.15 | 1.22 | — |

site improvement has strategic value or an exception is known through past research or experiences.

Additional benefit from nitrogen fertilization may be achieved by using nitrogen application as a method of manipulating livestock utilization of the range. Although it is not widely practiced, it has been shown that use of underutilized range forage can be increased by applying nitrogen and other fertilizers to that forage (George et al. 2007). Once the livestock find this area of application, they seek it out and use it to a greater extent than before it was fertilized. Similarly, it has been shown that the application of nitrogen to weed infestations can increase their utilization. If the utilization of medusahead and immature summer annuals such as yellow starthistle and tarweed is increased and grazing is properly timed, it can reduce flowering and seed set of these weeds.

## Soil and Plant Tissue Testing

With a global shortage of phosphorus fertilizer, single superphosphate and other phosphorus fertilizers are expensive and often unavailable. Thus, range fertilization is infrequent, and soil and plant tissue testing that can help determine the need for phosphorus and sulfur are also infrequent. In the 1970s and 80s, when range fertilization was more common, soil was often tested for phosphorus, and plant tissue was sometimes tested for phosphorus and sulfur. On rangelands it was recommended that soil be sampled to 6 inches with 20 samples composited from each area to be tested. If phosphorus was less than 5 parts per million (ppm), a response to phosphorus application was likely; but if it was more than 10 ppm, a response was unlikely. Critical levels of phosphorus, potassium, and sulfur were established for annual clover tissue testing and have been reviewed by Jones (1978).

### What to Apply

Ammonium sulfate (21-0-0-24S), ammonium phosphate sulfate (16-20-0-13S), and urea (40-0-0) are most frequently applied on annual rangeland. Ammonium sulfate is frequently used because sulfur deficiencies are widespread on annual rangeland, and it is less expensive than 16-20-0 containing both sulfur and phosphorus. Where sulfur and/or phosphorus are deficient, application of these nutrients should be considered. When the soil contains adequate levels of phosphorus and sulfur, urea may be used. Nitrate nitrogen tends to leach too rapidly, and it is often lost early in the first year before it can be utilized by the forage plants. Although urea is an inexpensive nitrogen source, volatility losses can reduce its effectiveness if soil pH is greater than 7 and if applied too early in the fall when soil temperatures are still high. To avoid volatilization, rainfall in excess of ¼ inch is necessary for urea soil incorporation, and greater than ½ inch is desired. A worst-case scenario is an early fall rain of less than ¼ inch that breaks down the prills but does not carry the urea into the soil. Chicken manure and other manures can be satisfactory sources of nitrogen where transportation and spreading costs do not prohibit their use. Manures are longer-lasting nitrogen sources because the nitrogen is released slowly as the organic matter decomposes. Soil and tissue testing (see sidebar) can help to answer the question of what nutrients to apply in addition to nitrogen. Commercial agricultural testing laboratories can conduct needed soil and plant tissue tests at very low costs.

### When to Apply

In the 12-to-30-inch rainfall zone, nitrogen is generally applied in the fall to lengthen the green feed period by increasing winter growth. The amount and distribution of rainfall, as well as temperature, are principal factors governing the timing of application. Nitrogen is not profitable in central and southern California, where annual rainfall is less than 12 inches annually, because reduced soil moisture restricts plant growth and response to fertilizers.

Research at the Hopland Field Station, where nitrogen was applied monthly from September through January in a 36-inch rainfall zone, showed that the earlier nitrogen was applied in the fall, the greater the winter forage growth (Jones 1960). Total forage as measured at the end of the growing season was not affected by the time of application unless the application was made after February. Nitrogen is generally not recommended where rainfall is greater than 30 inches, since leaching losses are high. Denitrification can contribute to nitrogen losses, especially on poorly drained soils that are saturated for extended periods.

Winter temperatures averaging much below 50°F severely limit responses to nitrogen fertilization. Daily mean temperatures below this limit are common in northern California and Oregon during the months of December, January, and February. Therefore, nitrogen should be applied before the first autumn rains when mean temperatures are 50°F or more. Lack of response in cold weather is mainly a simple restriction of plant growth, but nitrogen-fertilized grass often is less damaged by frost and appears to recover faster than nitrogen-deficient grass. Nitrogen should not be applied to ground covered in snow, as much of the snow may be lost to evaporation along with the applied fertilizer.

### How Much to Apply

Generally, a good forage response is gained from applying between 40 and 80 pounds/acre of nitrogen. To apply 80 pounds of nitrogen would require application of approximately 400 pounds of ammonium sulfate or 160 pounds of urea. The variation in recommendations between counties is a reflection of year and range site differences, especially annual variation in amount and distribution of precipitation. How much nitrogen to apply has been a continuing question and the subject of numerous fertilizer trials. Rates of nitrogen up to 200 pounds/acre have been applied and forage or animal yield measured.

Production functions for nitrogen fertilization follow the law of diminishing returns. Therefore, beyond a certain level, each additional increment of fertilizer will give less production than the previous increment. The point of diminishing returns is where the return equals the cost of the added increment. On California annual rangelands, this point is commonly in the range of 40 and 80 pounds/acre, and it will vary within this range due to seasonal and yearly variations in weather. Lower rates seldom yield adequate forage production to justify the expense.

### How Often to Apply

Traditionally, nitrogen applications have been made in the fall near the time of the first rains. In regions of high rainfall and where heavy winter grazing has occurred, the forage may become extremely nitrogen deficient in the spring, even though nitrogen was applied the previous fall. Under these circumstances, spring applications of nitrogen fertilizer may be beneficial, but this practice has not been adequately evaluated on annual rangelands.

Where rainfall is not great enough to leach all of the fertilizer nitrogen out of the soil, and plant nitrogen uptake is insufficient to use all of the fertilizer nitrogen, there may be a carryover response to nitrogen fertilization during the next growing season. In the 1950s, many grazing trials were conducted to demonstrate the response of range livestock gains to range nitrogen fertilization. Carryover effects were assessed in 13 of the tests. In all but one test there was an appreciable carryover effect from fertilization, the additional gain being equivalent to about 50 percent of the first-year effects on the average. Part of the gains in these studies should be credited to the phosphorus and sulfur also applied, but the amount of credit to be given cannot be determined with the available data. Without applied nitrogen or a good stand of legumes, there is usually no response to phosphorus or sulfur on annual rangelands of California.

### How to Apply

Fertilizer can be applied from the ground or by aircraft. Large, inaccessible, rough, and rocky ranges are usually fertilized by aircraft. Fertilizer application equipment and tractors are usually restricted to use on rangeland where slopes are less than 20 to 30 percent and the surface is relatively free of rocks or other obstructions to the equipment. The analysis of range sites on a given ranch during a range management planning process will help to identify those areas that can be treated from the ground and those that must be treated from the air.

### Forage Quality

Fall nitrogen fertilization generally increases the protein content in annual grasses and broad-leaved forbs early in the growing season. However, an increase in protein in winter is not beneficial, since there is typically adequate protein for animal needs in unfertilized pasture at that time of year. The primary benefit from nitrogen in the early part of the season is an increase in dry matter production. As the season advances, the protein levels may decrease more rapidly in plants fertilized at moderate nitrogen levels than in those not fertilized. As a result, at the end of the growing season fertilized plants are often lower in protein than are unfertilized plants. Exceptions may occur in very dry spring seasons when moisture becomes limiting and plants are unable to grow to their full potential, thus drying up before growth dilutes the nitrogen (protein) to a low level.

Yearly application of nitrogen generally increases the percentage of grasses and forbs. The particular grasses or forbs that increase will depend upon the grazing or clipping management of the pasture in question. For example, slender wild oats *(Avena barbata)* or ripgut brome *(Bromus diandrus)* often become dominant where nitrogen fertilizer is applied to ungrazed plots. In similarly treated plots that are heavily grazed, soft chess may become dominant. This is due to the greater tillering ability of soft chess when grazed as compared to wild oats or ripgut, which tiller poorly. Moderate to heavy grazing pressure tends to reduce the impact of fertilizer on botanical composition.

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