MANIPULATIVE RANGE IMPROVEMENTS—PRINCIPLES AND PRACTICES

CARLTON H. HERBEL
U.S. Department of Agriculture

Our expanding population is demanding more productivity from our rangelands. Range science is concerned with the plants, animals, soils, and waters on rangelands, and particularly, the interaction of these factors. Native plant communities should only be used as guides to determine site potential. Extensive practices on rangelands include manipulation of animals and burning. Intensive practices include control of unwanted plants, revegetation, and fertilization. When properly conducted, intensive manipulative practices result in much higher production than occurred before treatment.

The most effective method, whether chemical or mechanical, for control of unwanted plants varies with the site, the species, and the degree of infestation. Revegetation may be required where desirable vegetation has been depleted by past grazing abuses, droughts, and encroachments of unwanted plants. Water is generally the primary factor limiting plant growth but when that need has been satisfied, additional plant nutrients such as nitrogen and phosphorus may be useful. Principles and practices of plant control, revegetation, and fertilization are presented. These more costly practices are riskier and require higher management inputs, but the potential benefits are great. With changing technology or favorable economic conditions, the range manager may decide to intensify his range improvement efforts.

INTRODUCTION

Our expanding population is demanding increased productivity from all of our agricultural lands, including rangelands. The rise of our present civilization has been made possible by the advances of food production in agriculture. This development occurred because people were able to influence their environment. The primary principle of range management is that the natural plant communities provide the best guides to potential herbage cover and production (Love 1961). We must remember that the native plant communities are only guides to site potential. Some plant species may be introduced to an area, by the use of manipulative treatments, that may be superior in some, if not all, aspects of rangeland management. An example of this is the introduction of crested wheatgrass (*Agropyron desertorum*) in some of the western areas of Canada and the United States. These manipulative treatments require the application of ecologic and agronomic principles. Both sciences involve the use of factors inherent in studies of climate, soils, plants, and animals.

This paper is an attempt to establish some of the major principles that the resource manager should consider when conducting manipulative treatments of rangelands. The following definition is used:

> Rangelands are a land resource dominated by native vegetation or introduced plants, i.e., grasses, grass-like species, forbs and/or shrubs, suitable for grazing or browsing uses and for other beneficial uses. Rangelands include natural grasslands, savannahs, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows (adapted from Kothmann 1974).

It is useful to conceptualize the practices used in range science in a diagram (Fig. 1). The extensive category is discussed in this paragraph. Manipulating the grazing animal, as in various grazing systems, does not by itself result in large economic gains by the user (Herbel 1973). Similarly, burning of old growth may result in making more new growth available to the grazing animal, but by itself burning will not result in large economic gains for the user (Wright 1974). Both grazing systems and burning may result in a shift in the plant composition of the plant community. After several years, this shift in plant species composition may permit the operator to increase the use of the resource. Therefore, as long as the operator practices sound ecological principles that maintain or slightly improve the rangeland resource, there is little risk in manipulating the grazing animal or burning the exisiting vegetation. Similarly, the cost of implementing these practices is relatively low. It is true that the manipulation of animals may require additional fencing and water resource development, but costs related to these changes are comparatively low. The benefits obtained from these practices are relatively small, i.e., when grazing systems and burning are initiated and practiced over a number of years, large shifts in the production of rangelands do not generally occur. Furthermore, large inputs from management are not not required to properly conduct a grazing system or a burning program. These practices are instituted and the land manager obtains the results in several years. Grazing systems and burning programs may be generally considered as extensive practices largely based on ecological principles. The definition of ecology used here is:

> Ecology is the branch of science concerned with the relationships of organisms with their environment.

RANGE SCIENCE

Extensive	Intensive
Low Risk	High Risk
Low cost	High Cost
Low Production	High Production
Low Benefits	High Benefits
Low Management Inputs	High Management Inputs

Sciences

Ecology — Agronomy

R a n g e S c i e n c e

Practices

Manipulating Grazing

Burning

Control of Unwanted Plants

W a t e r M a n a g e m e n t

R e v e g e t a t i o n

F e r t i l i z a t i o n

0 200 400 600 800 1000

Potential Productivity (% increase)

Figure 1. Concept of range science

As applied to range management, ecology generally means plants native to that environment, and the management of those plants.

On the other hand, drastic manipulations of range ecosystems are sometimes required or desired. The invasion of unwanted plants, severe droughts, past abuses by grazing animals, or the desire by the operator to change plants, or production, on all or part of the range unit, result in practices to control the unwanted plants and/or to revegetate with desirable plants. The latter practices require great attention to every detail, as will be discussed later. The risk of using plant control or revegetation is high because if attention is not given to every detail, or even sometimes when everything is done correctly, the practice(s) may not give the desired effects. The relative costs of these practices are high. The potential benefits are high. Control of unwanted plants, revegetation, and/or fertilization may result in increasing production of that land 100 to 1,000 percent within 1-3 years (e.g., Herbal et al. 1977). High management inputs are required because if these risky, costly practices are used, the land manager should attempt to maximize the outputs while maintaining the basic resource and minimizing the need to repeat the practice. To implement revegetation one may ask the question, what is the potential for this site? Are there plant species, even on the other side of the world, that may be more productive or better meet a particular requirement than the plants growing there now? Generally, control of unwanted plants, revegetation, and fertilization are intensive, agronomic practices for rangelands with the use of some ecologic principles. The definition of agronomy used here follows:

> Agronomy is the branch of science concerned with plant production and soil management.

As applied to range management, agronomic practices generally refer to intensive agricultural practices such as revegetation (particularly at 1 to 3-year intervals), weed control, and fertilization. In considering the control of unwanted plants, revegetation, and fertilization, we will be discussing both agronomic and ecologic principles.

Few, if any, land managers use only agronomic principles exclusively on a unit of rangeland. Rather, some combination of beneficial practices is used whereby both ecologic and agronomic principles are utilized. For increased plant production and soil protection in the future, each unit of rangeland must be managed to maximize economic and cultural factors while maintaining or improving the basic resource. In the Northern Great Plains of Canada and the United States, this may mean seeding part of the range unit with Russian wildrye (*Elymus junceus*) and crested wheatgrass, and using nitrogen fertilizer on both native and introduced species (e.g., Smoliak 1968). In portions of the Northern Great Plains, the best practices may include judicious burning practices on parts of the native rangeland and plowing up the native sod on some of the better sites and seeding wheat for forage, or for forage and grain. On the semiarid Southern Great Plains of the United States and associated grasslands of Mexico and the United States, the best strategy may include seeding weeping lovegrass (*Eragrostis curvula*), sideoats grama (*Bouteloua curtipendula*), wheat, and sudangrass (McIlvain 1976). In the arid portions of the southwestern United States and northern Mexico, range productivity could be greatly increased by control of mesquite (*Prosopis juliflora*) and tarbush (*Flourensia cernua*) and seeding with Lehmann and Boer lovegrass (*Eragrostis lehmanniana* and *E. chloromelas*) and fourwing saltbush (*Atriplex canescens*) (Herbel et al. 1977). Where big sagebrush (*Artemisia tridentata*) is growing on rangeland, control of the sagebrush and seeding with crested wheatgrass will often result in much greater productivity and soil stability than would be obtained with the native plants. In some instances, composition of plant species may be manipulated to improve wildlife habitat, while at the same time maintaining or improving livestock production. The use of various practices is changing with time as dictated by economic or social conditions, or as improved technology becomes available. Range science utilizes various principles for use on rangelands. It may be defined thusly:

> Range science (range management) is a branch of science concerned with plant, animal, soil, and water management on rangelands, and the interaction of those factors. Ecologic, agronomic, and other principles are used where appropriate.

However, we should not be bound by semantics; some people use broader or narrower definitions for "agronomy" and "ecology". It is only important that the range resource is maintained or improved as it is managed to meet various objectives. My plea is for land managers, and others working with land managers, to be flexible and innovative in planning operations on a range unit. What will work well on one range unit may not work as well on the range unit next to it, or on the range unit 250 km distant. Differences in opinion over management objectives can, and do, lead to serious conflicts. The manipulations discussed in this paper include: control of unwanted plants, revegetation, and fertilization. These are relatively intensive practices that require much attention to detail.

CONTROL OF UNWANTED PLANTS

Many millions of hectares of rangeland around the world are dominated by, or are being invaded by, unwanted plants. In North America, most brush cover is native vegetation that has invaded large areas of former grasslands and savannahs, converting them into brushlands and woodlands. Originally, woody plants were present as a lesser component of the climax vegetation of grazing lands. In semiarid and subhumid rangelands having sufficient fuel, repeated fires kept grasslands relatively free of woody plants. During those times, less intensive utilization of forage by animals permitted enough litter to accumulate to serve as fuel for the occasional fires that killed young trees and shrubs. After colonization, intensive livestock grazing steadily reduced the amount of fuel available for fires, and this method was largely stopped on rangelands (National Academy of Sciences 1968). There has been an accelerated invasion of rangelands by undesirable shrubs. For example, mesquite dominated only 5% of a southern New Mexico range in 1858 before colonization, but dominated about 50% of the range in 1963; creosotebush (*Larrea tridentata*) occupied less than 1% of the area in 1858 and more than 14% in 1963; and tarbush dominated less than 1% of the area in 1858 and about 9% in 1963 (Buffington and Herbel 1965).

Once established, woody plants such as mesquite, juniper (*Juniperus* sp.), oak (*Quercus* sp.), cresotebush, tarbush, and sagebrush cannot be eliminated by proper grazing practices alone. The unwanted plants must be controlled before rangelands can benefit from other practices such as grazing systems, revegetation, fertilization, or water management. Each method of suppressing unwanted plants has advantages and disadvantages, but the objective in all cases is to substitute desirable plants for those not wanted. The most effective method for control of unwanted plants depends on the site, the species, and the degree of infestation. Any control of unwanted plants requires considerable attention to detail to maximize results. Control is generally less costly when infestation is low and the plants are small.

In this situation, a method is selected that will not destroy the residual forage plants. On sandy soils heavily infested with brush, a broadcast chemical method will control the undesirable plants and result in an increase of forage plants. Mechanical control methods are generally avoided on sandy soils because of the wind erosion hazard if a good plant cover is not maintained. A mechanical method of control accompanied by seeding may be required on soils with medium to heavy textures, heavy infestations of brush, and poor stands of desirable plants (Herbel 1979).

It is important to consider the plant species growing in association with target plants. Some desirable plants may be present that should not be killed. On the other hand, two or more undesirable plant species may be present, so the control method must meet the requirements of the land manager (Gould and Herbel 1970).

The management of animals on an area before and after treatment may influence the ultimate results. It may be desirable to defer grazing of animals during the growing season prior to treatment to improve the vigor and seed production of desirable plants. After control of the unwanted plants, it is extremely important to defer grazing until the desirable plants have become established. The number of growing seasons needing deferment will depend on the stand of desirable plants present when treated, the precipitation after treatment, and the degree of plant improvement desired by the land manager.

Principles and Examples of Chemical Control

Satisfactory control of unwanted plants and considerable improvement in the grazing capacity of rangelands may often be obtained by applications of herbicides. Specific approaches to this problem have been developed for numerous plant species, but information is still needed on some plants (National Academy of Sciences 1968).

Herbicides may be classified as contact, translocated, selective, nonselective, and soil sterilant (Vallentine 1971). A contact herbicide kills only those plant parts that are directly exposed to the chemical, e.g., diquat (6,7-dihydrodipyrido [1,2-*a*:2',1'-*c*] pyrazinediium ion) and paraquat (1,1'-dimethyl-4,4'-bipyridinium ion). A translocated herbicide is applied to one part of a plant but is carried to other parts of the plant by plant tissues, e.g., 2,4-D ([2,4-dichlorophenoxy] acetic acid), 2,4,5-T ([2,4,5-trichlorophenoxy] acetic acid), silvex (2-[2,4,5-trichlorophenoxy] propionic acid), picloram (4-amino-3,5,6-trichloropicolinic acid), and dicamba (3,6-dichloro-*o*-anisic acid). A selective herbicide kills or damages a particular species or group of species with little or no injury to other plants, e.g., the herbicides listed as translocated herbicides. A nonselective herbicide kills or damages all plant species, e.g., amitrole (3-amino-*s*-triazole) and paraquat. A soil sterilant may be a selective or nonselective herbicide that kills or damages plants when it is present in the soil, e.g., bromacil (5-bromo-3-*sec*-butyl-6-methyluracil), dicamba, monuron (3-[p-chlorophenyl]-1,1-dimethylurea), picloram, or tebuthiuron (*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea).

Broadcast spraying is the method of herbicide application most commonly used on rangelands. Since the herbicide is applied to all plants, desirable as well as undesirable, selective herbicides are generally required. Broadcast sprays can be applied either by ground equipment or by aircraft. Applying granulated or pelleted herbicide is also used to control unwanted plants. The latter method is less dependent on stage of growth than foliar sprays but does require precipitation to dissolve the granules or pellets so the herbicide may penetrate into the soil. In some areas, excessive herbicide losses may result from leaching beyond the root zone of the target plants, adsorption on soil colloids, or desensitization by light or high temperatures. Fundamentals to consider follow:

1. Proper herbicide. Herbicides such as 2,4-D, 2,4,5-T, silvex, picloram, and dicamba control a wide variety of plants. Spraying with ground or aerial equipment may be used to control most plants.

2. Proper rate of herbicide. The amounts of herbicide required to provide adequate control vary among plant species. Higher rates than those needed for adequate plant kill cause damage or death to leaves and branches so that herbicides are not translocated to the proper site and death of the plant does not result. Effective rates are 0.3 to 0.6 kg/ha acid equivalent (a.e.) of 2,4,5-T for mesquite, and 2.2 to 3.3 kg/ha (a.e.) of 2,4-D for big sagebrush. Higher rates than those required for adequate plant control are rarely more effective.

3. Proper volume. On mesquite, aerial applications of a total volume of 9.3 liters/ha gave as much or slightly better plant kills as a total volume of 46.5 liters/ha. This total volume is composed of 1/8 herbicide, 1/8 diesel oil, and 6/8 water.

4. Proper time. The phenologic development of the target species, or associated plants, is a reliable index to seasonal susceptibility. Some or most plants are most sensitive to foliar sprays when they are growing vigorously and the leaves are fully expanded. In New Mexico, there was an increase in amount of control of mesquite when the precipitation for the November to May period before treatment was average or above average (Valentine and Norris 1960). Dry herbicides, applied to individual plants or broadcast, should be applied just before or in the early part of a period of expected precipitation.

5. Proper method. Fixed wing or helicopter aircraft are commonly used to apply herbicidal sprays to large areas. Foliar sprays may also be applied with ground equipment, but the size of the job, the terrain, or the size and density of plants often prevent such operations. Aerial spraying is a specialized job. Gould and Herbel (1970) listed factors that must be considered:

a. Application equipment. The application equipment on the aircraft must be in good condition and the nozzles must be properly placed.

b. Weather conditions. Best coverage will result if spraying is done under calm, cool conditions. Spraying should be discontinued when the average wind velocity exceeds 10 km/hr and the temperature exceeds 30°C.

c. Swath width. The pesticide dispersal mechanisms must be calibrated and the swath width determined for the proper amount of spray material for a unit area. For fixed wing aircraft, the swath width is often about 10 percent greater than the wing span. Proper marking of the target area is necessary to obtain uniform coverage of the spray area.

d. Flight height. The aircraft should fly as low as safety will permit, but not more than 3 m above the top of the brush.

e. Mixing-loading equipment. The equipment must provide adequate agitation to mix emulsions and suspensions properly and rapidly. The equipment must also be large enough and have adequate plumbing to quickly load an aircraft.

f. Spray material. Recommended mixing instructions must be followed because the herbicide must be mixed with the carrier materials in the proper order to obtain a suitable spray material. In an oil-water emulsion, the oil phase is mixed first and then the water phase is added.

g. Proximity to non-target plants. Some herbicides are toxic to a broad range of species. Drift during application, volatilization from the soil or target plants and subsequent drift of the fumes, or dust blown from treated areas have caused damge to non-target plants. A non-volatile herbicide (e.g., a dry material) should be used near sensitive plants or if the prevailing wind direction poses a problem.

h. Remove livestock. Most herbicides have a low toxicity to livestock. To assure that livestock are not injured by the herbicide or by grazed plants that develop an increase in toxic properites after spraying, it is desirable to defer grazing of livestock from just before treatment to a period after spraying. In most situations the deferment to avoid poisoning of livestock need not exceed 30 days, but up to 6 months may be required when specific toxins are present.

i. Follow directions on the herbicide container. Herbicides have been developed for certain uses, and specific recommendations are indicated on the label.

Downy brome *(Bromus tectorum)*, also known as cheatgrass and downy chess, is an annual weedy grass that is widely distributed on rangelands of the western United States (Evans 1966). Paraquat at 0.6-1.1 kg/ha aerially applied in the spring has controlled downy brome. Applying atrazine (2-chloro-4- [ethylamino] -6 [isopropyl-amino] -*s*-triazine) at 1.1 kg/ha during one fall, followed by seeding to perennial grasses the next fall (chemical fallow), is another approach to improvement of areas infested with downy brome.

Locoweeds (*Astragalus* and *Oxytropis* sp.) can be controlled with 2.2 kg/ha 2,4-D applied aerially when the plants are in full bloom. Much higher plant kills are obtained when there is abundant soil moisture at the time of treatment (Parker 1966).

Aerial spraying of honeymesquite (*Prosopis juliflora* var. *glandulosa*) resulted in plant kills of 8-57% during 11 years (Herbel et al. 1974). Control was best in years with available soil water before and at the time of spraying, and when the plants were fully leafed and growing vigorously. Control was poor in years with no or little available soil water during the winter-spring prior to spraying. The most effective treatment to control mesquite, considering the price of herbicide, has been 0.6 kg/ha 2,4,5-T in a 1:7 diesel oil to water emulsion at a total volume of 9 liters/ha. An area aerially sprayed twice for mesquite control during 1958-61 had an annual average yield of 204 kg/ha of air-dry perennial grass herbage for 1953-57 compared to 33 kg/ha on an adjacent unsprayed area (Herbel et al. 1977). The cover of mesquite has not increased appreciably since the initial control. Mixtures of 2,4,5-T and picloram or 2,4,5-T and dicamba are also used for controlling mesquite, particularly where mesquite occurs in mixed stands with other unwanted shrubs that may be more susceptible to picloram or dicamba.

Yucca (*Yucca glauca*) can be controlled with an aerial application of 0.8-2.2 kg/ha silvex during the prebloom stage. Effects of this treatment may not become apparent for several months and some resprouting may occur one or more seasons after treatment (Bovey 1966). The degree of plant kill on shrubby plants generally can not be ascertained for 2-3 years after herbicidal treatment.

Principles and Examples of Mechanical Control

The choice of whether to use manual methods, such as grubbing, or mechanical equipment to remove unwanted plants depends on the cost, on the availability of the equipment, the size and stand of the plants to be eliminated, whether the target plants have sprouting or nonsprouting characteristics, soil conditions, and the type type of terrain (National Academy of Sciences 1968).

1. Size and stand of the target plants. The best time to employ hand-grubbing is during early invasion of unwanted plants, before the stand of desirable species becomes greatly reduced. Hand-grubbing of small shrubs (up to 90 cm in canopy diameter) is an economical control method when the stand is relatively thin, usually less than 80 plants/ha. With sprouting species, the root must be severed below the budding zone (Herbel et al. 1958). Cabling or chaining is most effective in controlling even-aged, mature shrubs or small trees with stem diameters of 8 cm or more. Bulldozing is effective on sparse stands and medium-sized trees. Disking is limited to small plants. Rootplowing or disking is used when there is a sparse stand of desirable plants and revegetation is needed.

2. Sprouting or nonsprouting plants. This characteristic must be considered in choosing a method. Mechanical methods that do not give a high degree of kill on plants that sprout below the surface of the ground are cabling, chaining, and disking.

3. Soil conditions. Cabling or chaining is most effective in areas with sandy or loamy soils. Bulldozing, rootplowing, and disking excessively disturb the soil, destroy desirable plants, and may result in soil erosion. Most mechanical methods cannot be used when the soil is excessively wet.

4. Topography. Most mechanical methods leave the soil bare, unprotected, and subject to erosion. There should be a minimum of rocks and gullies so that the equipment can operate at a relatively high speed. Therefore, most mechanical equipment should be used on relatively level terrain.

Some of the other factors to consider in selection of equipment for mechanical control are the ultimate use of the land and the distance from maintenance and repair facilities (Caterpillar Tractor Company 1970). Various techniques and types of equipment have been developed for different situations. Bulldozing and mechanical grubbing, rootplowing, disking, cabling, and chaining are the major mechanical methods to control unwanted shrubs on rangeland. Bulldozing is best adapted to removing scattered stands of large shrubs or trees. Pinyon (*Pinus* sp.) and juniper will grow back very slowly where bulldozing has killed most of the plants. However, small trees missed in the operation respond rapidly to release of soil water formerly used by the larger trees (Arnold et al. 1964). Bulldozing is well adapted for uprooting scattered stands of relatively large mesquite trees in Arizona (Martin 1966) and in Texas (Rechenthin et al. 1964). Summer was the best time for bulldozing, but control was considered adequate anytime. Bulldozer blades or front-end loaders may be fitted with a small blade (a stinger) extending below or to the side of the existing bulldozer blade of the bucket on the front-end loader. The stinger blade is pushed under the crown of the target plant to ensure uprooting of any sprouting zone. This procedure is termed "mechanical grubbing" (Herbel et al. 1974).

A rootplow is a horizontal blade attached to a track-type tractor. Fins are welded to the top of the blade to push roots out of the ground to reduce the possibility of their rerooting (Abernathy and Herbel 1973). Rootplowing is best adapted to large brush too dense for other types of mechanical treatment and to species not affected by herbicides. Rootplowing is limited to deep soils that are fairly free of rocks. To be effective, the rootplow blade must sever the roots of the target plants below the budding zone. Recommended depth is 38 cm for control of mesquite and 20 cm for control of creosotebush (Rechenthin et al. 1964)

In disking, shrubs are uprooted with a large disk plow or tandem disk. Plows equipped with disks are widely used on plowable range sites for killing small, shallow-rooted plants and preparing a seedbed. Disk plows are useful on sagebrush (*Artemisia* sp.), rabbitbrush (*Chrysothamnus* sp.), creosotebush, tarbush, and some annual and perennial weeds. Disk plowing has the advantage of leaving considerable mulch near the surface of the soil but the method is not well adapted to areas that are quite rocky or excessively gullied, or where large shrub plants are present (Plummer et al. 1955). The season for most effective plowing depends upon the species present, precipitation patterns, and seeding practices to be used. Summer plowing in Nevada when the soil was dry and firm, killed more mature sagebrush plants than either spring or fall plowing (Bleak and Miller 1955).

Chaining is accomplished by dragging heavy anchor chain in a U-shape, half circle, or J-configuration behind two crawler tractors travelling in a parallel direction. The length of the chain is commonly 60-150 m, and the most effective chains weigh 35-40 kg/link (Fisher et al. 1959; Plummer et al. 1968). Chaining is adapted to varied terrain and is particularly useful on areas too rocky, rough, and steep for other equipment. It is an effective and widely applicable method for removing mature, nonsprouting, single-stemmed species such as most junipers. It can also be used to improve appearance and facilitate livestock movement where shrubby, sprouting species have been treated previously with herbicides. Steel cables 4-5 cm in diameter and 60-180 m long may be used instead of the anchor chain. Since it is lighter, the cable tends to slip over small trees that an anchor chain might uproot. Cabling is effective for controlling cholla cactus (*Opuntia* sp.) in northeastern New Mexico when applied in the winter when the plants are dormant and the joints will dry up before they resprout.

REVEGETATION

Where desirable vegetation has been severely depleted by past grazing abuses, droughts, and encroachment of unwanted plants, natural recovery may take several years, or it may never occur. Under such conditions, seeding may be the only hope of reestablishing desirable plants. Other objectives of seeding are to improve soil stability and to alter plant composition to meet the user's objectives. Seeding arid rangelands is generally a difficult undertaking because of limiting climatic, soil, and/or topographic features. Merkel and Herbel (1973) outlined the principles of seeding as:

1. Remove or reduce competition from unwanted plants. Most plants used for revegetation are perennials. Seedlings of these species are often slow-growing and cannot compete with existing, unwanted plants. A good seedbed will provide the best possible moisture conditions for germination and plant growth. This requires

the control of most existing plants before seeding. In addition, it is sometimes necessary to control unwanted plants that are competing with the seedlings of the desirable plants. (See the section, "Control of Unwanted Plants," for further discussion of this subject).

2. Use of adapted plant materials. The plant species selected for seeding must be compatible (e.g., palatability and growth period). They should be selected to obtain the management objectives. It is important to use only those species and varieties that are well adapted to the soil, climate, and topography of the specific site being revegetated. If necessary, native species from local origin are used. Local origin would include species at about the same elevation, and within 320 km north, east, or west, and 480 km south of the area to be treated. Improved ecotypes, varieties, and introduced species are also available for revegetation and should be used when available.

3. Seeding rates. It is important to use enough seed to get a good stand, but excessive use of seed is undesirable. Too much seed may produce a stand of seedlings so thick that individual plants may compete with each other. Species of plants, number of pure live seeds (PLS) per kg, and potential productivity of the site are the major factors determining the rate of seeding. PLS is determined by multiplying the germination of a lot of seed by its purity. Seeding rates providing about 250 PLS/m^2 should be used when the seed is placed in the soil with a drill. Broadcast seeding is an ineffective and inefficient method of revegetation, and should be avoided. Many seeds are left on top of the soil where germination and seeding establishment are tenuous. Where it must be used, a rate of at least 500 PLS/m^2 should be used with any form of broadcast seeding.

4. Depth. Each plant species must be seeded at its proper depth. For optimum emergence, small-seeded species such as the lovegrasses (*Eragrostis* sp.) should not be seeded deeper than 0.6 cm, whereas species such as crested wheatgrass should be seeded at a depth of 1.2-1.8 cm. Optimum depth of seeding is roughly 4-7 times the diameter of the seed. Seeding equipment should be used that provides for positive seed placement at the desired depth. More stands are lost because seed is planted too deeply rather than too shallowly.

5. Seeding dates. The most desirable time to seed rangeland is immediately prior to the season of the most reliable rainfall.

6. Seed distribution. Uniform distribution of seed is essential. Seeding equipment must be checked frequently to assure that it is working properly.

7. Alteration of the microenvironment. Most range areas are deficient in soil water for germination and seedling establishment of the desirable plants. In many areas, associated rangeland treatment is needed to reduce the high soil temperatures and provide more soil water (e.g., mulching), or just provide more soil water (e.g., summer fallow or establishing basins or pits).

8. Seedbed preparation. The major objectives of preparing seedbeds for range seedings are to: (a) remove or substantially reduce competing vegetation, (b) prepare a favorable microenvironment for seedling establishment, (c) firm the soil below seed placement and cover the seed with loose soil, and (d) if possible, leave mulch on the soil surface to reduce erosion and to improve the microenvironent.

Several types of drills used for range seeding are: (a) rangeland drill, (b) press seeder, (c) grain drill, (d) range interseeder, and (e) browse seeder. The major broadcasting methods are aerial seeding, and ground applications such as rotary spreaders and mechanisms using an airstream.

Most range managers recommend that range seedings must be protected from grazing by animals through the second growing season, or until the seeded species are well established, however, this has not been supported or documented by research. Spraying to control weeds that are competing with the new seedlings may prevent the loss of the seeding. Rodents, rabbits, insects, and other pests should also be controlled where they are a menace to new seedings.

The Intermountain area of the United States includes western Colorado, southwestern Wyoming, Utah, southern Idaho, Nevada, and southeastern Oregon (Medin and Ferguson 1972). Besides cattle and sheep, these rangelands are also grazed by deer, elk, pronghorn antelope, and bighorn sheep. A representative example of deer range improvement in Utah is a 400-ha restoration project (Plummer et al. 1970). The site was chained in one direction to partially control the undesirable juniper and pinyon trees, aerially seeded with a mixture of nine species at a rate of 13kg/ha, and then chained a second time to cover the seed and kill trees not controlled by the first chaining. Before treatment, the area provided about 80 kg/ha of understory herbs. In 1964, 3 years after treatment, the site produced 1766 kg/ha of total herbage yields, 84% of which consisted of the seeded species (Table 1).

Successful regeneration of rangelands in the Northeast Pastoral Zone of South Australia depends on: (1) trapping windborne seed, (2) concentrating moisture from light rains, and (3) protecting young seedlings from the effect of blasting by windborne sand (Young 1969). A tined pitter was developed for use in this area, and it has resulted in a natural revegetation of desirable plants such as bluebushes (*Kochia* sp.) and saltbushes (*Atriplex* sp.).

Waterponding assisted in reclaiming bare scalds in arid (less than 250 mm annual precipitation) portions of New South Wales in Australia (Newman 1966). The treated areas were relatively flat, and the soils were deep clay to clay loam. Banks were constructed to pond water to depths of 15-25 cm. Good stands of several saltbush species were obtained.

A plow with opposed disk blades and a centrally mounted ripper point was developed for furrow-seeding in northwestern Australia (Fitzgerald 1969). Early experience indicated that a bank formed from loose soil heaped onto compacted ground collapsed when wetted. The bank of loose soil proved more stable when a ripper point was placed between the disks. Buffelgrass (*Cenchrus ciliaris*), birdwoodgrass (*C. setigerus*), and kapokbush (*Aerva javanica*) have been successfully seeded with this technique.

Paroda and Mann (1979) studied the effects of seeding on a number of sites in Western Rajasthan, India. They reported that planting the seed 1 cm deep on the ridge of furrows 75- cm apart was the most advantageous. They used *Lasiurus sindicus*, buffelgrass, birdwoodgrass, Pretoria angletongrass (*Dichanthium annulatum*), and blue panic (*Panicum antidotale*). Some of these species have yielded in excess of 3,000 kg/ha. Seeding of the local climax species has revealed that average production can be increased to about 2,000 kg/ha. However, seed production of desirable species has been a problem.

TABLE 1

Herbage Production (kg/ha) by Vegetal Classes in 4 Selected Years on Range Seeded in 1961

(Adapted from Plummer et al. 1970)

	1964	1966	1969
Seeded grass	1,229	503	1,259
Native grass	222	3	1
Seeded forbs	200	152	480
Native forbs	59	6	6
Seeded shrubs	56	99	165
Total production	1,766	763	1,911
Precipitation (mm)	363	250	377

The effects of dead shrubs on soil temperatures were studied on a fine sandy loam site in southern New Mexico (Herbel 1972). A single shrub plant was used for the light plant cover and a layer of three shrubs was used for the heavy cover. The maximum air temperature 10 cm above the ground surface for a summer period was 33°C. The average daily maximum soil temperate at the 13-mm depth was 57°C under no cover, 49°C under light cover, and 36°C under heavy brush cover.

A light chamber study elucidated the effects of soil temperatures, observed under field conditions, on emergence and initial growth of 12 grass species and one shrub species in a soil medium (Sosebee and Herbel 1969). The two maximum daily temperatures were 39° and 53°C, and the soil moisture was maintained at field capacity. An example of the results showed that the emergence of fourwing saltbush was 0.5% in the high-temperature regime and 170% of viable seed, as determined by a standard germination test, in the low-temperature regime. The latter indicated a more favorable environment than conditions considered "optimum" in a standard laboratory germination test. There was no survival of emerging seedlings of fourwing saltbush after 21 days in the high-temperature regime and 98% survival in the low-temperature regime. In a similar study, but with various levels of soil water, it took 7 cm of water for survival of two grass species in the low-temperature regime and 23 cm for survival in the high-temperature regime for a 21-day trial (Herbel and Sosebee 1969).

Trials in Israel indicated that *Atriplex halimus* could not emerge from a compacted surface (Koller et al. 1958). Seeds were sown in moist, shallow furrows at a depth of 2-5 cm. In part of the furrows, the covering soil was firmly packed while in others it was left loose. On drying, the packed soil formed a hard crust which most of the germinating seedlings were unable to penetrate. Full rows of seedlings appeared within 3-4 weeks after sowing in the furrows covered with loose soil.

FERTILIZATION

The variety encountered in the world's rangelands, with the diversity of climate, topography, soil types, and vegetation, complicates any attempt to generalize on a range management practice such as fertilization. Seasonal variations in local weather conditions add further complications. In addition, the complex mixture of plants found on rangelands requires more diligent management than does a seeded pasture with one or two species. Each species will respond differently to fertilization.

In some areas, low amounts of available nitrogen (N), phosphorus (P), and other soil nutrients limit plant growth. Water is generally the most important factor limiting plant growth but when that need is satisfied, additional plant nutrients may be useful. N was the major growth-limiting plant nutrient on the rangelands of the Northern Great Plains, with measurable responses to P occurring as N became non-limiting (Wight and Black 1979). Fertilizing with the deficient nutrients is economical only where there is adequate mosture and plants respond to the added nutrients. The root systems of range plants often act as nutrient-deficient sinks that have a high potential to immobilize relatively large quantities of applied N and P (Black and Wight 1979). Wight (1976) gave some points on range fertilization to consider:

1. Soil water. Response to fertilization is directly related to availability of soil water. Range fertilization should not be used in areas with a low average

precipitation, but seasonal distribution of precipitation and evaporative demand may be confounding factors. Range fertilization has been effective in the Northern Great Plains in areas where annual precipitation is as low as 280 mm. Annual precipitation of 380 mm or more may be necessary before range fertilization is feasible in warmer regions and where precipitation is more evenly distributed during the year. Areas that have overland flow or are subirrigated may have less precipitation but they have sufficient water so the plants can use the added nutrients.

2. Economics. Applications of 30 to 50 kg/ha of N annualy or in annual rate equivalents are most efficient in the Northern Great Plains. This rate will produce up to 20 kg of additional forage per kg N applied, or, under a grazing situation, about 1 kg beef/kg N. Thus, when the price of beef exceeds the cost of applying N, fertilization becomes an economical management practice. The total cost of fertilization must be weighed against the benefits.

3. Ecology and fertilizer timing. Usually, cool-season species respond most to N fertilization. However, the effect of fertilization on species composition can be somewhat offset by timing fertilizer applications. Late spring or summer applications tend to benefit warm-season species, whereas late fall or early spring application tend to benefit cool-season plants. If application rates are high enough to cause a significant carryover of fertilizer N from one year to the next, cool-season species may use the fertilizer to the detriment of warm-season plants. Nitrifying bacteria, occurring in the soil, are less active in cool weather than in warm weather (Lorenz and Rogler 1973). Thus, plants growing earliest in the season will use the residual N.

4. Toxicity. At N rates above 200 kg/ha, nitrates accumulate in some plants, especially annual forbs. Caution is required if applying high N rates on rangelands with nitrate-accumulating plants. Groundwater contamination with nitrates may also result where high N levels are used and where the groundwater is close to the surface.

5. Water use efficiency. Range fertilization increases the efficiency of the limited water supply in plant growth processes. Fertilized range plants extract more water from the soil profile than do unfertilized plants. Thus, if precipitation is adequate to fully recharge the soil profile, fertilized range will use the precipitation more effectively than unfertilized range.

6. Drought. There has been concern that fertilization will compound the affects of droughts, resulting in additional damage to the range vegetation. In some situations, there is a greater loss of desirable plants during drought (Donart et al. 1978). However, fertilizer not used during drought years is available for plant use following the drought.

7. Fertilizer materials. There have been very little response differences to the inorganic forms of N and P. Under some conditions, urea, an organic formulation, will undergo high volatilization losses when broadcast on the soil surface.

8. Management. It is generally necessary to fertilize the entire range unit or the animals will concentrate on the fertilized portion and neglect the unfertilized area. Plants that have been fertilized generally are green earlier in the spring and later in the fall if soil water is available. Increased palatability of fertilized plants may be useful as a management tool to improve animal distribution

and forage utilization. However, plants toxic to animals on fertilized areas may also become more palatable and create toxicity problems among the animals using rangeland. Plants growing on fertilized range generally have a higher nutrient content and this will also affect management decisions.

In an extensive review of research in the Great Plains of North America, Rogler and Lorenz (1974) found that high-yielding, cool-season grasses were most responsive to fertilization with N. Cool-season species showed a marked early-spring response to N fertilizer, even on soils high in total N, because low soil temperatures reduced the nitrification rate at the time of the year these species are beginning growth. Soil water often limits plant growth during summer in the Northern Great Plains, but early in the spring, soil water is usually adquate to allow efficient plant use of the additional N applied by fertilization. In the central and southern parts of the Great Plains, Rogler and Lorenz (1974) found reports that fertilization of the warm-season species increased forage production, but weedy species were often favored. The weedy species often show some growth in the cooler seasons of the year, i.e., before of after growth by the warm-season grasses. Rogler and Lorenz (1974)concluded that benefits from fertilization generally outweigh disadvantages in most areas of the Great Plains (semiarid to subhumid climate). Benefits reported in their review included increased forage and livestock production, increased palatability, better livestock distribution, a longer green-feed period, higher forage quality, increased root growth, greater water-use efficiency, greater use of solar energy, and improvement in range condition. The major disadvantages included problems related to increased weed growth or other undesirable changes in species composition, possibility of groundwater pollution, and a remote possibility of metabolic disorders in livestock.

Two years of fertilization with 101 kg/ha N each year did more to improve deteriorated mixed prairie rangeland near Mandan, North Dakota than did 6 years of deferment from grazing (Rogler and Lorenz 1957). A deteriorated rangeland is one in which the more productive species have been reduced in vigor or eliminated and have been replaced by less desirable plants. Deferment from grazing, sometimes combined with one or more appropriate manipulative treatments, has been the common means of attempting to correct the situation. However, where applicable, fertilization will hasten the return to a productive condition by stimulating a rapid change in species composition, accompanied by an increase in plant vigor (Lorenz and Rogler 1973).

The relative effectiveness of deferment from grazing versus use of N to restore productivity of deteriorated mixed prairie in North Dakota is shown in Table 2. The major undesirable species was fringed sage (*Artemisia frigida*). One application of 2,4-D and annual application of 45 kg/ha N, with grazing continued, did more to increase production of usable forage than did deferment for up to 55 years (Rogler and Lorenz 1974).

Westin et al. (1955) found that residual N increased forage production for 3 years after the single application of 22, 45, or 90 kg/ha N on heavily and lightly grazed pastures in South Dakota. Also, the application of 90 kg/ha N once in 3 years resulted in more herbage per unit of N than did 90 kg N applied once each year for 3 years.

In the tall-grass prairie of north-central Oklahoma, Gay and Dwyer (1965) increased forage yields by burning old growth and fertilizing with 56 kg/ha N or 112 kg/ha N. Fertilizer response was negligible without burning. Graves and

TABLE 2

Dry-matter Yield of Mixed Prairie near Mandan, North Dakota, Comparing Various Periods of Isolation from Grazing with Fertilization and Weed Control for Improving Deteriorated Range (Adapted from Rogler and Lorenz 1974)

Years of complete rest	Dry matter (kg/ha) Grass	Forbs	Total
55	1353	1425	2778
30	1708	421	2129
26	1793	391	2184
20	2185	221	2406
5	2010	246	2256
0[a]	4926	0	4926

[a] Grazed and fertilized annually with 45 kg/ha N for 5 years; broadleaf forbs, mostly fringed sage, controlled with one application of 2,4-D.

McMurphy (1969) included burning with fertilization in an attempt to improve poor-condition range in central Oklahoma. Burning and fertilizer increased the desirable grass species, but an increase in undesirable forbs was a major problem. Graves and McMurphy (1969) concluded that rangeland infested with low-quality vegetation should not be fertilized.

Herbel (1963) conducted a 5-year fertilizer study on flood plains in southern New Mexico dominated by tobosa (*Hilaria mutica*). In only 2 years was there a significant increase in production due to the fertilization with N and/or P. During one year with available soil moisture for a continuous 60-day period, fertilization with 101 kg/ha N increased herbage production by 4,664 kg/ha, but in the other 4 years herbage increases were small. Protein content of the herbage at the close of the growing season was generally 20-35% higher with 67 or 101 kg/ha N. One application of 80 kg/ha N plus 28 kg/ha P increased forage and beef production in Chihuahua, Mexico (Gonzalez 1972).

Rangeland in New Mexico dominated by blue grama (*Boutelous gracilis*) was fertilized with 45 kg/ha N annually and was grazed by yearling heifers (Dwyer and Schickendanz 1971). Average summer gains for 3-year period were 26 and 54 kg/ha for the unfertilized and fertilized pastures, respectively. During a severe drought, 1971, the pastures were not grazed, but the 8-year (1968-1976) average gain per head while the pastures were grazed was 98 kg on the fertilized pasture and 89 kg on the unfertilized pasture (Donart et al. 1978)

Warnes and Newell (1969) applied N annually to a mixture of five warm-season grasses seeded on 12 problem sites in Nebraska. This treatment maintained superior stands of vigorous plants that controlled erosion and reduced weed invasion. Warnes and Newell (1969) stressed the importance of proper time and rate of of fertilization and proper time of mowing to improve forage yield and prevent unwanted invasion by cool-season grasses and other weedy species.

Average steer gains/grazing season were 41 and 104 kg, respectively, on caucasian bluestem (*Bothriochloa caucasica*) unfertilized and fertilized with 84 kg/ha N in western Kansas (Launchbaugh 1971). McIlvain and Shoop (1970) showed that applications of 39 kg/ha N on weeping lovegrass in the Southern Great Plains in Oklahoma increased forage production about 40% and beef production about 31% over the control in a 4-year grazing trial.

SUMMARY

We must increase the output from our agricultural lands, including rangelands, because of the increasing demands of our world's people. Native plant communities serve as a guide to site potential, but manipulative treatments can transform these communities on some sites to more useful communities, The manipulations discussed include control of unwanted plants, revegetation, and fertilization. The relationships among the various practices are depicted in a diagram. Application of both ecologic an agronomic principles is useful in range science.

Manipulative practices on rangelands have been developed because the land manager wishes to change plants or production on all or part of the range unit. The increase of unwanted plants, severe droughts, and past abuses by grazing animals animals will result in low production on rangelands.

Large areas of the world's rangelands are dominated by unwanted plants. The manager may choose among several chemical or mechanical methods to control these plants. The methods(s) selected will depend on the site, the plants present, and the degree of infestation.

When the causative factor of depletion of range plants has been alleviated, the land manager may wish to establish or reestablish more productive and/or more protective plants. Also, addition of nutrients to the soil-plant complex may dramatically increase plant production. With all manipulative practices, it is important to consider all factors involving the weather-soil-plant-animal relationships. For example, an expensive manipulative treatment may be properly used, but poor animal control following treatment will result in failure to obtain the desired outcome.

Range units have different characteristics and uses, and must be managed accordingly. They differ in the amount of improvements, the proportion of various soil and vegetation types, numbers and kinds of wildlife species, recreational opportunities, and livestock characteristics. Often the degree of management is determined by economic or cultural conditions. Generally, the less costly practices involve the least risk and management inputs, but the benefits to be derived are less productive. The more expensive practices are riskier and require higher management inputs, but the potential benefits are great. With changing technology or improving economic condtions, the manager may decide to intensify his range improvement efforts.

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