Herbicides for Plant Control

Herbicides can be an effective, necessary, and environmentally sound tool for the control of weeds and brush on rangelands (Young and others 1981b). As a result, chemical control is a widely used means of removing unwanted or noxious plants from range and other pasture lands. Selective plant control by mechanical, biological, fire, or manual means should also be considered but is not always a satisfactory alternative to chemical control.

New herbicides, new formulations, new application techniques, and new uses for herbicides have been developed for rangelands in recent years. Any person who is involved in the development of rangelands must be well versed in the properties and proper use of herbicides. Martinelli and others (1982) recommend that all range managers take advantage of the program for training and certification of pesticide applicators. They conclude that these schools, now being offered in most States with Environmental Protection Agency approval and financing, can be extremely valuable as a refresher program even if one does not plan to apply restricted herbicides. Most States require certification to purchase, handle, and apply many herbicides.
Handbooks and manuals suggested for planning and carrying out plant control programs on Intermountain rangelands, including the use of herbicides, include Bohmont (1983), Klingman and others (1982), Rutherford and Snyder (1983), Weed Science Society of America (1989), and State Agricultural Extension Service and Experiment Station publications.

**Potential Results of Herbicide Use**

Plant control, including the use of herbicides, requires a carefully planned program. The first step in a plant control program is evaluating: (1) the desirability of resident and potential plant species in the habitat, and (2) at what population levels various plant species are desired. Desirability must be based on the objectives of land ownership, the multiplicity of range products desired, and the animal species (domestic or wild) that will be favored. Along with deciding which plant species are to be increased or decreased, and by how much, or which will be kept at present levels, consideration must be given to avoiding or reducing damage to desirable, nontarget plant species.

The major objective of herbicide application to rangelands is often to improve animal habitat. Animal habitats must provide food, water, and whatever cover is needed; but each animal species has its own unique habitat preferences and requirements. In general, ideal big game habitat has been equated with: (1) a greater mixture of forage species than is needed for livestock, (2) a mosaic of vegetation types, and (3) greater availability of cover than needed for livestock (Vallentine 1989). Mosaic vegetation can be maintained or created by treating high potential sites and leaving untreated draws, ravines, rough ridges, and shallow, rocky sites. Selective checkerboard treatment of specific sites is generally more effective than aiming for low plant control levels over the entire area.

Morrison and Meslow (1983) concluded that the indirect effects of herbicides on wildlife were far greater than the direct effects. Residues of herbicides in the environment were found to be of low concentration and short lived; herbicides in wildlife tissues were low and did not accumulate; and toxic effects on wildlife were deemed incapable of happening if recommended application practices were followed. Indirect effects on habitat modification, however, were considered potentially negative or positive. Even preferred browse species for big game could be increased through herbicide use, but careful planning is required.

Proven uses of herbicides on rangelands include:

1. Selective control of undesirable plants as a sole treatment to favor more desirable forage species, for example, control green rubber rabbitbrush (fig. 1) on foothill sites (Evans and Young 1975a).
2. Combination treatment with mechanical, fire, or biological methods, for example, burning or mechanical treatment of salt cedar, Gambel oak, black greasewood, with follow-up herbicidal treatment of sprouts.
3. Release of particularly desirable plant species over which undesirable woody or even herbaceous plants have gained dominance, for example, juniper invasion on deep soil benches (Evans and others 1975) or tarweed in mountain meadows.
4. Thinning or removal of trash trees in commercial forests, or both, thereby enhancing herbaceous and browse understory as well as timber production, for example, removal of juniper from ponderosa pinesites.
5. Rejuvenation of tall shrubs and low trees, used as forage by big game, by top killing with light rates of 2,4-D and stimulating new growth from sprouts and seedlings, for example, old growth aspen stands, Gambel oak, mountain maple (Harniss and Bartos 1985).
6. Eradication of poisonous plants on sites suitable for such intensive treatment, for example, tall larkspur on high mountain range and rush skeletonweed (Cronin and Nielsen 1979).
7. Eradication of small infestations of serious plant pests or “environmental contaminants” not previously found locally, for example, spotted knapweed, musk thistle, and others.
8. Total plant kill to meet the needs of chemical seedbed preparation for range seeding or planting (fig. 2), for example, 2,4-D and paraquat on sagebrush-cheatgrass sites.
9. As a post-planting treatment, to enhance establishment by selectively controlling weed competition, for example, dense annual broadleaf weeds or perennial ragweed in new wheatgrass-alfalfa seeding.
10. Maintenance control or retreatment when applied periodically following primary treatment, for example, periodic suppression of Gambel oak stands.

Herbicidal control has some distinct advantages over other plant control methods, this explains the current widespread use of herbicides, particularly on private lands. These general advantages include:

1. Can be used where mechanical methods are impossible, such as steep, rocky, muddy, or certain timbered sites.
2. Provides a selective means of killing sprouting plants that cannot be effectively killed by top removal only.
3. Provides a rapid control method from the standpoint of both plant response and acreage covered when applied by broadcasting or spraying.
4. Has low labor and fuel requirements.
5. Are generally cheaper, in some cases, than mechanical control methods, but may cost more than prescribed burning.
6. Can be selectively applied in most cases so that damage to desirable plant species can be minimized.
7. Maintains some vegetal and litter cover and does not expose soil to erosion.
8. Safe and reliable when proper safeguards are followed.
9. Can often use regular farm and ranch spray equipment.

Disadvantages of using chemicals to control undesirable range plants exist. Recognizing them may permit minimizing or circumventing them.

1. No chemical control has yet proven effective or practical for all plant species.
2. Herbicides provide a desirable, noncompetitive seedbed for artificial seeding only under certain situations.
3. Costs of control may outweigh expected benefits on lands of low potential.
4. The careless use of chemicals can be hazardous to nontarget plants, to cultivated crops or to other nontarget sites nearby, or may contaminate water supplies.
5. Lack of selectivity may result in killing associated forbs and shrubs.

**Chemical Seedbed Preparation**

Herbicides show promise for chemical site preparation. Seeding or planting can be done shortly after spraying or after a fallow period maintained by herbicides. Seedbed preparation by chemical means, when effectively used, has the following advantages when compared with mechanical methods:

1. Leaves a firm seedbed for better plant establishment.
2. Has good erosion control since the mulch and litter are left in place.
3. Can be used on land that is too steep, rocky, erosive, or wet for mechanical treatment.
4. Does not invert the soil profile, which would be undesirable on shallow, poorly drained, or poorly structured soil.
5. Provides a means of selective plant kill when desirable native forage plants are present.
6. Averts most soil crusting and reduces frost heaving.
7. Conserves soil moisture and nitrogen, similar to mechanical fallow, when used as chemical fallow (Eckert and Evans 1967).
8. Improves moisture penetration and retention as a result of mulch cover on the ground.
9. Allows spraying, drill seeding, transplanting, and fertilization in a single operation while climatic conditions are still optimum (Kay and Owen 1970).
10. Protects grass seedlings by means of the standing vegetation killed by herbicides.
11. Permits seeding an entire field, riparian zone, or watershed having erosive soil, at one time.
12. May be less costly than mechanical seedbed preparation.
13. Does not destroy the soil seedbed of desirable native species.

On the other hand, dead mulch and litter following chemical seedbed preparation may be excessive, or otherwise hinder seeding. However, use of the range-land drill with its various modifications permits drilling into all but the most extreme sites. Also, herbicide applications may not kill weed seeds resident in the soil unless used as chemical fallow during a growing season. This may require additional herbicide application during the seedling year as a maintenance treatment.
How to Apply

Several methods are available for applying herbicides to undesirable plants. For convenience, these are divided into foliage, stem, and soil application. See Bohmont (1983) for details about various herbicide applications.

I. Foliage application
   A. Foliage spray (selective 2,4-D and related phenoxy herbicides, dalapon, dicamba, parquat (at low rates), pimorod, triclopyr; nonselective amitrole, ASM, diesel oil, glyphosate).
      1. Aerial (airplane or helicopter) (fig. 3).
      2. Ground (hand and power equipment).
         (a) Non directional (mist blowers).
         (b) Directional (boom sprayers; single nozzle sprayers) (fig. 4).
            (1) In row (rowed plants physically protected from spray by shields).
            (2) Strip (chemical seedbed preparation for interseeding) (fig. 4).
   B. Wipe on (rope wicks, rollers, or sponge bars).
   C. Dust (unimportant on range or wildlands).

II. Stem application (individual plant) (2,4-D, hexazinone, pimorod, triclopyr) (fig. 5).
   A. Trunk base spray (may be enhanced by use of frills or notches).
   B. Trunk injection.
   C. Cut stump treatment (fig. 6).

III. Soil application (selective; atrazine, dicamba, fenac [partly], monuron, pimorod, tebuthiuron [partly], nonselective; bromacil, hexazinone, karbutilat [now tabled]).
   A. Broadcast (spray, granules, or pellets).
   B. Grid ball (spaced placement of pellets).
   C. Individual plant or motte.

Figure 3—Helicopter equipped with boom sprayer.

A

Figure 4—Boom sprayers can be (A) hand held and (B) vehicle mounted. Spraying strips of crested wheatgrass with Roundup to facilitate transplanting desired shrubs.

1. Soil injection (liquid).
2. Soil surface placement (around stem base or spread under canopy).

Broadcast spray application has been the most commonly used method on rangelands. Because an herbicide is applied to desirable as well as undesirable plants on the site when broadcast, selective herbicides are required. Broadcast spray applications can be made either by ground rigs or by aerial application. When herbicides are applied by ground rigs, a spray volume of 10 gal/acre (93.5 L/ha) is common but volume may vary from 5 to 40 gal (46.8 to 374.2 L/ha) depending on need. With aerial application, spray volume can be reduced down to 1 to 3 gal/acre (9.3 to 28.1 L/ha), with ultra low volumes down to 0.50 gal/acre (4.7 L/ha) or even less being satisfactory in some situations.

The comparative advantages of using ground application or aerial application of herbicide sprays are as follows:
Chapter 10  Herbicides for Plant Control

Although fixed wing aircraft are more commonly used, helicopters are advantageous in some situations (USDA Agricultural Research Service 1976). Helicopters that require no landing strip are interfered with less by trees, snags, and steep terrain, permit slower air speed for application, and have greater maneuverability. However, they are generally less available when needed, have less lifting power in thin, warm air, have less payload capacity (50 to 150 gal [190 to 570 L]) compared to 125 to 600 gal [475 to 2,270 L] for fixed wing aircraft), and are more costly per acre on larger projects.

Foligespray application with ground rigs generally use boom applicators that are as narrow as 4 ft (1.2 m) for hand application to as wide as 100 ft (30.5 m) for self propelled systems. Ground sprayers adapted to range use are discussed by Young and others (1979b). Maxwell and others (1983) describe adapting all-terrain vehicles for herbicide application on difficult-to-reach sites. Boomless ground applicators have been used conveniently in tall brush, along fence rows, or in very rough terrain. Such mist blowers have been used in applying low levels of phenoxy herbicides, using crosswinds of 5 to 12 mph (8 to 19 km/h), thereby permitting strips up to 100 ft (30.5 m) wide to be covered.

Wipe-on applicators have permitted taller, noxious plants to be controlled with nonselective herbicides without damaging low growing desirable plants (Mayeux and Crane 1983; Messersmith and Lym 1981; Moomaw and Martin 1985). Wipe-on applicators have advantages in applying selective herbicides because low volume is required, the total amount of herbicide used is reduced, spray drift is mostly eliminated, and low cost equipment can be used in getting selective control.

Individual plant treatments including wetting sprays, stem application (fig. 6), or soil application may have advantages over broadcast application for spot infestations, for widely scattered plants, on terrain that is too rough for wheeled machinery, or where only a small portion of the plants are to be removed, such as in commercial forests. Individual plant treatment generally allows nonselective herbicides to be used selectively through positive control of spray direction. However, individual plant treatments have a high cost per plant, high labor demand, slow job completion, and are difficult to control when treating plants over 6 ft (1.8 m) high with a foliage application. Hand held boom sprayers or mist blowers provide advantages somewhat intermediate between broadcast application and individual plant treatment.

Soil injection, soil surface placement around the stem base, application in continuous narrow bands on the soil surface or underground, or use of the gridball technique permit nonselective herbicides to be used.
with significantly reduced herbaceous plant injury. The gridball technique provides for placing pellets in grid fashion, resulting in conical columns of active herbicide in the soil that can intercept the deep roots of woody plants while minimizing intercept by the roots of herbaceous plants.

Where desired, applying soil-active herbicides in granular or pellet form has the advantage of minimizing drift, not being intercepted by foliage, having controlled release, ease of handling and application, premixing; thereby reducing formulation errors, simple application equipment generally, and prolonged soil activity.

What to Apply __________________

The following terminology will be useful in evaluating the characteristics of herbicides:

Herbicide, a chemical that kills plants (syn. phytocide).

Contact, an herbicide that kills only plant parts directly exposed to the chemical and is direction toxic to living cells.

Translocated, an herbicide applied to one part of a plant that is spread throughout the plant where effects are produced (syn. synthetic hormone herbicide, systemic herbicide, or growth regulator).

Selective, an herbicide that kills or damages a particular plant species or group of species with little or no injury to other plant species (are often nonselective at heavy rates).

Nonselective, an herbicide that kills or damages all plant species to which it is applied (general weed killer).

Soil sterilant, an herbicide that kills or damages plants when herbicide is present in the soil. The effect may be temporary or permanent and either selective or nonselective.

The properties of herbicides used or proposed for use on rangelands are given in table 1. General information on clearance and general uses are given for each herbicide. More detailed information on individual herbicides can be found in Berg (1985), Bohmont (1983), Bovey and Young (1980), Spencer (1982), Thomson (1983), and Weed Science Society of America (1989).

The phenoxy herbicides, primarily 2,4-D (and also MCPA and 2,4-DP or dichlorprop in some areas, or 4-DB when damage to legumes is to be avoided) have been the most widely used on rangelands. Silvex and 2,4,5-T, previously widely used in brush control, by regulation can no longer be manufactured or used in the United States or Canada.

New herbicides such as glyphosate, tebuthiuron, hexazinone, and triclopyr are now in widespread use on western rangelands. Other potential range herbicides still in the experimental stages are karbutilate, fosamine, clopyralid, buthidazole, ethidimuron, prodiamine, and metribuzin.

Soil-active herbicides may be selective or nonselective and have either temporary or lasting effects. Herbicides such as dicamba and picloram are effective when applied to either soil or foliage. Atrazine, fenac, 2,3,6-TBA, and tebuthiuron are effective only when applied to the soil. Soil-active only herbicides are generally applied as dry granules or pellets since vegetation will intercept some or most of the spray, but other soil-active herbicides can be applied in either dry or liquid form.

Only a few herbicides have been effectively used, either singly or in combination, on range sites in preparation for seeding or transplanting. Chemical application followed by direct seeding into the killed mulch, without further soil treatment, is effective if the herbicide (1) controls a broad spectrum of undesirable plants, (2) dissipates rapidly after weed control is accomplished, and (3) is broken down or leached away by the time seeded species germinate, or is not toxic to seedlings of the seeded species (Eckert and Evans 1967). Chemical fallow during the previous growing season has been more successful in low rainfall areas than spring herbicide treatment and seeding.

The herbicide 2,4-D has been effective in chemical seedbed preparation on those sites where the principal competition has been brush and forbs susceptible to it, such as on big sagebrush or tarweed sites (Hull and Cox 1968). Aerial spraying with 2,4-D and drilling with a rangeland drill have been effective for establishing additional perennial grasses on sagebrush-grass and forb-grass sites with a fair understory of perennial grasses. A second herbicide application may be required in the spring of the establishment year if sprouting shrubs such as rabbitbrush are present or a large number of sagebrush seedlings develop.

Picloram can be used in chemical seedbed preparation where rhizomatous forbs and shrubs not killed by 2,4-D are present. Although low chemical residual amount in the soil will not be harmful to grass seedlings, 2 or 3 years must be allowed before forb and shrub species are introduced following picloram application.

On sites dominated by annual grasses, spring application of paraquat and drilling perennial grasses have been effective. Since paraquat is quick acting and leaves no soil residues, planting of perennial forage species can follow immediately (Evans and others 1975). Paraquat has only a temporary effect on perennial grasses and does not kill most broadleaf plants. Where broadleaf weeds and undesirable shrubs are growing with cheatgrass, 2,4-D should be combined with the paraquat application (National Research Council 1968). Band "tilling" with paraquat and drilling down the center of each band has also been effective on annual grass sites (Kay and Owen 1970).
<table>
<thead>
<tr>
<th>Common name (trade name)</th>
<th>Group and type of herbicide</th>
<th>Uses, restrictions</th>
<th>Range and pasture uses; comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transline)</td>
<td>+2,4-D (Curtail)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicamba (Banvel)</td>
<td>Benzoic; selective, translocated, foliage or soil</td>
<td>Cleared for pasture and range at rates up to 8 lb a.e./acre (9 kg/ha); LD$_{50}$ = 566 to 1,028</td>
<td>Controls difficult plants such as Russian knapweed, Canada thistle, leafy spurge. Also useful in brush control. Persists in soil for up to a few months. Low volatility</td>
</tr>
<tr>
<td>+2,4-D (weedmaster)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,4-D (several trade names)</td>
<td>Phenoxo; selective translocated, foliage</td>
<td>Pasture and range; LD$_{50}$ = 300 to 1,000</td>
<td>Highly effective as foliage spray on many broadleaf herbaceous plants and some shrubs. Also used in furrit cuts. Persists in soil for 1 to 4 weeks. Volatility depends on chemical form</td>
</tr>
<tr>
<td>Glyphosate (Roundup)</td>
<td>Aliphatic; nonselective translocated</td>
<td>Range and pasture; broad spectrum herbicide; LD$_{50}$ = 5,000</td>
<td>Used in brush control but also kills desirable grasses and forbs. Used to kill foliage. Undesirable grasses such as foxtail barley or saltgrass. Persists 1 to 3 weeks in soil. May be applied selectively</td>
</tr>
<tr>
<td>Oust (Oust)</td>
<td>Sulfometuron methyl; translocated by roots and foliage; partly selective, temporary soil sterilant</td>
<td>Rangelands, forestry, and noncroplands</td>
<td>Kills annual grasses at rates between 0.25 to 1.0 oz/acre; can be fall and spring applied. Persists 1 to 2 years. Sensitivity of most native species is not known. Can be used to control and exhaust seed bank of annual weeds. Fall seeding 1 year after treatment appears successful</td>
</tr>
<tr>
<td>Paraquat (Paraquat, Granonione)</td>
<td>Bipyridyl; selective to nonselective contact, foliage</td>
<td>Use as spot treatment on noncrop or for pasture or range renovation; LD$_{50}$ = 150</td>
<td>Selectively kills annual grasses by application at 0.25 to 1 lb/acre (0.28 to 1.12 kg/ha); can be applied just prior to range seeding. Rapid acting, nonvolatile. Soil contact inactivates. Has minor effect on broadleaf perennials. Low rate chemically cures but does not kill perennial grasses</td>
</tr>
<tr>
<td>Picloram (Tordon)</td>
<td>Picolinic; selective, translocated</td>
<td>Range and pasture; LD$_{50}$ = 8,200</td>
<td>Effective on leafy spurge, Russian knapweed, low and tall larkspur, whorled milkweed, and also many shrubs, such as rabbitbrush and oaks. Nonvolatile. Rates over 1 lb/acre (1.12 kg/ha) may persist for 2 or 3 years. Often synergic with phenoxy herbicides</td>
</tr>
<tr>
<td>+2,4-D (Grazon P + D)</td>
<td>Phenoxo; selective translocated, foliage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tebuthiuron (Spike)</td>
<td>Substituted urea; partly selective, translocated, soil</td>
<td>Cleared for range use in some states; LD$_{50}$ = 286 to 644</td>
<td>Holds promise for controlling woody plants. Persists up to several months. Spot apply for broadcast as pellets. Selective at 0.5 lb/acre rate or when high rates applied selectively</td>
</tr>
<tr>
<td>Triclopyr (Garlon)</td>
<td>Phenoxo-picolinic; selective, translocated, foliage</td>
<td>Experimental on rangelands; LD$_{50}$ = 713</td>
<td>Shows promise on broadleaf weeds and shrubs including oaks and other root sprouters Also effective in basal spray and trunk injection. Degraded rapidly in soil</td>
</tr>
<tr>
<td>+2,4-D (Crossbow)</td>
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</tbody>
</table>

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*Registration of herbicides for range and pasture uses and the accompanying restrictions are subject to continual change. Current clearance and restrictions at both State and Federal levels should be checked and complied with. Silvex, Amitrole, Dalapon, Atrazine, Fenatrol, and 2, 4, 5 T have been removed from the market or are no longer approved for use on rangelands in the United States and Canada. LD$_{50}$ taken from Weed Science Society of America (1989). See Woodward (1982) for herbicide tolerance of trout.

*Publication directed herbicide control of individual plant species (Bartel and Rittenhouse 1979; Bowes 1976; Britton and Sneva 1981, 1985; Ciary and others 1985a, b; Cronin and Nelson 1979; Eckert 1979; Eckert and Evans 1967; Engle and others 1983; Evans and Young 1975a, 1977b, 1985; Evans and others 1975; Hull 1971b; Hull and Cox 1968; Johnsen and Dalen 1984; Marquiss 1973; Miller and others 1980; Mohan 1973; Roeth 1980; Sneva 1972; Thilenius and Brown 1974; Thilenius and others 1974b; Van Epps 1974; Warren 1982; Whitton and Alley 1984; Williams and Cronin 1981; Wilson 1981; Young and Evans 1971, 1976; Young and others 1984c.*
Herbicides for Plant Control

Chapter 10

Herbicide Approval

All pesticides must be registered by the Pesticides Registration Division, Office of Pesticides Programs, Environmental Protection Agency, before entering into interstate or intrastate commerce. The Environmental Protection Agency approves all uses of pesticides including herbicides, regulates instructions on pesticide labels, sets tolerances in animal feeds and human foods, may seize any raw agricultural commodities not complying with these tolerances, and can punish violators using nonregistered pesticides or making unapproved use of registered herbicides.

Herbicides approved for range use are not hazardous to livestock, wildlife, or humans at recommended application methods and rates. Environmental Protection Agency registration of herbicides is intended to insure that they are released for public sale and use only after detailed research and thorough testing. Tolerance levels set for human intake of pesticides include rather large safety factors and are generally set at one percent or less of the highest level causing no adverse effect in the most sensitive animal species; but zero tolerance is mandatory in some cases.

The relative degree of toxicity of the various herbicides to warm-blooded animals has been determined experimentally. The relative degree of toxicity is expressed as the acute oral LD₅₀ (the single dosage by mouth that kills 50 percent of the test animals expressed as mg/kg of body weight). The LD₅₀ for each herbicide is given in table 1. Toxicity classes are related to LD₅₀ levels as follows:

<table>
<thead>
<tr>
<th>Class</th>
<th>LD₅₀ (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly toxic</td>
<td>50 or less</td>
</tr>
<tr>
<td>Moderately toxic</td>
<td>50 to 500</td>
</tr>
<tr>
<td>Mildly toxic</td>
<td>500 to 5,000</td>
</tr>
<tr>
<td>Nontoxic</td>
<td>Above 5,000</td>
</tr>
</tbody>
</table>

In addition to the Environmental Protection Agency, one lead agency within each State is designated by its governor to participate in pesticide regulation. Individual States may have special registration and use requirements for pesticides. Also, the designated State agency is charged with certifying pesticide applicators. Only certified pesticide applicators are permitted to purchase and use "restricted use" pesticides, including paraquat and picloram, or those on emergency exemption.

In addition to the regular Federal registration of pesticide uses, three special registrations are provided for additional pesticide use approval.

1. Experimental label. This special Federal label permits new products, or old products being considered for removal of registration, to be further researched and evaluated before final approval is given.

2. Emergency exemption. The Federal administration of the Environmental Protection Agency may exempt any Federal or State agency so requesting unapproved pesticide usage provided that the emergency requires such exemption.

3. Special state label. A state may provide registration for additional uses of Federally registered pesticides within the State, if such uses have not previously been denied, disapproved, or cancelled by the Environmental Protection Agency. Final approval of the State

Fall application of 0.5 to 1 lb/acre (0.6 to 1.1 kg/ha) of atrazine has effectively controlled cheatgrass during a chemical fallow period (Eckert and Evans 1967; Young and others 1969b). However, at least 1 year must be allowed for dissipation prior to grass seeding. When atrazine is used for chemical fallow, adequate broadleaf control may require spring application of 2,4-D (National Research Council 1968). Integrating 2,4-D or picloram spraying for brush control and atrazinefallow for cheatgrass control has proven effective in Nevada (Evans and Young 1977b).

Dalapon has been more effective than either paraquat or atrazine in killing medusahead (Young and Evans 1971). Since dalapon is slower acting than paraquat and the residual remains longer in the soil, grass seeding should be delayed for at least 6 weeks following dalapon application. Dalapon gives some control of perennial grasses but is ineffective on broad leaved plants.

One of the most promising herbicides for site preparation for range revegetation is glyphosate (trade name, Roundup). When broadcast sprayed or applied in strips, it provides nearly complete kill of all resident vegetation. Since it dissipates rapidly in the soil, seedings can be made within 1 to 3 weeks after glyphosate applications. Although effective in brush and weed control, it has also been effective on foxtail barley and saltgrass.

Oust has remained effective in controlling cheatgrass for 2 years when applied at 1 oz/acre. Satisfactory stands of crested wheatgrass have been established by drill seeding into the treated sites 1 year after fall treatment. Although individual species exhibit different degrees of sensitivity, it appears sites treated at rates up to 1.0 oz/acre can be planted within 180 days following fall treatment.

The compiled herbicidal plant control recommendations published by the respective State agricultural experiment stations and extension services, many of these revised annually, are current and locally adapted. Examples include Alley and others (1978), Chase (1984), Cords and Artz (1976), Dewey (1983b), Duncan and McDaniel (1991), Heikes (1978), Hepworth (1980), or Washington Agricultural Extension Service (1984) or their revisions or replacements. Other compiled sources of individual plant control recommendations include Bovey and Rodney (1977), Hamel (1983), Spencer (1982), and USDA Science and Education Administration (1980).
Evaluating Herbicide Sprays

Preparation of a spray mix involves mixing the commercial product formulated by the manufacturer with the right kind and amount of carrier and adding any additional surfactant needed. The combination of formulation, dilution with the carrier, rate of application, and method of application generally determines whether a recommended herbicide will be highly selective and effective or not. The proper preparation and use of herbicides requires an understanding of the following terms:

Toxicant, the herbicide or chemical agent that causes a toxic effect on plants.

Carrier, the diluent in which the toxicant is mixed to provide greater bulk for more effective application.

Commercial product, the herbicide formulation prepared in liquid form for spray application.

Surfactant (surface active agent), materials used in herbicide formulation to facilitate or accentuate emulsifiability, spreading, wetting, sticking, dispersibility, solubilization, or other surface modifying properties.

Active ingredient, that part of a commercial product or spray mix that directly causes the herbicidal effects.

Acid equivalent (a.e.), the amount of active ingredient expressed in terms of the parent acid or the amount that theoretically can be converted to the parent acid.

The active ingredient of phenoxy herbicides is expressed in terms of acid equivalent. This is a relative term relating esters and salts to the pure acid, a form that is seldom available but may occur in minor amounts mixed with the other chemical forms. The acid equivalent is a more precise measurement than the actual amount of the particular chemical form. However, acid equivalent measures toxicity only indirectly since other factors in the formulation also affect toxicity to plants. For example, the ester chemical forms of 2,4-D are more toxic per unit of acid equivalence (a.e.) than the salt forms or the pure acid. The herbicide label on the commercial product generally provides the amount of toxicant therein in terms of both (1) lb a.e./gal, and (2) percent a.e. (by weight).

Water is the carrier most commonly used today, but the addition of diesel oil to comprise up to 25 percent of the total carrier may increase effectiveness with some woody plants. Water has good driving force through the upper foliage, is easier to work with, and is low cost; but the addition of diesel oil often reduces evaporation of the spray mix, spreads more evenly on the leaf, and penetrates plant cuticles better. Surfactants increase emulsifiability, spreading, sticking, and other desirable surface modifying properties of the spray mix. They are added to the commercial product at the factory, but additional amounts or kinds may be included in specific recommendations. However, excessive use of surfactants may reduce or eliminate normal selectivity of an herbicide.

Herbicide recommendations are generally given in one or more of the following ways:

1. Pounds of active ingredients (or acid equivalent) per acre, or per square rod, for broadcast application.
2. Pounds of active ingredients (or acid equivalent) per 100 gal of mix (a.e.h.g.) for wetting sprays, frill or cutstump application, or plant or soil injection.
3. Weight (grams or ounces) or volume (tablespoons or cups) of commercial product per plant or clump of plants.

The amount of herbicide required to provide adequate control varies with kind and chemical form of herbicide, plant species, and method of application. Herbicide rate recommendations primarily consider optimum toxic effects within legal limits. Higher rates are rarely more effective and may prove detrimental; selective herbicides often become nonselective when applied at excessive rates. However, reducing rates below recommended levels to save money or to be environmentally conscious may sharply reduce kills, particularly when less than ideal conditions are encountered.

Greater selectivity can be realized with herbicides by carefully controlling the application rate, fully considering the relative growth stages of the target and nontarget plant species, using appropriate or even differential application techniques, and using adequate but not excessive amounts of surfactants. When multiple herbicides are required for additive or synergistic effects, or when repeat applications are required for satisfactory kill, the single application of one herbicide but at a higher rate is seldom a satisfactory alternative.

Calculations

The following are examples of calculations frequently used in mixing and applying herbicides:

1. Rate per acre for liquid formulation. If 2 lb a.e. per acre is recommended and a commercial product containing 4 lb a.e. per gallon is purchased, then use the following:

   \[ \frac{2 \text{ lb a.e./acre}}{4 \text{ lb a.e./gal. product}} = 0.5 \text{ gal (or 4 pt) of product is required per acre. Add enough carrier to give desired volume of spray mix, and apply.} \]

2. Rate per acre for granular form. If 3 lb active per acre is recommended for a commercial product.
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containing 10 percent active ingredients in granular form then use the following:

\[
\frac{3 \text{ lb a.e./acre} \times 100\%}{10\%} = 30 \text{ lb of granules is required per acre.}
\]

3. Rate per gallon for wetting spray. If a “wetting” spray containing 6 lb acid equivalent per 100 gal (a.e.h.g.) is recommended and a commercial product (C.P.) containing 2 lb a.e. per gallon is used, then use the following:

\[
\frac{6 \text{ lb a.e.h.g.} \times 256}{2 \text{ lb a.e./gal in C.P.} \times 100} = 7.68 \text{ T of C.P. is required per gal of spray mix. Apply to plants until wet.}
\]

4. Amount per small plot. If a 400 ft² plot is to be sprayed at the rate of 3 lb a.e./gal and a commercial product containing 4 lb a.e./gal is used, then use the following:

\[
\frac{3 \text{ lb a.e./gal \times 400 ft}^2 \times 256}{4 \text{ lb a.e./gal in C.P.} \times 43,560} = 1.76 \text{T of C.P. is required. Add enough carrier to give desired amount of spray mix and apply to plot.}
\]

5. Amount per field unit. If a 150 acre unit is to be sprayed with 2 lb a.e. of 2,4-D in 10 gal of spray mix per acre, and a commercial product containing 6 lb a.e./gal is used, then the following is needed:

Total spray = 1,500 gal (150 acre \times 10 gal/a)
Commercial product = 50 gal (2 lb \times 150 acre \div 6 lb)
Carrier = 1,450 gal (by subtraction)

\[1 \text{ gal} = 4 \text{ quarts} = 8 \text{ pints} = 16 \text{ cups} = 256 \text{ tablespoons} = 768 \text{ teaspoons} = 231 \text{ inches}^3 = 3.785 \text{ L.}\]

When to Apply

The age, stage of growth, and rapidity of growth affect the susceptibility of plants to herbicides. The most effective kill by phenoxy herbicides and most other foliage-applied, translocated herbicides is obtained when carbohydrate production and translocation rate is at the maximum, often near full leaf stage (fig. 7). Since such herbicides are carried with the photosynthate stream throughout the plant, intrinsic plant factors as well as external environmental factors that stimulate growth generally increase plant kill. Maximum growth rate and herbicide kill are associated with ideal soil moisture and fertility, ideal temperature, and adequate light.

Reduced susceptibility periods of desirable species in the plant composition can often be found and followed. For example, 2,4-D should be applied early in the spring for big sagebrush kill, in order to reduce damage to bitterbrush (fig. 8). Spraying at the time of leaf origin in bitterbrush, and before the appearance of distinct twig elongation or flowering, generally causes only slight damage to large bitterbrush plants. Selective application methods permit nonselective herbicides to be used selectively.

Foliar herbicide application must be timed not only to coincide with ideal plant growth stages, but the best associated environmental and climatic conditions as well. To get the best kill from broadcast spraying of phenoxy herbicides, do not spray:

1. During prolonged drought when low soil moisture retards plant growth.
2. Before most leaves are well developed—exact timing will vary somewhat between different plant species.
3. After leaves have stopped growing rapidly, begin maturing, and develop thickened cuticles.

Figure 7—Mountain big sagebrush killed with aerial spraying of 2,4-D. Spraying occurred when growth rate, soil moisture, temperature, and light were ideal. With better control of helicopter flight paths there would not have been misses that are evident in the background.

Figure 8—With proper timing, big sagebrush was killed and antelope bitterbrush was unharmed by aerial spraying of 2,4-D.
4. When plant growth has been retarded by late frost, hail, insects, or excessive leaf removal by grazing.

5. When temperature is over 90°F (32.2°C) or under 55°F (12.8°C). (Temperatures between 70°F [21.1°C] and 85°F [29.4°C] are best).

6. When wind is above 10 mph (16 km/h) for aerial application or 15 mph (24 km/h) for ground spraying, or when the air movement is great and updrafts.

7. When thunderstorms are approaching. (Rain 4 or 5 hours after spraying will reduce effects very little.)

Soil surface application is less dependent on stage of plant growth than foliage sprays but does require precipitation to dissolve and move the herbicide into the soil. Application just prior to normal rainy season is ideal unless excessive leaching is anticipated then.

**Herbicides Can be Effective and Safe**

Even though herbicides are among the least hazardous of all pesticides, recommended safeguards in their handling and application must be followed. These routine safeguards include following all directions and restrictions shown on the pesticide label, storing pesticides only in the original containers, properly disposing of excess chemicals, and cleaning spraying equipment after use.

Herbicides now approved for range and pasture use pose no hazard to livestock, wildlife, the applicator, or local inhabitants when properly applied. The Environmental Protection Agency requires temporary removal of livestock following application of the most toxic herbicides, but this is mostly precautionary or directed to dairy cows only. However, livestock should be denied access to spraying equipment, herbicide containers, or herbicide in concentrated form. Herbicides may temporarily increase the palatability of treated plants, and this may increase the hazard from poisonous plants. In some cases the natural poisoning agent in the poisonous plants may be increased also.

For these reasons, care must be taken that poisonous plants affected by herbicides are not grazed until they begin to dry and lose their palatability (generally 3 weeks or more after herbicide application).

Proper swath widths are important in preventing skips or overlapping of swaths and in obtaining complete coverage of the foliage in broadcast spray application. Since height above the ground will affect swath width, it should be carefully controlled. Application rates should be checked periodically by proper calibration methods and corrected as needed (Bohmont 1983; Portman 1984; Young and others 1979b). Flagging is essential in aerial application, and some form of ground marking will generally be required with ground application. Many aircraft are now equipped with automatic flaggers that dispense strips of wet, colored paper to mark flight lines reducing or eliminating the need for manual flagging. Gebhardt and others (1985) described a foam marking system for use with boom sprayers operated on the ground.

Herbicide drift is a special problem associated with foliage spray applications, and can be hazardous to susceptible plants downwind unless controlled. The direction, distance, and amount of spray drift that occurs before the herbicide reaches the ground are influenced by several factors. Drift is reduced by increased size of droplets and higher specific gravity of the spray mix, lower evaporation rate, reduced height of release, low velocity of the wind, no vertical air movements, and carefully selected application equipment. Spray drift is a greater problem in aerial application because of the elevated release point and air turbulence generated, but can be serious in ground application as well. Herbicides that volatize after application are again subject to wind movement. Certain ester forms of the phenoxy herbicides are highly volatile while others are not. Low volatile ester or salt forms should be selected for use if susceptible crops or areas to be protected are in the immediate vicinity.

In addition to using herbicide formulations with low volatility and thus drift potential, other means of reducing drift of herbicides include:

1. Using application equipment that will maintain adequate size and uniformity of droplets. Finely atomized spray drops may drift from the target area or evaporate before reaching the foliage. Spray droplets should be large enough to minimize drift hazards and yet be sufficiently small and properly distributed to give good coverage.

2. Reducing height of release, particularly in aerial application.

3. Avoiding spraying on windy days and when vertical air movement is great; favorable conditions are more apt to be found in early morning, late evening, and night.

4. Using water as the carrier since water droplets are heavier and drift less than oil droplets, while being aware that antievaporants may be needed to reduce evaporation in dry atmospheres.

5. Selecting spray days with a slight, continuous wind movement blowing away from susceptible crops or other nontarget areas.

6. Using positive liquid shutoff systems in aerial application and avoiding flights over susceptible crops.

7. Using invert emulsions (water in oil), recognizing that special equipment will be required for application because of its thick, nonflowing physical characteristics.
