CHAPTER 16

Brush and Weed Control on Range and Pastures

Approximately half of the total land area of the United States is used for pasture and grazing purposes, and weeds and brush are a problem on nearly all these forage lands. Economic losses from weeds on forage lands are virtually incalculable and include low yield of forage and animal products per unit area, reduced livestock gains, and livestock poisoning.

Tremendous weed problems have been created on grazing lands by the introduction of exotic plant species or the shift of nonforage native species to positions of major importance. Changes in the vegetation communities of vast areas of range and noncropland are constantly occurring through the influences of grazing practices, cultural manipulations, plant introductions, diseases, insects, various other fauna, and many other environmental factors. In areas where vegetation is disturbed or removed, the species remaining or introduced tend to increase and become dominant.

Trends toward dominance by weeds can be halted or changed by judicious use of mechanical and chemical control methods, introduction of new forage-plant species, fertilization, and control of the kinds and numbers of grazing animals and their seasons of use. Because of factors such as climate, native animal life, plant species, and soil depletion or erosion, some ranges do not respond readily to improvement measures. Nevertheless, many forage lands can be made more productive by present techniques, which almost always will include some form of weed control.

Unfortunately, efforts directed at correcting weed and brush problems of forage lands have been minimal. Almost every year there is an increase in the scope of the problem. While future research undoubtedly will improve control methods, we already know enough to be doing far more in this field.

BRUSH AND WEED CONTROL ON RANGELANDS

Although herbaceous weeds are found on all rangelands in the United States and result in forage losses, brush is the primary problem. Various brush species dominate an estimated 320-million acres of grazing land. Problem areas include 70-million acres of mesquite (*Prosopis* spp.), 75-million acres of juniper (*Juniperus* spp.), and 96-million acres of sagebrush (*Artemisia* spp.). More than 80 percent of 107-million acres of grazing land in Texas alone is infested to some extent with brush.

Most brush cover is native vegetation that has invaded large areas of former grasslands and savannas, converting them into brushlands and woodlands. Originally, woody plants were present as a lesser component of the climax vegetation of North American grazing lands. Some authorities believe that in early times repeated fires kept grasslands relatively free of woody plants. During those times, less-intensive utilization of forage permitted enough grass to accumulate to serve as fuel for the intense fires that killed young trees and shrubs. After settlement of the frontier, intensive grazing steadily reduced the available fuel. More recently, man has largely excluded fire from rangelands. Deterioration of ranges has resulted in accelerated invasion by undesirable brush. For example, mesquite dominated only 5 percent of a southern New Mexico range before 1858, but had taken over 50 percent of the range by 1963; tarbrush occupied less than 1 percent of that area in 1858 and 9 percent in 1963. Today, brush invasion of grazing lands annually exceeds the acreage on which control measures are applied.

MANAGEMENT PRINCIPLES FOR BRUSH CONTROL

Sound management principles are essential to the use of any control method on brush-infested rangeland. Once established, woody plants such as mesquite, juniper, oak (*Quercus* spp.), and sagebrush cannot be eliminated by good grazing practices alone. Measures must be taken to convert brush-dominated rangeland to more productive types of vegetation. Brush control must be combined with other practices favorable to forage production that will alter the direction of successional trends.

Careful consideration should be given to selecting methods that are most effective for a particular range and its specific vegetation. A satisfactory management approach to one site may not work at all with another. The first and most-significant improvement measure, however, is to eliminate the brush by burning, grubbing, root-plowing, cabling, spraying, or other methods. Each method of brush elimination has advantages, and many have certain limitations, but the objective in all cases is to substitute forage species for brush.

Adverse environmental conditions in arid and semiarid rangelands make seeding difficult. Brush control is therefore of utmost importance when invasion is just beginning and grass has not yet been depleted. In brush-infested areas that still have a good stand of grass, a herbicidal or mechanical method should be employed that will not destroy the grasses. Mechanical methods alone may prove most effective if there is a dense stand of brush with few or no desirable grasses, if soil and climate are adequate to support grass production, and if there is a good probability of grass establishment after brush removal.

Domestic livestock, game, rodents, and other animals contribute to range weed problems by spreading seeds or vegetative propagules and creating opportunities for the establishment of weed seedlings. Grazing alters the botanical composition of range vegetation because of differences in the palatability of plant species as forage and their ability to withstand grazing. Animals first graze the most palatable forage plants on easily accessible parts of the range or in patterns characteristic of the animal species. As plants are progressively weakened by close, frequent cropping, less palatable plants (weeds) grow unhindered.

Severe grazing may kill forage plants. Persistent heavy grazing increases the proportion of short grasses at the expense of more-productive taller grasses. The vigorous tall grasses offer greater resistance to invasion by range weeds such as mesquite, whose seedlings require full sunlight. Good grazing management usually results in more desirable species composition, vigorous individual forage plants, and ample seed production. Usually, perennial grasses thrive under stocking rates that remove about 50 percent of the year's herbage. Rangeseeding and related cultural practices may also be used to directly increase forage stands.

Some measure of weed control may be obtained by selection of the kind of animals and the timing of grazing on a range. Goats, for example, browse more heavily than cattle or horses on woody plants. Sheep can sometimes be used to control herbaceous weeds, e.g., St. Johnswort in Australia. The fruits of many range weeds are relished by livestock, and, since the viable seeds pass through their digestive tracts, they are spread to uninfested areas. Livestock feeding on mesquite or cactus fruits, for example, should not be moved to uninfested range until their digestive tracts have been given about a week to clear.

Some form of deferred or rotational grazing is particularly necessary to restore forage after brush-control treatment on overgrazed sites near sources of water and salt. Alternate periods of grazing and nongrazing on a range are the best means of improving forage stands to the point where establishment of weed seedlings is reduced. Intervals between grazing reduce the amount of grazing on more accessible sites and permit forage plants to regain vigor and set seeds.

On rangelands where brush-control measures have been employed, forage production may be 400 percent greater in the first two to four years. This high forage production may create a false impression that the improvement will continue at the same rate. Actual long-term improvement of forage after brush control, however, may be only 30 percent on sand sagebrush and mesquite rangelands and 100 percent on sand shinnery oak rangelands. Nevertheless, one successful brush-control operation on such rangelands may double profits per acre on sand sagebrush rangelands over a 20-year period and increase them even higher on sand shinnery oak rangelands.

A problem peculiar to the southern Great Plains of the United States is the shift in the forage utilization pattern between lowland and upland or swales and dunes, which often occurs after brush control. The coarse, tall, somewhat unpalatable bluestem grasses (*Andropogon* spp.) that grow more rapidly on the lowlands are shunned by cattle, while they overgraze the more palatable forage of the higher and drier sites. If lowland-grazing is delayed too long, the animals will refuse to graze the coarse grasses. Management and cultural practices have not been fully developed to solve the problem of high and variable production of coarse bluestem grasses that occurs after successful brush control. Measures that have been found valuable include: (1) using controlled burning at the start of spring growth, (2) windrowing in the fall and using the excess range forage in the winter, (3) cutting grasses as hay in midsummer, and (4) intensifying grazing (at the maintenance level of nutrition) in the winter.

An effective practice that avoids some of the problems mentioned is the use of control on only a portion of brush areas by means of herbicides rather than eradication or general control. Partial brush control may increase forage production from 50 to 100 percent and usually results in a more manageable grass stand. The sand shinnery oak that may remain will retard wind during severe drought and decrease erosion. If only part of an area is treated, livestock will concentrate on the controlled acreage and overgraze it. Grazing of that area, therefore, should be delayed at least one growing season or longer to permit re-establishment of forage plants.

Benefits of brush control are not confined to grass production. Brush control may increase the ease and reduce the cost of caring for livestock, increase livestock offspring, lead to a need for fewer breeding males, result in tamer livestock, reduce screw-worm and other parasitic damage, improve the habitat for many wildlife species, and result in more groundwater over a longer period.

METHODS OF BRUSH CONTROL

Brush-control methods vary greatly in cost and effectiveness and include chemical, mechanical, and manual, as well as biological and selective grazing measures. Because potential income from grazing lands with a brush problem is low, costs and benefits of various alternative methods should be subjected to more-rigid scrutiny than would be necessary for more-valuable lands. Because of the large areas involved, brush eradication on rangelands is rarely an objective; emphasis is usually placed on control or regulation of a problem weed species. One of the major difficulties in achieving control is the efficient reproduction of many woody species: The capacity to regenerate vegetatively is common to such problem species as mesquite, sagebrush, elm (*Ulmus* spp.), and juniper.

Chemical Control

Good brush control and striking improvements in the grazing capacity of rangeland may often be obtained most economically by low-rate and low-volume applications of foliage sprays. Economical methods have been developed for numerous plant species, although much research still remains to be done.

Herbicides such as 2,4-D, 2,4,5-T, silvex, and benzoic acids control a wide variety of species. Picloram also shows exceptional promise on many brush species. A combination of 2,4-D and 2,4,5-T sometimes is used to control mixed brush because of the differential susceptibility of species, although 2,4-D and 2,4,5-T do not act synergistically, and their effects are not fully additive.

To be effective, foliage applications of systemic herbicides must be applied at the proper stage of growth. This must be determined experimentally for each weed species. Failure to carry out treatments at the proper growth stage often results in lack of successful control. Treating honey and velvet mesquite even one week too early, for example, drastically reduces the effectiveness of 2,4,5-T treatments.

For some species, the phenologic development of associated species is a more reliable index to seasonal susceptibility than a calendar date. There are physiological reasons for the effectiveness of phenoxy herbicides at a particular phenologic stage. Brush is most susceptible after the flush of new leaf development has stopped and terminal growth has slowed, and before the production of thick leaf cuticle. This stage also coincides with the time that transport of photosynthate to the roots begins. Since herbicides are translocated coincidentally with the photosynthate, there is greater probability they will reach roots and kill the plant.

Plants are generally most sensitive to foliage sprays of growth-regulator herbicides under optimum growing conditions. In some dry years, herbicide treatments should not be made at all, since plants under moisture stress do not readily translocate phenoxy herbicides. In Oregon, for example, poor control resulted after soil moisture was depleted before rabbitbrush reached a susceptible growth stage. Studies in New Mexico showed that there was a 39 percent increase in control of mesquite for each additional inch of rainfall during the October-to-May period preceding treatment.

Heavy rates of silvex proved effective in controlling pricklypears (*Opuntia* spp.) in Wyoming, particularly when spraying was preceded by crushing with a cultipacker. The cultipacker causes abrasions that apparently facilitate herbicide absorption. The roller may also orient the punctured pads in a horizontal position that improves coverage.

Brush control on rangelands will not last indefinitely after treatment. Many species resprout from the base of the stem or roots after tops are killed by herbicides. Recovery of brush by sprouting occurs over various lengths of time, depending on the plant species and environment. Treated areas also become reinfested by seedlings arising from seeds present in the soil or brought in from nearby areas. As a result, retreatment becomes necessary, and ranch managers should plan for a long-range follow-up control program on their grazing units.

To achieve adequate initial control of many woody plants, two or more herbicidal treatments are necessary in consecutive or alternate years. About the same amount of control results from retreatments made in successive years as in alternate years. Adequate control will usually last 7 to 15 years. Retreatment of extremely susceptible brush or species with weak regenerative potential may be required at less-frequent intervals.

The amounts of herbicide required to provide adequate control vary among species. Effective herbicidal rates are 1/3 to 1/2 pound per acre of 2,4,5-T for velvet or honey mesquite; 2 pounds per acre of 2,4-D for big sagebrush; and 2 pounds per acre of 2,4,5-T applied for two or more years to post and blackjack oak. Higher rates are rarely more effective. High rates cause foliage and branches to die so quickly that the herbicides are not translocated to the vital sites.

Fixed-wing or helicopter aircraft are commonly used to apply herbicidal sprays to large areas. Foliage sprays may also be applied with ground equipment, but terrain and size and density of brush often preclude such operations.

Since minimal rates and volumes of herbicide are used in spraying for brush control, efficient spray distribution is critical. Poor results can often be traced to inadequate spray distribution and coverage. Factors influencing spray distribution include swathe width, height of spray release, nozzle placement and orientation, wind, and physical characteristics of the spray. In applying phenoxy herbicides to mesquite, it has been established that about 70 drops per square inch are needed for minimum coverage. Finely atomized spray drops may drift from the target area or evaporate before reaching foliage. Spray-droplet size should therefore be large enough to minimize drift hazards yet sufficiently uniform to provide good coverage.

Soil applications of herbicides are another means of chemical brush control. Variability in seasonal susceptibility is not as great a problem with herbicides absorbed from the soil as with foliage-applied treatments. Monuron, fenuron, picloram, and other herbicides are applied as granules in broadcast treatments or around the bases of individual plants. Applications should be made when there is a reasonable chance that rainfall will carry the herbicide into the soil. If herbicides are applied to soil when rainfall is light, losses of herbicide through photodecomposition and volatilization may be excessive.

Individual stem treatments of brush with herbicides are usually limited to situations where there are sparse stands of single-stem trees or to small areas of rangeland. There are three categories of stem or basal treatments: basal stem, frill or tree injection, and cut stump.

In basal-stem treatments, either diesel oil or kerosene, alone or fortified with a herbicide, is sprayed on the base of the tree stem so that it thoroughly wets the bark and runs down the stem to wet the crown at ground level. The method is particularly effective against hardwood trees, during winter or summer, where the trunk diameter is less than 6 inches and bark is not too thick. Applications of phenoxy herbicides in a water carrier are not effective.

Most species can be controlled by the frill or tree-injection techniques. In the frill method, diluted or undiluted herbicides are introduced into cuts made around the tree stem with an ax or other sharpened tool. Bark cuts should be made as close to the ground as possible. Tools for tree injections have a hole in a chisel point through which herbicide is injected after the chisel is driven into the stem. Depending on plant size and species susceptibility, injections must be made at intervals of from 1 to 3 inches around the stem. Treatments are effective during any season.

The cut-stump method consists of treating the cut surface of a recently cut stump. Ammonium sulfamate crystals, herbicides in diesel oil, or water-soluble herbicides in water are applied to the cut surface. The method is effective with most sprouting species. Application soon after cutting improves the likelihood of herbicidal absorption before sprouting can occur. Control is most effective on trees cut close to the ground, since the distance the herbicide must travel to the sprouting zone is reduced.

Mechanical and Manual Methods

The choice of whether to use manual methods, such as cutting or grubbing, or mechanical equipment to remove brush depends on the size of woody plants, whether the species have sprouting or nonsprouting characteristics, soil condition, and the type of terrain. Mechanical methods have been used for control of mixed stands of brush and species that occur in almost pure stands. Various techniques and types of equipment have been developed for different situations.

The best time to employ manual methods of cutting or grubbing is during early brush invasion, before the grass stand becomes greatly reduced. Hand grubbing or cutting sparse stands of small shrubs (up to 36 inches in canopy diameter) is an economical control method. With sprouting species, the root must be severed below the budding zone. With large trees and multiple-stemmed plants, the cost is usually prohibitive. After cutting, sprouting species may be advantageously treated with herbicides to prevent sprouting.

Mechanical methods of rangeland brush control include cabling or chaining, bulldozing, root-plowing, and disking.

Cabling or chaining is the process of uprooting trees by means of a 300- to 500-foot length of anchor chain or heavy cable looped between two large tractors traveling in a parallel direction. The method is most effective in controlling even-aged, mature, nonsprouting species such as one-seed juniper and Utah juniper. It is less successful against sprouting species such as mesquite and most oaks.

Under difficult conditions, and especially for sprouting species, better results are obtained by chaining in two directions, but the process is expensive and may destroy residual grasses. Chaining a second time in an opposite direction completes the uprooting of trees in heavy soil, while the first operation pulled trees down but left much of their roots remaining in the ground.

Chaining will not severely damage small trees or shrubs that easily bend, and medium-sized plants may be only partially uprooted. Follow-up work by bulldozing or hand grubbing is required in stands that contain a large number of small or medium-sized trees.

Cabling or chaining is most successful in areas with light soil and a level topography that support plants of 3 inches or more in diameter. Terrain should never be steep, and there should be few gullies or rocks, thus allowing tractors to operate at their highest possible speed.

Bulldozing is effective against medium-sized trees of some basal-sprouting species and sparse stands of any species, since it pushes or pulls the plants out of the soil. Small trees and shrubs are often overlooked and may not be removed by this method. Large trees are difficult to uproot. One of the problems with bulldozing is that much soil is torn up, and large pits are left.

Bulldozer blades may be fitted with a projection, sometimes called a "stinger," which is pushed under the tree crown to assure uprooting of the bud zone. Experienced operators can lift and push over a tree in one smooth operation. Another modification of equipment is a blade that can be both tilted and angled. Experienced operators can use this type of blade in a manner that causes far less soil disturbance than with the normal bulldozer blade. Bulldozing is difficult on steep, rocky land.

In Arizona, the cost of bulldozing an acre containing about 100 small juniper trees is $6, and the cost for the same number of larger trees is $9. Cost per tree decreases as density increases, because there is less travel time between trees. In a hardwood-pine area, bulldozing costs $11 for a tree density of about 427 per acre if 90 percent of the trees are 6 inches or less in diameter at breast height. Costs of bulldozing larger trees may exceed $20 per acre. Follow-up treatment is necessary because small plants are missed and resprouts and seedlings soon appear.

Root-plowing with a track-type tractor and horizontal blade cuts off brush below the ground surface. Fins are welded to the top of the back of the blade to push roots out of the ground and reduce the possibility of their rerooting. Root-plowing generally kills most of the brush and all the grass in an area. It is essential that the blade strike below the budding zone of plants.

Root-plowing is limited to deep soils that are fairly free of rocks and obstructions. Areas that are root-plowed must be seeded, so the operation should only be carried out in areas favorable to the establishment of forage species by seeding. Because a high percentage of control is achieved, root-plowing is effective if there is no seed source of the woody plants in the soil or in nearby areas.

Disking for brush control is carried out with a large disk plow, or tandem disk, which plows up much of the brush. The method is limited to small, shallow-rooted plants such as creosote bush, sagebrush, and tarbush. Soils must be plowable and should contain few desirable grasses, since disking destroys most of the grass that is present. Disked areas may then be seeded with desirable grasses. Limitations that apply to root-plowing are generally the same for disking.

Another brush-control method—the oldest in use—is prescribed burning. Results of burning vary greatly and depend on the susceptibility of a species to fire and the amount of fuel accumulation that may be obtained from associated forage species. Time of year and moisture relationships are also important. Because burning involves such variables and may prove hazardous to other resources, it is not a generally applicable brush-control measure.

If burning is employed, consideration must be given to the direct effects of fire on forage species and the tendency for livestock and other animals to concentrate on recently burned areas. Forage species vary in their susceptibility to fire, and the season of greatest susceptibility for the undesirable plants may coincide with that of the forage species. Heavy grazing, coupled with frequent burning, will eliminate the better forage plants.

Several kinds of undesirable range shrubs are ideally controlled by burning at the proper season if moisture conditions are satisfactory and adequate precautions are observed. One example is big sagebrush, which does not sprout strongly after burning. Fire gives a very limited degree of control, however, to a number of shrubs and trees such as velvet mesquite, the oaks, several species of chaparral, and alligator juniper, since they resprout vigorously at or near the ground if burned. Under certain conditions, such as in the case of young velvet mesquite in southern Arizona and chaparral in California, burning may still be a useful method of control. After burning, seeding is generally carried out in the ashes. Spraying of sprouts and seedling brush and weeds should be performed the year after burning. Spraying of older brush is less effective.

Burning is no cure-all for range-brush problems, nor is it necessarily cheaper than other methods. Provisions must be made to insure that fires do not get out of control. This requires adequate preparation, trained manpower, fire-control equipment, prearranged firebreaks, and judgment as to when burning should be undertaken and when and where it should be stopped. The use of desiccating herbicides to permit more latitude in selecting the time and place of burning is under investigation but is not yet a widely recommended practice. Cost of burning includes not only the cost of fire lines and other safety precautions, but also the loss of one or more forage crops that are permitted to accumulate as fuel. Wherever burning can be fitted properly into a comprehensive, long-range vegetation-management program, however, it does control a number of woody plant species.

Biological and Selective Grazing Methods

Biological control of brush may be achieved by the use of insects or diseases as enemy agents of a plant species or through selective grazing. The use of insects and disease agents is discussed in Chapter 6. Discussion in this section will be confined to selective grazing.

Selective grazing by sheep or goats is useful in controlling some species of brush in small areas. The animals select the more palatable plants or portions of plants and are particularly effective in controlling seedlings and young sprouts. The tops of larger trees and shrubs should be removed before selective grazing is begun. Close and continuous grazing is essential to suppress and kill brush.

Careful management is necessary with selective grazing, but brush stands can be greatly reduced in three to five years if newly controlled areas are stocked with one to five sheep or goats per acre for the first two years and with lighter numbers thereafter. Overgrazing, especially at the wrong times of year, can be more detrimental to forage species than to the brush species being controlled. Expenses for the necessary fences, water, death losses, and management of animals can prove exorbitant.

METHODS OF HERBACEOUS-WEED CONTROL

Herbaceous weeds are found on all rangelands, and their harmful effects vary with range conditions. Good ranges usually have fewer herbaceous weeds; such weeds are abundant on poor ranges. Loss of forage from herbaceous weeds on rangelands is often not as spectacularly apparent as the losses from dense stands of brush. Nevertheless, such losses are great.

Weed Grasses

The grasses are the most important group of herbaceous weeds, and they dominate vast areas of rangeland throughout the world. Many of the problems related to control of weedy grasses on ranges can be illustrated best by discussing some of the problems involving medusahead and downy brome on western ranges. In the United States, medusahead is a spreading menace in California, Oregon, Washington, Idaho, and Nevada and is displacing forage plants as well as downy brome and other weed species on millions of acres of rangelands. Except for a short period in spring, this plant is unpalatable. Because of its low palatability, the weed accumulates and creates a fire hazard. Dead litter also builds up and inhibits early growth of seedlings of planted species. How far or how fast medusahead will continue to spread is not known.

Downy brome differs from medusahead in that it serves as the main forage on millions of acres of western range. While it is productive and palatable in spring, downy brome is undesirable on many ranges where well-adapted perennial grasses or other plants offer a more reliable, higher production of forage, particularly in adverse years. As downy brome matures, its usefulness as forage declines because of decreasing palatability. Furthermore, dead plants constitute a serious fire hazard.

Because downy brome and medusahead now occupy immense areas, their total elimination from a particular site is rarely feasible. Some exceptions exist with medusahead, since it still has not reached the limits of its ecological range, as has downy brome. Control of these weeds is essentially a matter of sustained suppression by perennial forage grasses. The presence of troublesome stands of either weed usually indicates a range has lost its native perennial grasses or that they are too sparse or low in vigor to offer effective competition to these annual weeds.

Control of downy brome and medusahead often requires seeding of perennial grasses combined with grazing-management practices that favor the desirable forage species. Otherwise, any management will yield little except downy brome and medusahead. After initial establishment of perennial grass seedlings, selective herbicide treatments should be applied to suppress the weeds and thus enhance rapid growth of the perennials to a level of vigor and basal density that maintains suppression of the weedy annual grasses.

Successful control of downy brome and medusahead requires destruction of two successive seed crops. Some seeds of these species persist for two seasons, but virtually all seeds will have germinated before the third season if new seed has not been introduced. Studies showed that seed can be controlled by tillage in April for two years or by a tillage operation supported by subsequent herbicide treatment and vice versa. A more economical approach includes controlled burning as the first-year treatment after seeds have matured but before they shatter from the plants. In the second year, plants should be controlled by either tillage or herbicides.

That at least partial control of two successive crops of medusahead contributes to a successful seeding operation illustrates an important principle of annual-weed control. Regardless of the number of plants per unit area, whether 10 or 1,000, their control is essentially a percentage matter, and high populations are best reduced by successive control measures. For example, medusahead populations in southwestern Idaho range from 250 to over 1,000 plants per square foot, with mean values of 325 to 400 plants per square foot. Initially, there may be as many as 14,000 seeds per square foot. A controlled fire before seed-shattering will destroy much of the seed and reduce next year's medusahead population from 85 to 90 percent below that of unburned areas. Therefore, there will be about 35 plants per square foot on a burned site as compared with about 350 per square foot on an unburned site. Dalapon applied at a rate of 2 pounds per acre will kill 98 percent of both populations in the spring a year after burning. The surviving population on the burned site will then be about 0.7 plants per square foot as compared with about 7 on the unburned site. Practically, this may represent the difference between success and failure in a new seeding of perennial grass.

Under climatic conditions such as exist in parts of California and Nevada, tillage in April for one year will give weed control adequate for the establishment of legumes or forage grasses, especially if seeding is accompanied by other weed-control treatments and if annual forage species are seeded.

Control procedures in new seedings would be greatly simplified if there were a truly selective herbicide that would kill the annual weed species and leave a seeded species uninjured. The similarity in physiological and environmental requirements of seedlings of annual and perennial grasses makes selective control of weed grasses one of the most difficult unsolved problems in range improvement. The potentialities for such a herbicide are illustrated best by siduron, which selectively controls seedlings of crabgrass, foxtail, downy brome, medusahead, and many other weeds without injuring seedlings of bluegrass, crested wheatgrass, and fescue. For effective action of siduron, moisture must be available soon after treatment. This may limit the usefulness of this herbicide for range seedings.

Because of the slower growth rates of perennial grasses, a second treatment is often needed to control the annual weed grasses during establishment of perennials. Several of the wheatgrasses are suitable for seeding in ranges infested with downy brome and medusahead. Mature plants of the wheatgrasses are strongly competitive, but the seedlings are not. The use of selective herbicides releases wheatgrass seedlings from the intense competition of weed grasses.

Paraquat has proved effective in Nevada and northeastern California for weed control in a program of nontillage spring seeding of perennial grasses. Paraquat, combined with a surfactant, effectively controls downy brome seedlings, leaves no soil residues, and permits planting of perennial grasses immediately after spraying. Applications of 2,4-D, combined with paraquat, control broad-leaved weeds that are often associated with downy brome. The application must be made in the spring when moisture is often available only for a short time, leaving a limited period for seeding operations. Stands must be established early so that seedling forage plants are large enough by summer to withstand the drought and heat. In years of extreme drought, chances for successful seeding are almost nil, despite the degree of weed control that is obtained. Planting the seed in furrows will improve the microenvironment and enhance perennial-grass establishment.

Herbicides active in soil, such as atrazine, effectively control annual grasses but are also toxic to seedlings of perennial grasses. To achieve selectivity between the weed and seeded species, methods must be employed that are based on either timing or placement or a combination of both. A chemical fallow technique in which atrazine is applied in the fall of one year and perennial grasses are seeded the next has proved effective. Atrazine is nearly always dissipated from the soil during the intervening year. Weed control during that year eliminates seed production and conserves soil moisture and nitrogen. The technique reduces annual grasses markedly during the seeding year, but sometimes increases broad-leaved weeds. Under such conditions, good stands of crested and intermediate wheatgrass have been obtained by planting the seed in furrows, spraying broad-leaved weeds with 2,4-D the following spring, or carrying out both operations.

Broad-Leaved Herbaceous Weeds

Broad-leaved herbaceous weeds are serious problems in rangelands, since many of them are unpalatable or have spines and thorns. Because livestock avoid such weeds unless other forage is lacking, broad-leaved herbaceous species tend to increase on improperly grazed ranges. Furthermore, they compete directly with desirable forage species for moisture and nutrients, decrease the amount of forage produced, and inhibit establishment of forage seedlings.

Control of broad-leaved herbaceous weeds is complicated by the fact that individual species often occur in scattered stands, frequently on terrain not easily accessible for direct control measures. Some species, such as the low larkspurs, mulesears, and lupines, occur in stands of sufficient density and area to justify over-all applications of herbicides.

Many species, notably the poisonous larkspurs (*Delphinium* spp.) and deathcamas (*Zigadenus* spp.), become more resistant to phenoxy herbicides at later growth stages. Time of treatment is therefore critical. In addition, plants of species such as the tall larkspurs begin growing as snowbanks recede.

This results in many growth stages among closely associated plants of the same species. Under these conditions, plants may range from susceptible to resistant, and therefore retreatment becomes necessary, and eradication is costly.

The extensive root systems of some perennial herbaceous weeds, exemplified by Canada thistle, leafy spurge, hoary cress, and whorled milkweed, and the variable effectiveness of phenoxy herbicides on such plants makes repeated treatments necessary. Despite the need for repeated annual treatments with phenoxy herbicides, they are in general use in combination with improved grazing management, cultivation, and reseeding. Reasonable control may be achieved in this way, but eradication is seldom achieved on grazing land. In a six-year study in the Gulf Coast area of Texas, 1 pound per acre of 2,4-D was used in March of each year, and forage production increased from 2,400 to 5,300 pounds per acre. The annual cost of the operation was $2 per acre.

Poisonous Weed Species

More than half of the perennial broad-leaved herbaceous plants recognized as weeds on rangelands are poisonous. Some of these are introduced species, but most of them are native plants. The subject of poisonous weeds in general is treated in Chapter 21. Few of the poisonous weeds are abundant, even locally, on good range. Examples of locally abundant poisonous species in climax vegetation are tall larkspur, greasewood, chokecherry, and certain oaks. Many poisonous plants increase in density on misused rangeland because they are not grazed when palatable forage plants are available. However, there are exceptions such as tall larkspurs and locoweeds (*Astragalus* spp.) that may be habit-forming to livestock.

Poisonous plants are found on nearly all rangelands in the western United States. Whether they present a problem depends on a number of factors. Toxicity of poisonous plants varies with species and their stage of growth. Sneezeweeds (*Helenium* spp.) are mildly poisonous; animals may become ill on them but seldom die if they are removed from an infested area when symptoms first appear. Timber milkvetch is so toxic that once cattle exhibit symptoms they seldom recover. Tall larkspurs are most toxic during their early growth stages. Halogeton, however, becomes more toxic with age.

Sparse infestations of poisonous plants are seldom troublesome. Heavy stands of even mildly toxic plants may constitute a serious hazard to livestock. Even small areas of dense infestations of highly toxic species may remove large areas of grazing lands from profitable production.

The life cycle of a poisonous plant may determine whether and when it is a range problem. Low larkspurs and deathcamas are problems on ranges grazed early in the year, because they are among the earliest green plants available to livestock. On similar ranges grazed later in the season after forage plants are large enough, the animals seldom eat these poisonous species. Still later in the season, both plants complete their life cycles and disappear from the range. Tall larkspurs, however, may reach maximum toxicity during the grazing season.

Jimsonweed is extremely unpalatable and seldom eaten unless animals are starving. Timber milkvetch is apparently relished by cattle and sheep.

Poisonous plants are not equally poisonous to all classes of livestock. Tall larkspurs and timber milkvetch are far more toxic to cattle than to sheep. Only a few cattle losses are definitely known to be caused by halogeton poisoning, but thousands of sheep losses can be attributed to the plant.

Poisoning is one of the most persistent problems confronting the livestock producer, and economic losses from it are heavy. Estimates based on numerous reports indicated death of about 3 to 5 percent of the livestock grazing larkspur-infested rangelands can be attributed to the plant. In some years, deaths on such ranges are higher than 15 percent.

Losses from poisoning may be reduced by identifying the weed hazard and keeping livestock out of the area; providing an abundance of forage through improved grazing management, especially in areas where poisonous plants are unpalatable; and controlling or eradicating the infestation. Usually, control of the weeds by some means is the most desirable approach.

Where good range management or other biological control practices do not reduce poisonous weeds to nonhazardous levels, herbicidal treatment may be necessary. Properly timed applications of certain phenoxy herbicides control many poisonous weeds. Repeated annual treatments are required for many perennial species and for annuals and biennials if there is a residual seed supply. The benzoic acids and picloram show special promise against some poisonous weed species.

On sites where herbicides are used for control, judicious grazing management is necessary to increase desirable vegetation, both in vigor and number of plants, thus reducing the possibility of reinfestation. If an area does not contain sufficient palatable species for natural revegetation, it should be seeded. Proper herbicidal treatments after seeding will reduce weed competition and increase the probability of successful control even on marginal sites. This fact has been demonstrated numerous times in salt-shrub desert vegetation when halogeton and Russian thistle were controlled in new seedings of crested wheatgrass.

The early detection of new weed species and prompt application of measures to prevent their establishment and spread are important to the maintenance of our western ranges. Halogeton is an example of a weed that was recognized early but not controlled until it had spread over a wide area. Much has been learned about halogeton, although a satisfactory and economical means of control on the low-value ranges on which it grows remains to be developed.

No forage species is available to replant over 10-million acres of saline ranges now occupied by halogeton. Although future research should find ways to minimize losses in livestock and deferred range use resulting from halogeton, the weed will probably remain a permanent component of the flora of many western states, continuing to plague the livestock industry.

Among introduced species of biennial and perennial broad-leaved herbaceous weeds that are relatively limited in their infestation are Dalmatian toadflax, diffuse knapweed, spotted knapweed, and rush skeletonwood. These species are still confined to only a small portion of their ecological range, although they are spreading rapidly on foothill and mountain ranges that receive at least 15 inches of rainfall annually. While eradication of any of these species is probably not feasible, vigorous efforts should be made to contain them in the present areas of infestation.

BRUSH AND WEED CONTROL ON PASTURES

In the United States, estimated losses of potential production of forage because of weeds, including brush in pastures, is 20 percent annually for the 31 eastern states. This estimate does not include weed losses resulting from ineffective management of livestock, undetected sublethal poisoning, mechanical injury from needles and thorns, and reduced quality of animal products. In addition, no estimates are included of losses from weeds in new seedings of forage crops, weeds in hay crops, or weeds in improved pastures.

Every pound of herbaceous weeds grown in pastures reduces production of forage plants by almost an equal amount. Forage reduction attributable to weeds may vary, depending on moisture conditions and the weed and pasture species involved. If legumes are established in the space formerly occupied by weeds, forage production will be greater because of the legume's vigorous growth habit and ability to fix nitrogen.

In a pasture experiment in Nebraska, it was found that two thirds of the production of all plant material consisted of unpalatable weeds. Use of 2,4-D on this pasture was more efficient than mowing for control of broad-leaved weeds and contributed to the successful management and reseeding of parts of the pasture after plowing. Three annual sprayings with an ester of 2,4-D at rates of 1 pound per acre reduced the weed stand by 70 percent; mowing reduced the stand only 30 percent; combining annual sprayings with plowing and seeding reduced weeds by more than 90 percent.

The experiment indicated that control of weeds increased the amount of vegetation eaten by cattle. In untreated pasture areas, cattle ate an average of 0.55 of a ton of dry matter per acre. In areas mowed for weed control, cattle ate 0.65 of a ton; in areas sprayed with 2,4-D, 0.85 of a ton; and in seeded and sprayed areas, 1.4 tons. The cattle harvested about 20, 50, and 150 percent more forage, respectively, in the three treated areas than in the control areas.

PRINCIPLES OF PASTURE MANAGEMENT

Any practice fostering development of a thick sod and vigorous growth of permanent pasture species will in time reduce the density of many weed species. Grasses and legumes in pastures vary widely in vigor and density. Vegetation on most permanent pastures in humid regions consists of volunteer grasses and weeds. The forage-weed balance is highly variable, and in areas with naturally nonacid soils, common white clover will usually volunteer.

Liming and fertilization are particularly effective in reducing the weed populations in pastures over a period of time. In Connecticut, applications of nitrogen, phosphorus, and potassium on a sparse stand of Colonial bentgrass resulted in a shift to denser bluegrass sod and a consequent reduction in weeds. Some weed species, however, are favored by fertilization and improved grazing management. Examples are chickweed and curly dock, which are severe problems only on fertile soils.

Weed-control measures in pastures should assist in high production of nutritious and palatable forage. Weeds can now be controlled in pastures more effectively than ever before. In pasture-forage production, the integration of all possible beneficial practices into the management system is required to achieve the highest efficiency.

BRUSH- AND WEED-CONTROL METHODS

The general techniques discussed for control of brush and weeds on rangelands also apply to their control in pastures. In general, pastures are usually more intensively managed and have a higher productive capacity. There is, therefore, more flexibility in the choice of possible control methods on pastures than on rangelands. The potential for a greater increase in forage production also may permit the choice of more-expensive control methods. For this reason, fertilization and liming are more important practices in pasture management than on arid rangelands.

A large part of the land pastured in the United States is cutover forest. Here, without constant control of sprouts and seedlings, the land will gradually revert to timber and shrub species. Major woody plants that must be kept under control include oak, hickory (*Carya* spp.), red cedar (*Juniperus* spp.), pine (*Pinus* spp.), poplar (*Populus* spp.), maple (*Acer* spp.), sweetgum, holly (*Ilex* spp.), basswood (*Tilia* spp.), persimmon (*Diospyrus* spp.), sassafras, common snowberry, rose (*Rosa* spp.), elder (*Sambucus* spp.), hazel (*Corylus* spp.), elm, and blackberry (*Rubus* spp.).

The potential of phenoxy herbicides for controlling weeds in pastures, alone and in combination with other agronomic practices, has been demonstrated in studies conducted at several locations in the humid and semihumid areas of the United States. These herbicides, including 2,4-D, 2,4,5-T, MCPA, silvex, and 2,4-DB alone or in combinations, control a broad spectrum of brush and broad-leaved weeds. Herbicides such as 2,3,6-TBA, dicamba, and fenac have value against some weeds that are less susceptible to the phenoxy herbicides. Picloram shows particular promise against some weed and brush species.

The practice of mowing many annual and biennial weeds in pastures during the bloom stage of growth largely prevents seed production and may eventually eliminate the weed from the pasture. The time of mowing is of critical importance. Prostrate species and those that branch laterally from buds very close to the ground cannot be controlled by mowing. Herbicides are more effective on such species, and, even then, treatments may be required for several years to exhaust the weed-seed supply in the upper soil stratum.

Plants growing under optimum conditions are usually more susceptible to herbicides than those doing poorly in adverse environments. Moderately high soil moisture and relative humidity with an air temperature in the range of 70 to 80°F appear optimum for effectiveness of phenoxy herbicides.

Perennial weeds vary greatly in susceptibility to phenoxy compounds, not only between species but between ecotypes within a species. Variable responses to 2,4-D, ranging from resistant to susceptible, have been found among ecotypes of Canada thistle in Montana. In Oklahoma, perennial ragweed has been readily controlled by 2,4-D at rates as low as 1 pound per acre. Rates of 1 and 2 pounds per acre proved sufficient to control the same weed in central Nebraska, although stands of perennial ragweed in Lincoln, Nebraska, have resisted control on pasture plots sprayed annually for 15 years with 1 pound per acre of a 2,4-D ester.

Perennial weeds usually can be controlled best by phenoxy herbicides when they are applied in the prebud to early-bloom stages. Application timing is critical with some species and less important with others. Hoary cress is easily controlled if 2,4-D is applied while the plants are budding, but applications two weeks later, after the full-bloom stage, result in only fair control.

A few perennial species can be controlled by a single herbicide treatment, but, usually, one or more retreatments are required. Retreatments not only improve control of perennial weeds but remove annual weeds as well. Herbicide use should continue through the years until adequate weed-stand reduction is achieved. Herbicide treatments combined with proper fertilization and grazing management should result in replacement of weeds by forage species.

In many pastures, a wide spectrum of broad-leaved weeds may create control problems. Rotation of kinds of herbicides or repeated treatments within a season may therefore be necessary to carry out an effective control program where mixtures of winter-annual, annual, biennial, and perennial weeds exist. For example, treatments may be necessary in the spring for thistle rosettes, many species of the mustard group, dandelions, and common snowberry. Such treatments would precede the susceptible stage or emergence of such weeds as goldenrods, ironweed, hoary vervain, asters, and ragweeds.

Use of 2,4-D and other phenoxy herbicides may retard the growth of legumes such as white clover and lespedeza. Legume stands may be depleted by early spring spraying. Ordinarily, white clover and lespedeza will recover and eventually benefit from elimination of weeds and the improved management practices accompanying weed control. If white or ladino clover is a significant component of the pasture vegetation, then 2,4-DB should be used, since it causes little injury to clover and controls many weeds susceptible to 2,4-D.

Combinations of spraying and mowing have not yet been adequately explored in pasture weed control. In some areas, mowing is desirable for reasons other than weed control. It may, for example, encourage more-uniform grazing and favor development of associated legumes.

To be successful, a weed-control method must be combined with proper management practices that ensure meeting fertility needs of growing forage plants. The objective must always be to encourage vigorous growth of forage crops to fill the space formerly occupied by weeds.

RENOVATION

Herbicides are useful in renovating many pastures that are too steep, rocky, or poorly drained to be plowed in the preparation of seedbeds. Some of these areas become heavy producers of improved forage if fertility needs are met and improved plant species become established. Requirements for establishing forage stands are: (1) killing undesirable plants and preventing their reestablishment, (2) making soil corrections by intelligent use of lime and fertilizer, (3) providing good seed–soil contact at a proper depth for good emergence, and (4) suppressing competing vegetation while forage plants are becoming established.

Herbicidal renovation permits surface-seeding with a minimum of soil disturbance. In New Jersey, application of TCA combined with two diskings was found to be equivalent to plowing. Both plowing and chemical renovation treatments were found to be considerably better than 12 diskings for seedbed preparation, as evidenced by a higher forage yield. However, use of any of the three methods more than doubled forage as contrasted to yields obtained from untreated areas.

The potential for herbicidal renovation has increased with development of herbicides more efficient than TCA. Dalapon at rates of 4 to 10 pounds per acre has been effective when applied to closely grazed sods during the growing season and three weeks before seeding. Paraquat has shown promise, particularly where Kentucky bluegrass is the dominant species. No waiting period is required before seeding after application of paraquat, which is inactivated through soil adsorption. Since treatments are most effective during rapid growth of the plants, adequate moisture is necessary to achieve success with all these methods. Consideration should be given to spraying broad-leaved weeds during their most susceptible stage even if the treatments need to be made several weeks or months before applying the renovation herbicide.

Herbicides that fail to kill pasture species such as Kentucky bluegrass may be used to thin the turf and permit establishment of legumes such as birdsfoot trefoil, alfalfa, and white clover. Birdsfoot trefoil is tolerant to dalapon and may be seeded at the time of treatment.

Control of weeds that germinate during the seeding year is often necessary for successful renovation. Dalapon can also be used as a follow-up treatment to prevent invasion of weedy summer grasses, such as crabgrass (*Digitaria* spp.) and foxtails (*Setaria* spp.), without injury to birdsfoot trefoil. White clover and alfalfa, however, are more susceptible to injury. As renovation occurs, bluegrass gradually thickens and thus provides a grass-legume mixture. Broad-leaved weeds can be controlled in renovation seedings of white clover, alfalfa, and birdsfoot trefoil by spraying with 2,4-DB. Mowing may provide some partial control that benefits the new seeding.

MANAGEMENT PRACTICES FOR ROTATIONAL PASTURES AND HAY

ESTABLISHING LEGUMES

Seedling legumes are particularly vulnerable to weed competition. They grow slowly and provide the opportunity for rapidly developing weeds to overtop and severely shade them. In Indiana, broad-leaved weed seedlings in one study were found to grow five times more rapidly than legume seedlings (dry-matter production). To reduce weeds in spring seedings, a companion crop of cereal grains, peas, or other crops is often planted.

Research in many northern and northeastern states has shown that companion crops such as barley and oats may injure slow-starting forage species as much as weeds. Nevertheless, many farmers consider it advantageous to grow a crop of grain, silage, or pasturage while legumes are becoming established.

Practices that favor the rapid germination and growth of legumes assist them in competing with weeds. For instance, legumes band-seeded with press wheels behind the drill are placed directly above but not in contact with fertilizer. The press wheels firm the soil over the seed row but leave a loose seedbed between rows. The method not only results in more-vigorous legume seedlings, but the loose soil between rows constitutes an unfavorable environment for germination of weed seeds. Other practices that can be used to help control weeds while establishing legumes include: crop rotations that reduce the prevalence of weed seed in the soil, thorough seedbed preparation, fertilization, liming, growing companion crops, mowing, and the use of herbicides. Each method involves the integration and use of certain weed-control principles.

Timing of Planting

Planting of small-seeded legumes can be timed to avoid particular weed problems. Problem weeds in early spring plantings are pigweeds, smartweeds, mustards, lambsquarters, and green foxtail. Weeds germinating in late spring include ragweeds, yellow foxtail, barnyardgrass, and crabgrass. Weeds of most concern in late-summer seedings are winter annuals, biennials, and some perennials, which characteristically start their growth at the onset of cooler temperatures. Species in this group include common chickweed, knawel, pepperweed (*Lepidium* spp.), shepherdspurse, henbit, and yellow rocket.

The prevalence of the various kinds of weeds in a field may determine the optimum time to seed legumes. In areas where spring- and summer-germinating annual or perennial weeds are problems, planting in the fall, if environmental conditions are favorable, will provide the legumes an opportunity to become established and attain sufficient growth to compete with weeds that emerge in the spring. Thus, better stands of legumes often result, even though favorable rainfall distribution is less likely in the fall. However, fall plantings may be heavily damaged by insect pests such as grasshoppers. In northern areas, winter killing of seedling plants frequently takes a heavy toll. It is difficult to control perennial weeds that germinate and become established before winter.

Spring seedings are vulnerable to weed competition not only in the spring but throughout the summer. Although moisture supply is usually adequate in many regions during the spring, there are often long periods of drought and high temperatures during summer that kill young forage plants if they are not well established. Control of weeds reduces the drain on the moisture accumulated in the soil and may determine whether a successful seeding is achieved.

Use of Herbicides

Control of annual weeds in new legume seedings by means of herbicides permits substantial forage yields during the year of seeding. The development of herbicides that selectively kill weeds with minimal injury to legumes has caused some shifting from seeding with a companion crop to seeding with legumes alone. Herbicides may be applied before planting, at planting (pre-emergence), or after emergence of weeds and legumes.

Application of EPTC and its immediate incorporation into the soil before planting will control most annual grasses and, under favorable conditions, will kill many germinating broad-leaved weeds. Most of the small-seeded legumes will tolerate 1 to 3 pounds per acre of this herbicide, which is incorporated to a depth of 1 to 2 inches. Only minor stunting of some seedlings will occur. The treatment is also effective in reducing a competing stand of nutsedge and some perennial grasses. However, an application rate of 3 to 6 pounds per acre and incorporation to a depth of 4 inches is desirable for nutsedge and perennial-grass control.

EPTC is extremely volatile. Immediate incorporation of the spray after application to a relatively dry surface will minimize volatility loss. Conversely, moist soils, high temperatures, windy conditions, and delay in incorporation, all will increase loss and decrease the persistence of the herbicide in the soil.

Although EPTC is taken up by roots of plants, research indicates that the chemical thus absorbed is ineffective. Absorption of the herbicide through the leaf or stem tissue is necessary to achieve a lethal result. A high concentration of herbicide near sensitive parts of germinating seedlings is required for control. EPTC normally persists in the soil from 2 to 6 weeks, depending on soil moisture, temperature, and wind. Cool, dry, calm conditions will increase the persistence of the herbicide and the effectiveness of weed control.

When broad-leaved weeds are a problem they should be controlled by a selective herbicide or mowing. Most legumes tolerate 2,4-DB, which is selectively more effective if applied while broad-leaved weeds are less than 4 inches tall. Seedling sweet clover is killed by 2,4-DB. CIPC is effective for common chickweed control if applied in late fall or early winter. Other weeds can be controlled by dinitro herbicides in late winter.

Weed grasses infesting new seedlings of legumes can also be selectively controlled by herbicides. Dalapon may be used in alfalfa and birdsfoot trefoil. Birdsfoot trefoil is especially tolerant to dalapon, while alfalfa has a marginal tolerance and is usually stunted for some time after treatment. However, if weedy grasses are serious, dalapon can be used to advantage. The herbicide will kill lespedeza and seriously injure white and red clover. Annual weed grasses in red clover, white clover, and other legumes can be controlled by IPC and CIPC. These two herbicides are useful in controlling winter-annual grasses in fall seedings of legumes.

It is obvious from the above that species within a family of plants possess differential tolerance and susceptibility. Research is required on each species with each herbicide to establish the behavior pattern. Other examples of differential tolerance include lespedeza, which tolerates moderate dosages of 2,4-D but is very susceptible to silvex, as well as to cinquefoil and heal-all, which are readily controlled with 2,4-D but only somewhat susceptible to silvex.

Use of herbicides on "stale seedbeds" is another means of controlling weeds in new seedings. The seedbed is either prepared in the fall and not seeded until spring or prepared in the early spring and seeded late in spring or summer. Sometime before seeding, the weeds that germinate are killed with herbicides such as IPC combined with 2,4-D and amitrole-T. After the herbicides have dissipated from the soil, the forage crop is then seeded without further seedbed preparation. The use of paraquat and diquat at seeding time offers even greater promise. Since these are effective contact herbicides adsorbed by the soil, they permit immediate seeding without injury to new seedlings. Since the soil is not disturbed by tillage, new weed seeds are not brought to the surface, and a lengthy, relatively weed-free period is available for establishment of forage seedlings.

Control by Mowing

Mowing overtopping weed vegetation is an advantageous control method against broad-leaved weeds if the legumes recover more rapidly than weeds, but it will not control weed grasses. Time of mowing is important in this method. If weeds are mowed while still too small, branches and stems develop from lateral buds, and the plants may compete more effectively for light than if the mowing operation is not performed.

Mowing should, therefore, be carried out when weeds are 12 to 18 inches high. If weed growth is extremely dense and vigorous, use of a rotary mower scatters cut vegetation and reduces the possibility of smothering legume plants. Delayed mowing also permits broad-leaved weeds to suppress weed grasses for a longer period. To provide maximum control, mowing should be performed as close to the soil as possible. Mowing of tall weeds or a companion crop should not be carried out on clear, hot days, since this exposes tender legumes to the sun and may injure them severely.

When legumes are seeded with small grain in the spring, several practices are often helpful in weed control. Control of broad-leaved weeds may be achieved by applying 2,4-DB and other phenoxy herbicides at various stages of growth of the grain. Ragweeds (*Ambrosia* spp.), spanishneedles, annual weed grasses, other weeds, and volunteer grain are particularly troublesome after harvesting small grain. Cutting the grain stubble and removing all material after combining has resulted in improved stands in Ohio, Wisconsin, and Indiana. Low clipping of the seeding after weeds have attained considerable growth will favor the seeding and reduce weeds. Such treatment is more effective on tall broad-leaved weeds than on annual weed grasses.

Combined Mowing and Herbicide Treatments

Mowing controls tall broad-leaved weeds, but often increases the problem of weed grasses. Timely mowing combined with the use of selective herbicides has resulted in improved stands of birdsfoot trefoil in Missouri. When mowing has been combined with the use of dalapon, the establishment of birdsfoot trefoil plants has been twice as great as with mowing alone. Even more significant was the much greater vigor of plants as evidenced by the yield of birdsfoot trefoil in the year after treatment. On plots receiving the best combination of dalapon and mowing treatments during the seedling year, production of birdsfoot trefoil in the year after seeding amounted to nearly 4,000 pounds of dry matter per acre. Plots receiving the best mowing treatment without the supplemental herbicide yielded only 140 pounds of birdsfoot trefoil per acre. Dalapon effectively controls grasses without a noticeable effect on birdsfoot trefoil.

Generally, mowing injures legume seedlings by removing their tops. It is mainly useful where adequately effective and selective herbicides are unavailable or uneconomical.

Weed Control in Hay

Legumes grown for hay compete with most weeds as long as the stands remain dense and the plants are vigorous. Conditions influencing vigorous growth thus contribute to weed control. Adapted legume varieties respond to drainage, moisture availability, neutral pH, high fertility, freedom from diseases and insects, and proper timing of mowing.

Timely cutting of hay crops practically eliminates competition from several weed species. Canada thistle can be reduced by three or more mowings of alfalfa each year. In Minnesota and Wisconsin, however, perennials such as hoary alyssum and white cockle, which infest much of 5-million acres of alfalfa, cannot be controlled by the management practices that are followed in alfalfa production. Annual weeds usually decrease after the first cutting of hay. In the northeastern states, wintercress will not produce seed if the forage crop is cut in May for silage, well in advance of the usual date for cutting hay.

Although established legume stands compete well with summer annuals in some areas, they are endangered by winter annuals such as common chickweed, henbit, mustards, and annual bromegrasses, which emerge in the fall about the time legumes enter dormancy. The weeds grow rapidly in the early spring and become large and competitive. Soil treatments in the fall control some of these weeds. Applications of IPC, CIPC, and diuron in the fall proved effective in various regions. The dinitro herbicides, applied on a warm day in late winter or early spring, are effective in control of annual broad-leaved species. In Michigan, MCPA is applied in late fall on established alfalfa fields or new seedings of red clover to achieve good control of yellow rocket, field pepperweed, and bull thistle and achieves reasonable control of sweet clover.

Selective herbicides such as 2,4-DB may be used on susceptible weeds during the growing season. For example, applications of 2 pounds per acre of 2,4-DB in late April in Mississippi controlled curly dock and more than doubled the yield of ladino clover. The herbicide also showed promise in controlling hoary alyssum in the fall.

Selective control of some perennial weeds, such as quackgrass, in hay crops, cannot at present be accomplished. However, it is possible to control these weeds in other crops in the rotation before planting legumes. Proper use of atrazine in one or two crops of corn almost eliminates quackgrass, and afterwards the field can be planted to legumes for hay. For other weeds in other areas, it may be necessary to cultivate intensively for one or two seasons or to use herbicides to reduce weeds to the manageable level. If such practices are followed by effective weed-control practices, during the year of establishment, relative freedom from weeds in the hay crop results.

Seed Production

Preventive measures that avoid initial establishment of weeds are important control practices in legume seed fields.

Seed production in crops such as alfalfa requires lower plant populations than are needed for hay production. Consequently, seed crops often provide less competition to weeds than the same species grown for hay. Furthermore, seed-production schedules do not include frequent mowing. Certain weeds, such as prickly lettuce, may be very troublesome in seed fields, whereas mowing reduces the problem of such weeds in hayfields. Where a first crop is saved for seed, weeds are not cut and may become large and competitive.

In the western states where much of the alfalfa seed is produced, weed seeds commonly found in alfalfa seed include lambsquarters, barnyardgrass, foxtails, mallows, star thistle, Russian thistle, wild barley, and knotweeds. In most of the red clover seed-producing area, weed seeds commonly found include buckhorn, dock, cockle, foxtail, smartweed, quackgrass, field pepperweed, and wild carrot. Occasionally, bull thistle and hoary alyssum are problems. Improved seed-cleaning will remove weed seeds, but losses of crop seeds during cleaning are high.

Practices favoring competitive ability of the legume plant often cannot be utilized for controlling weeds in seed crops. Heavy vegetation growth may drastically reduce seed yields. Alfalfa for seed is often grown in rows and cultivated for weed control. Relatively sparse stands of alfalfa favor greater seed production but also permit invasion by weeds.

In irrigated regions where moisture can be controlled, intensive shallow cultivation with spring-tooth harrows, skew treaders, or finger weeders after irrigation, when little crop is present, will destroy seedling weeds. For best results, tillage should be continued until the soil surface is too dry to support further germination. By the time additional irrigation is required, sufficient crop growth is present to prevent or reduce germination and establishment of seedling weeds. Dodder and other annual weeds can be largely controlled by this method.

Flaming of legume stubble in the early spring, between hay and seed crops or after harvest, destroys seedlings and attached dodder as well as most other annual weeds. Flaming twice at three-day intervals with propane or butane field burners is recommended. Burning the crop residues left on seed fields after harvest also destroys many weed seeds and reduces the weed problem.

Cultural practices alone seldom result in complete weed control in legume-seed fields. Thus, a number of herbicidal control methods have been developed. In the western states, where alfalfa or birdsfoot trefoil become dormant or semidormant in winter, diuron is applied during dormancy at a rate of 1.5 to 3 pounds per acre. This treatment controls most annual weeds throughout the year. In the Pacific Northwest, simazine controls most annual weeds for a year when applied at rates of 1 to 2 pounds per acre. Winter-annual grasses and chickweed are controlled by spraying with IPC or CIPC at rates of 3 to 4 pounds per acre during the dormant season. Many annual broad-leaved weeds may be controlled by spraying their foliage with 2,4-DB. However, spraying while legumes are in the bud or flower stage may reduce seed yields. DNBP is effective in controlling winter-annual broad-leaved weeds while legumes are dormant.

Good control of dodder may be obtained by applying granular CIPC at rates of 6 pounds per acre to moist soil in the spring, before the dodder attaches to alfalfa plants. If a hay crop is removed, the soil should be irrigated and a second treatment applied immediately. If treatment is not carried out before the hay crop is removed, some dodder plants remain attached to the stubble. These must be removed by cultivation, flaming, or a contact herbicide before CIPC is applied a second time.

ESTABLISHING GRASS

Weed Control during Establishment

Many of the same principles of weed control used to establish legumes also apply to the establishment of grasses. Herbicides used in grass establishment are different, however.

Annual broad-leaved weeds often offer severe competition to grasses. After seeded grasses reach the two- to four-leaf stage of growth, they will tolerate low rates of phenoxy herbicides and substituted benzoic acids such as dicamba. Although such treatments result in some abnormal leaves (fused leaf edges), the perennial grasses usually recover and benefit from the weed control. Most of the broad-leaved weeds are killed.

Weed grasses are the most difficult weed problems in new seedings of perennial grasses. Few herbicides that are efficient or adequately selective are available. Siduron may prove useful in the establishment of a number of turf and pasture grasses. In greenhouse and limited field studies, siduron applied prior to emergence controlled weed grasses such as crabgrass, foxtails, downy brome, and barnyardgrass. The fescues (*Festuca* spp.), ryegrasses (*Lolium* spp.), wheatgrasses (*Agropyron* spp.), smooth brome, bluegrasses (*Poa* spp.), orchardgrass, timothy, and many others tolerate the herbicide. With siduron, it is important to irrigate the soil or apply the herbicide two or three days before rain. Soil incorporation of siduron in moist soils is also effective. The extreme selectivity of siduron offers much promise for the future.

In Oregon, herbicides have been used effectively before and after planting of grasses. The seedbed is prepared in the fall, and the soil is treated with IPC and 2,4-D in January, which controls weeds and volunteer crop plants. Paraquat is applied to later-germinating weeds in March, just before seeding perennial grasses. No further tilling of the soil is necessary for seeding. Little additional germination of weed grasses occurs after the perennial grasses are planted. By fall, perennial grasses are well enough established that the soil can be treated with diuron to control winter-annual weeds. Excellent stands of grasses result, which produce high yields of weed-free seed the year after establishment.

An outstanding example of the importance of weed control in grass establishment has been demonstrated by research in Mississippi. Coastal bermudagrass sprigged in May was sprayed immediately afterward with simazine at a rate of 4 pounds per acre. Weeds were eliminated, and grass yields amounted to 3.7 tons per acre of dry matter, as compared with 1.9 tons per acre of bermudagrass and 1.6 tons of weeds from an untreated plot. The treated area yielded 9.5 tons per acre the following year, whereas the untreated plot yielded only 6 tons per acre of bermudagrass. Obviously, the weed-control practice that was employed made possible better utilization of fertilizer by the forage grass, earlier grazing, and higher-quality forage.

Weed Control in Established Stands

A vigorous and well-fertilized stand of perennial grasses usually suppresses annual and many broad-leaved perennial weeds. Phenoxy herbicides and benzoic acids will control the broad-leaved species that are able to invade such stands.

In seed fields, low rates of phenoxy herbicides should be applied in the spring, before seed heads of the grasses emerge. Bent grasses are sensitive, and high rates of herbicide should not be used on them. Annual grasses that invade seed fields may be controlled with IPC or CIPC applied in the fall, before onset of winter and before formation of seed head primordia by the perennial grasses. Some species of fescue are sensitive to CIPC and should not be treated with it. In areas of moderate rainfall and mild winters, a fall application of diuron will control both annual grasses and broad-leaved weeds. Some *s*-triazine compounds offer promise on annual grasses. Both the phenylureas and *s*-triazines should be used with caution.

No herbicides other than nonselective grass-killers are available for control of unwanted perennial weed grasses in grass-seed fields. However, the selective control of dallisgrass and other *Paspalum* spp. by arsonate herbicides without injury to other turf species indicates that such herbicides eventually may be discovered.

WEED CONTROL IN GRASS-LEGUME MIXTURES

Most improved pastures are seeded to a mixture of grasses and legumes. The problem of selectively controlling weeds in these mixtures is more complex than control in a single species. Ideally, both legumes and grass must be tolerant to the herbicide, and all undesirable vegetation (both broad-leaved and grasslike) must be killed or controlled by the treatment. Such herbicides or combinations of herbicides, however, have not been discovered. Limited success in establishing birdsfoot trefoil–timothy and alfalfa–timothy mixtures has been reported with carefully controlled rates of treatment with a mixture of 2,4-DB and dalapon.

Herbicides are available that selectively kill broad-leaved weeds only in legume–grass mixtures. The stale seedbed technique briefly discussed earlier also may offer some promise of weed control in establishing legume–grass mixtures.