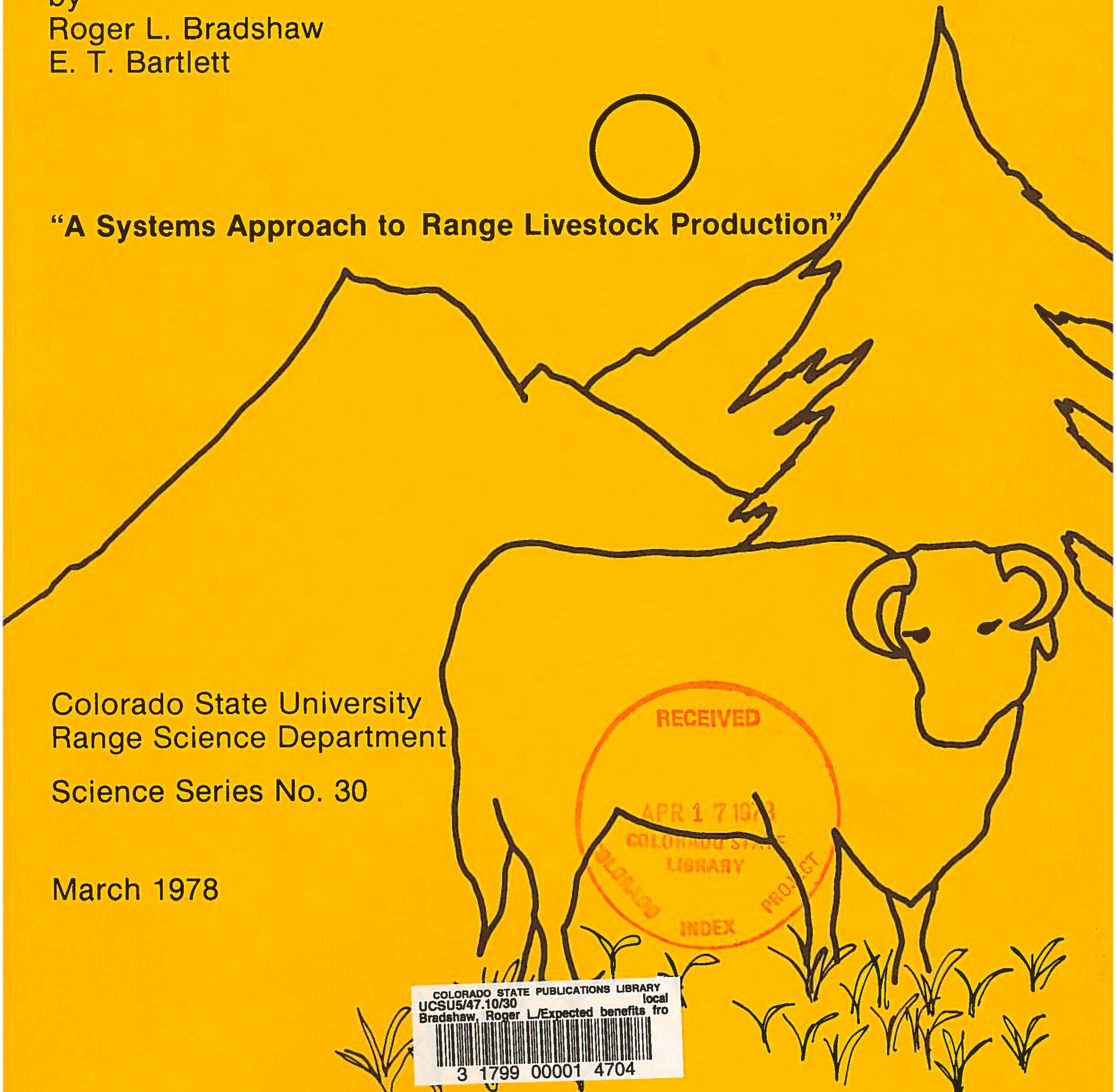
EXPECTED BENEFITS FROM RANGE IMPROVEMENTS IN COLORADO ECOSYSTEMS

by
Roger L. Bradshaw
E. T. Bartlett



"A Systems Approach to Range Livestock Production"

Colorado State University
Range Science Department

Science Series No. 30

March 1978

EXPECTED BENEFITS FROM RANGE IMPROVEMENTS IN COLORADO ECOSYSTEMS

A Report on NSF Contract No. RDI 75-17225,

"A Systems Approach to Range Livestock Production"

ROGER L. BRADSHAW

and

E. T. BARTLETT

Research Assistant and Associate Professor, respectively,

of the Department of Range Science,

Colorado State University

Fort Collins, Colorado

Range Science Department Series No. 30

March 1978

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

HIGHLIGHTS

There exists an extensive amount of data concerning the benefits of range improvement practices. Unfortunately, most of this data is scattered throughout numerous books, journals, bulletins, and other publications; therefore, information gathering is a time-consuming task. Few working range professionals have either the time or the library facilities necessary to perform extensive literature reviews.

The main objective of this study is to provide a single source of information concerning the benefits to be expected from the application of various range improvement practices in Colorado ecosystems. Since the general principles and methods for performing range improvements have been gathered and presented by other authors, there is no need to cover these principles and methods in this text. Instead, the specific results of many research efforts and field observations are reported; however, there are some potentially useful reports which could not be obtained. Benefits are given in terms of increased usable forage production for Colorado ecosystems as identified by A. W. Küchler. Where available, the expected life span of each practice is also presented.

The data presented in this report should be a useful guide for professional range managers, ranchers, educators, and students as they work to maintain and improve the rangelands of Colorado. The results of the studies covered in this report are subject to limitations and variation resulting from specific site and climatic conditions. The range manager is warned to consider these factors when planning any range improvement practice.

INTRODUCTION

Range management has evolved from early concerns for livestock, vegetation, and erosion into a highly technical field which covers all parts and functions of range ecosystems. This evolution has resulted from knowledge gained through research studies and years of experience. New information is continually being discovered about range ecology and integrated into range management. Years of research and experience have provided the principles and methods that contemporary range managers need in order to apply range improvement practices to various ecosystems. However, before a range manager could recommend a particular range improvement, he should know what benefits, if any, would result from the application of that improvement.

Range managers must often rely on personal experience in order to determine expected benefits simply because they do not have access to the applicable literature. Unfortunately, personal experience is not always convincing to a reluctant rancher or skeptical administrator. Also, personal experience may be limited for particular range improvements and/or ecosystems. This is especially important in Colorado where a move of only a few miles can result in a completely different set of environmental conditions.

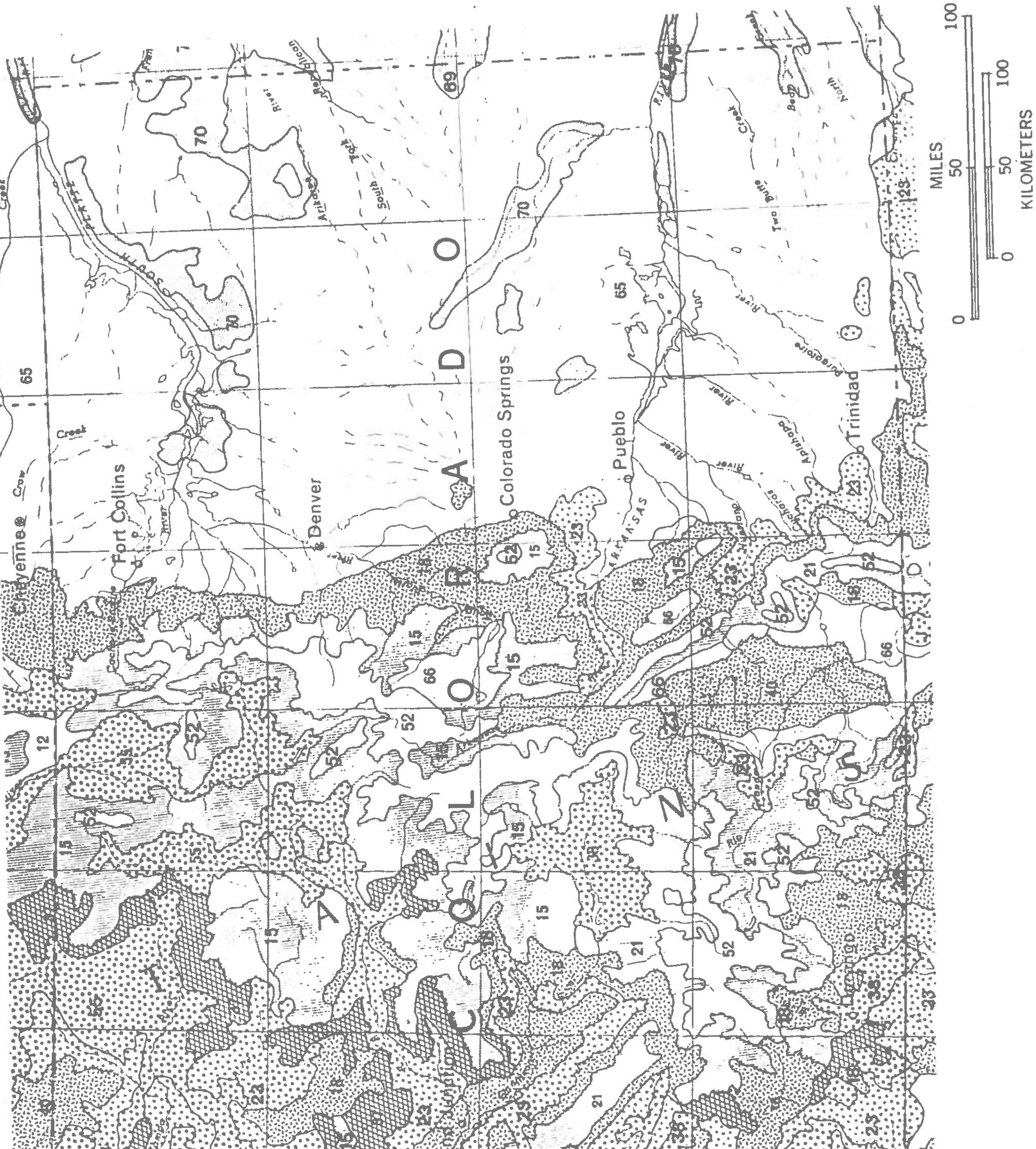
A. W. Küchler (1964) identified 14 major ecosystems in Colorado (Figure 1). Küchler based these ecosytems on the structure and composition of the potential native plant communities. Three of the

Colorado ecosystems, the Douglas Fir Forest, the Bluestem-Grama Prairie, and the Southwestern Spruce-Fir Forest were not covered in this study due to their limited extent and limited use as grazing land in Colorado.

Figure 1. Küchler's ecosystems in Colorado

LEGEND

Map Symbol	Ecosystem
12	Douglas Fir Forest
15	Western Spruce-Fir Forest
18	Pine-Douglas Fir Forest
21	Southwestern Spruce-Fir Forest
23	Juniper-Pinyon Woodland
37	Mountain Mahogany-Oak Scrub
38	Great Basin Sagebrush
40	Saltbush-Greasewood
52	Alpine Meadows and Barren
55	Sage Steppe
65	Grama-Buffalo Grass
66	Wheatgrass-Needlegrass
69	Bluestem-Grama Prairie
70	Sandsage-Bluestem Prairie


COLORADO
Cheyenne
Fort Collins
Denver
Colorado Springs
Pueblo
Trinidad
Durango
Grand Junction
MILES
0 50 100
KILOMETERS
0 50 100

BENEFITS OF RANGE IMPROVEMENTS

The effects of range management practices on Colorado rangeland ecosystems have been reported by many authors. The information presented herein surveys by ecosystems the literature on range improvement practices in Colorado.

The references cited were selected from *A Western Range Improvement Bibliography* (Bartlett, 1976). The references listed in the bibliography were initially sorted into groups based on which range improvements they covered. A second grouping was developed according to the Küchler ecosystem discussed by each reference. Correlation of the two groupings into a listing of publications on range improvements within Colorado ecosystems was performed using computer techniques. From this final listing, available publications were selected and reviewed (Table 1). The results of the above process are presented as a guide to expected range improvement benefits in the rangeland ecosystems of Colorado.

Most range improvement benefits have been expressed in terms of increased forage production over a period of years. In this report production figures have been presented as total production unless otherwise specified. Where available, the pre-treatment production level was given along with the post-treatment results. Also, the expected life span of practices was presented whenever possible.

Table 1. Selected references by ecosystems and improvement practices.

Ecosystem	Improvement Practice							
	Mechanical Control	Chemical Control	Biological Control	Fire	Fencing	Water Development	Salting	Seeding
Western Spruce-Fir Forest	---[1]	Torrell & Haas, 1963 Doran, 1951 Paulsen & Miller, 1968 Cronin, 1974 Smith & Alley, 1966	---	---	---	---	---	Doran, 1951 Forsling & Dayton, 1936
Pine-Douglas Fir Forest	McConnell & Smith, 1965 Thompson & Gartner, 1971 Robinson & Matthews, 1955	Eckert et al., 1973a Currie, 1975; 1976	---	---	---	---	Skovlin, 1965	Hull & Johnson, 1955 Robinson & Matthews, 1955 Eckert et al., 1973b Christensen et al., 1974 Lavin & Springfield, 1955
Juniper-Pinyon Woodland	Arnold & Schroeder, 1955 Aro, 1971 Hull & Doran, 1950 Plummer, 1958 Minnich, 1969 Phillips, 1977	---	---	Aro, 1971 Chilson, 1964 Barney & Frischnecht, 1974	---	---	---	Aro, 1971 Chilson, 1964 Plummer, 1958 Phillips, 1977
Mountain Mahogany-Oak Scrub	Jefferies & Norris, 1965	Marquiss, 1969; 1972; 1973 Jefferies & Norris, 1965 Bartel et al., 1973	---	Brown, 1958	---	---	---	Jefferies & Norris, 1965 Doran, 1951 Davis et al., 1975 Davis et al., 1973
Great Basin Sagebrush	Hanson, 1929 Cook, 1958	Eckert et al., 1972 Anderson, 1969	Frischnecht & Baker, 1972	Hanson, 1929	---	---	---	Cook, 1958
Saltbush-Greasewood	Hull & Vaughan, 1951	---	---	---	---	---	---	Nichols, 1964 Rollins et al., 1968 Hull & Vaughan, 1951
Alpine Meadows and Barren	n/a	Thilenius et al., 1974	n/a	n/a	---	---	---	---
Sagebrush Steppe	Mueggler & Blaisdell, 1958 Halandras, 1963	Alley, 1964 Hyatt, 1966 Thilenius & Brown, 1974 Mueggler & Blaisdell, 1958 Johnson, 1958	---	Greene & Aldworth, 1959 Mueggler & Blaisdell, 1958 Harniss & Murray, 1973	---	---	---	---
Grama-Buffalo Grass	---	Rauzi, 1974 Anonymous, 1967	---	Dwyer, 1967	---	---	---	Branson et al., 1966 Bement et al., 1965 Baizc et al., 1973 Bose et al., 1974
Wheatgrass-Needlegrass	---	---	---	---	---	---	---	---
Sandsage-Bluestem Prairie	---	---	---	---	---	---	---	Denham, 1973 Sims, 1973

Table 1.--Continued

Ecosystem	Improvement Practice							
	Interseeding	Fertilization	Pitting	Water Spreading	Contour Furrows and Trenches	Mulching	Ripping	Grazing Systems
Western Spruce-Fir Forest	---	Bowns, 1972 Smith & Lang, 1958 Cook, 1965 Ludwick & Ramburg, 1975; 1977	---	---	---	---	---	---
Pine-Douglas Fir Forest	---	Willhite, 1963 Smith & Lang, 1958 Currie, 1975; 1976	---	---	---	---	---	Smith, 1967 Currie, 1969
Juniper-Pinyon Woodland	n/a	---	---	---	---	---	---	---
Mountain Mahogany-Oak Scrub	n/a	---	---	---	---	---	---	---
Great Basin Sagebrush	---	---	---	---	---	---	---	---
Saltbush-Greasewood	---	---	---	---	Nichols, 1964	---	---	Aldon & Garcia, 1967 Hutchings & Stewart, 1953
Alpine Meadows and Barren	n/a	---	n/a	n/a	n/a	---	n/a	---
Sagebrush Steppe	---	---	---	---	---	Halandras, 1963	---	Layrock, 1961; 1962; 1967
Grama-Buffalo Grass	n/a	Klipple & Retzer, 1959 Goetz, 1969 Dwyer, 1967	Barnes et al., 1958 Branson et al., 1966 Rauzi, 1974 Rauzi et al., 1962	Hubbard & Smoliak, 1953	Barnes & Nelson, 1945 Branson et al., 1966 Brehm & Malmsten, 1954 Miles & Bradford, 1943	Beutner & Anderson, 1943	Barnes & Nelson, 1945	Cook et al., 1974
Wheatgrass-Needlegrass	Houston, 1971	Houston, 1971 Goetz, 1969	Houston, 1971	---	---	---	---	---
Sandsage-Bluestem Prairie	Hervey, 1960	Sims, 1973	n/a	---	Whitfield & Fly, 1939	---	n/a	Anderson, 1940 Sims & Denham, 1969

[1]Practices marked with a dash may be applicable to the ecosystem, but no references on benefits were found.

Western Spruce-Fir Forest

Low to medium tall subalpine fir[1] and Engelmann spruce trees comprising dense to open forests characterize the western spruce-fir forest ecosystem. In the northern Rocky Mountains, this forest ecosystem occurs at elevations between 8,000 and 11,500 feet (2438-3505 m) with annual precipitation in the 15 to 38 inch (38-96 cm) range. Usually, snowfall accounts for 50 to 75% of the total precipitation, and snowmelt occurs during April or May. Mountain grasslands found within the western spruce-fir forest ecosystem support numerous perennial grasses and forbs, but Thurber fescue tends to dominate in Colorado.

Soils are as varied as the parent material from which they developed, and fertility and productivity vary with local environmental factors. In general, grassland soils in this ecosystem are well developed and well drained resulting in good production potentials.

Open meadows in the western spruce-fir forest ecosystem have provided valuable summer grazing for livestock; however, undesirable plants, such as tall larkspur, sneezeweed, rabbitbrush, and alpine avens have invaded some meadows causing reduced production or, in the case of poisonous plants, livestock losses. Torrel and Haas (1963) obtained a 94% kill of tall larkspur resulting in a forage increase of 600 pounds per acre (672 kg/ha) following three years of spraying in the prebud stage with four pounds per acre (4.5 kg/ha) per year of 2,4,5-T. Cronin (1974) obtained 100% control of tall larkspur with two annual applications of 2,4,5-T or silvex at four pounds per acre (4.5 kg/ha). A mountain meadow invaded by sneezeweed produced only 90 pounds of forage per acre (101 kg/ha), but four pounds per acre (4.5 kg/ha) of 2,4-D gave

---

[1]Common and species names of plants mentioned are listed in the Appendix. Nomenclature follows Nickerson, Brink and Feddema (1976).

a 90% kill and increased forage production to 590 pounds per acre (661 kg/ha) (Doran, 1951). In a study by Paulsen and Miller (1968), control of Parry rabbitbrush with two pounds per acre (2.2 kg/ha) of Tordon decreased forb production but grass production went from 1,575 pounds per acre (1764 kg/ha) to 2,474 pounds per acre (2771 kg/ha) and total production remained at 2,600 pounds per acre (2912 kg/ha). Alpine avens, an unpalatable forb, was controlled with one pound per acre (1 kg/ha) of 2,4-D or 2,4,5-T and the resulting voids were filled by grasses within three years after treatment (Smith and Alley, 1966).

Seeding has been used to restore production in mountain grasslands where the native vegetation has deteriorated. Doran (1951) reported that seeding with timothy increased forage production to 2,000 pounds per acre (2240 kg/ha) as opposed to 130 pounds per acre (146 kg/ha) on native range. Forsling and Dayton (1936) also reported that any reseeded mountain range should carry one cow-month per acre (2.5 cow-months/ha); however, they noted that obtaining an adequate stand may require two to five years.

Another practice, fertilization, has been applied to mountain grasslands in the spruce-fir zone. Significant increases in forage production were obtained by Bowns (1972) with low levels of nitrogen and phosphorus fertilization (Table 2). Smith and Land (1958), however, failed to obtain production increases with the application of 67.5 pounds per acre (75.6 kg/ha) of nitrogen but utilization increased to 73%. On a non-irrigated brome meadow, Cook (1965) increased production from an original 2,559 pounds per acre (2866 kg/ha) to 3,728 pounds per acre (4175 kg/ha) by applying 40 pounds per acre (45 kg/ha) of nitrogen and to 3,558 pounds per acre (3985 kg/ha) with 80 pounds (90 kg) of nitrogen. Production on a native mountain meadow was increased from 1,479 pounds per acre (1656 kg/ha) to 2,548 pounds per acre (2854 kg/ha) following the application of 80 pounds (90 kg) each of nitrogen and phosphorus; however, 80 pounds per acre (90 kg/ha) of nitrogen alone increased production to 2,245 pounds per acre (2514 kg/ha) (Cook, 1965). Ludwick and Rumburg (1975) studied the effects of different rates of nitrogen fertilization plus 60 pounds per acre (67 kg/ha) of phosphorus on a well drained, irrigated bluegrass meadow and a poorly drained creeping foxtail-sedge meadow (Table 3). In a similar study on a wet loam and a wet sandy loam, Ludwick and Rumburg (1977) reported that the greatest fertilizer efficiency occurred at 80 pounds per acre (90 kg/ha) of nitrogen plus 60 pounds per acre (67 kg/ha) of phosphorus (Table 4). Fertilization effects have not lasted for more than two years in most cases (Bowns, 1972; Smith and Lang, 1958; Cook, 1965).

Table 2. Effects of nitrogen (N) and phosphorus (P) fertilization on forage production on a mountain meadow (Bowns, 1972).

Treatment (lbs/acre)	Yield (lbs/acre)
Control	470
30 P	675
30 N-30 P	697
60 N	728
60 N-60 P	836

Table 3. Effects of different rates of nitrogen (N) fertilization with 60 pounds per acre (67 kg/ha) of phosphorus on mountain meadow forage production (Ludwick and Rumburg, 1975)

Meadow Type	Yield (lbs/acre) 0 N	60 N	120 N	180 N	240 N
Bluegrass	1620	1780	2500	2920	3760
Foxtail-sedge	5340	6520	7420	8120	7680

Table 4. Effects of different rates of nitrogen (N) fertilization with 60 pounds per acre (67 kg/ha) of phosphorus on two wet mountain meadows (Ludwick and Rumburg, 1977)

Soil Type	Yield (lbs/acre) 0 N	80 N	160 N	240 N
Loam	4040	5060	5720	6120
Sandy loam	3760	4840	5780	6240

Pine-Douglas Fir Forest

Open to dense forests of tall needleleaf evergreen trees dominated by ponderosa pine and Douglas fir characterize this ecosystem. The herbaceous vegetation is a bunchgrass type and usually contains

Thurber fescue, Idaho fescue, and mountain muhly. This ecosystem occurs in the southern Rocky Mountains at elevations of 5,000 to 9,000 feet (1524-2743 m) where the average annual precipitation, of which approximately 50% falls as snow, varies from 10 to 30 inches (25-76 cm).

For the most part, soils are 10 to 30 inches (25-76 cm) deep with the deeper soils being found in the meadows. Surface soil textures vary from fine, sandy loams to clay loams depending on the parent material, and most of the soils in this ecosystem are highly erosive. As a result, consideration must be given to soil protection whenever the vegetative cover is disturbed.

The Pine-Douglas fir forest ecosystem has provided late spring, summer, and early fall grazing for cattle and sheep; however, animals have often concentrated in easily accessible meadows and only lightly grazed the timbered areas. Skovlin (1965) reported that cattle utilized only 20% of the understory vegetation in areas adjacent to meadows. Utilization increased to 30% when salt blocks were placed in the timbered areas. Also, isolated tracts have often been opened to proper utilization by constructing trails (Skovlin, 1965).

Usable forage production usually restricted by forest cover has been increased by timber harvesting. McConnell and Smith (1965) reduced the canopy cover of pine from 90% to 35, 18, 13% and observed a forage increase of two pounds per acre (2.2 kg/ha) for each one percent decrease in canopy cover three years after thinning. A long term increase of 21 pounds per acre (23.5 kg/ha) per one percent reduction was also reported (McConnell and Smith, 1965). In a study by Thompson and Gartner (1971) an east slope with 65 trees per acre (161 trees/ha) and a west slope with 170 trees per acre (420 trees/ha) were clear cut.

On the east slope, total forage production was 341 pounds per acre (382 kg/ha) uncleared and 1,842 pounds per acre (2063 kg/ha) cleared, and on the west slope, production was 236 pounds per acre (264 kg/ha) uncleared and 1,084 pounds per acre (1214 kg/ha) cleared. A similar study in a dense stand of aspen, fir, and other trees increased usable forage from one sheep-month per acre (2.5 sheep-months/ha) to 8 to 10 sheep-months per acre (20-25 sheep-months/ha) by clear cutting and seeding to introduced species, such as orchard grass, smooth bromegrass, intermediate wheatgrass, and tall oatgrass (Robinson and Matthews, 1955).

Controlling undesirable herbaceous vegetation and seeding adapted forage species also increased usable forage production. Rocky Mountain iris invaded wet meadow sites, but 91 to 100% control was obtained with two to four pounds per acre (2.2-4.5 kg/ha) of 2,4-D and resulted in forage increasing from 274 pounds per acre (307 kg/ha) to 2,364 pounds per acre (2648 kg/ha) (Eckert and others, 1973a). Eckert and others (1973b) also studied depleted mountain meadows invaded by sedges, cheatgrass, and povertyweed and increased production to 3,000-4,000 pounds per acre (3360-4480 kg/ha) by seeding with Luna pubescent and Amur intermediate wheatgrasses. Production of perennial grasses increased 13 to 16 fold following seeding of wheatgrasses in burns invaded by medusahead and downy brome according to Christensen, Young and Evans (1974). Forsling and Dayton (1936) stated that reseeded mountain range should support one cow-month per acre (2.5 cow-months/ha). Studies by Lavin and Springfield (1955) showed second year yields of crested wheatgrass to be 1,860 pounds per acre (2083 kg/ha) compared to 50 pounds per acre (56 kg/ha) from poor condition native range. Hull and Johnson (1955) summarized the results of 28 seeding studies made at 20 locations in the ponderosa pine zone of Colorado (Table 5) and concluded that crested wheatgrass was best adapted on dry sites while smooth brome-grass did well on moist sites.

Soil fertility influenced the performance and utilization of established grass stands. Studies showed that the application of nitrogen significantly increased forage production on wet mountain meadows (Willhite, 1963)(Table 6). Currie (1975 and 1976) found that spraying dry rangeland with 2.5 pounds per acre (2.8 kg/ha) of 2,4-D and fertilizing with 50 pounds per acre (56 kg/ha) of nitrogen, phosphorous and potassium provided the greatest production of desirable forage species (Table 7). Fertilization alone stimulated the growth of too many undesirable forbs. Nitrogen fertilization has also influenced grazing distribution. Smith and Lang (1958) noted that utilization on native mountain range increased nearly 20% following the application of urea.

Smith (1967) and Currie (1976) found that neither different grazing intensities nor different grazing systems resulted in significant produc-tion increases on depleted bunchgrass range. Ten years of livestock exclusion caused production on an open grassland to increase to 1,616 pounds per acre (1810 kg/ha) from the original 804 pounds per acre (900 kg/ha) (Smith, 1967). Currie (1969) did find that grazing intensity affected production on seeded ranges (Table 8).

Table 5. Performance of seeded species in the ponderosa pine zone of Colorado (Hull and Johnson, 1955).

Location	Total Yield (lbs/acre)					
	Native	Crested Wheatgrass	Intermediate Wheatgrass	Beardless Wheatgrass	Russian Wildrye	Smooth Bromegrass
Monument	469	1697	1841	---	---	612
Turkey Creek	58	---	167	---	198	---
Three Mile Creek	51	566	---	598	---	---
Glentivar	34	---	783	---	---	---

Table 6. Effects of nitrogen fertilization of wet mountain meadows (Willhite, 1963).

Nitrogen (lbs/acre)	Yield (lbs/acre)	Increase (lbs/lb N)
0	3000	--
100	5400	24
200	6700	13
300	7800	11
400	8800	10

Table 7. Effects of spraying and fertilization on dry bunchgrass range (Currie, 1976).

Treatment	Yield (lbs/acre)				
	1968	1969	1970	1971	Average
Control	1044	1099	1148	546	959
Fertilize	2110	1778	1477	686	1513
Spray	690	1151	1407	646	973
Fertilize & spray	1627	1965	1595	765	1488

Table 8. Production of seeded species when grazed to 2, 4, and 6 inch (5, 10, and 15 cm) stubble heights (Currie, 1969).

Species	Yield (lbs/acre)		
	2"	4"	6"
Crested wheatgrass	1196	1270	1264
Smooth brome	674	755	787
Crested & brome & yellowblossom sweetclover	1335	1578	1479
Intermediate wheatgrass	557	894	907
Russian wildrye	638	894	875
Big bluegrass	1136	1394	1362

Juniper-Pinyon Woodland

The juniper-pinyon woodland ecosystem occurs in Colorado at elevations of 4,500 to 7,500 feet (1372-2286 m) and consists of open stands of low evergreen trees. Oneseed juniper, Utah juniper and pinyon pine are the most common tree species found in this ecosystem with western wheatgrass, blue grama, sideoats grama, Indian ricegrass, muttongrass and sand dropseed in the understory. Annual precipitation, which averages between 12 to 18 inches (31-46 cm), is divided almost equally between summer and winter but snow is seldom deep or persistent.

Most topsoils are loams derived from shale or sandstone and depth is highly variable. Soils may be extremely shallow on ridges and rocky outcrops are common. Runoff and erosion are usually high due to the lack of ground cover.

Due to low rainfall and shallow soils in the juniper-pinyon ecosystem, root competition has proven very important; therefore, tree removal has been a major part of range improvements in this ecosystem (Hull and Doran, 1950). Arnold and Schroeder (1955) studied tree removal by hand chopping and obtained significant increases in native forage production where precipitation was at least 17 inches (43 cm) annually (Table 9). Aro (1971) evaluated several methods of converting juniper-pinyon woodlands to grassland and obtained production increases ranging from 400 to 900 pounds per acre (448-1008 kg/ha) following windrowing and seeding and increases from 400 to 1,200 pounds per acre (448-1344 kg/ha) following burning and seeding. In another study, burning followed by aerial seeding of a mixture of crested, siberian, intermediate, and pubescent wheatgrasses plus Madrid yellow blossom sweet clover increased carrying capacity from the original 20 acres (8 ha) per cow-month to only four acres (2 ha) per cow-month (Chilson, 1964). Barney and Frischnecht (1974) reported that burns remain free of trees for approximately 46 years. Plummer (1958) used cabling to increase forage production from the original 320 pounds per acre (358 kg/ha) to 1,160 pounds per acre (1299 kg/ha) and cabling coupled with seeding crested wheatgrass to increase from 60 pounds per acre (67 kg/ha) prior to treatment to 2,000 pounds per acre (2240 kg/ha) following treatment. Chaining, on the other hand, has been reported to increase tree density by releasing young trees (Aro, 1971); however, Minnich (1969) reported increased grass seedling density and ground cover following chaining of pinyon and juniper. Also, in a survey of 59 chaining projects ranging from 2-20 years old, Phillips (1977) found that chaining plus broadcast seeding with a mixture of crested, intermediate and pubescent wheatgrasses, alfalfa, bitterbrush and fourwing saltbush increased production from the original 100 pounds per acre (112 kg/ha) to 796 pounds per acre (892 kg/ha), and tree cover was reduced to a trace.

Table 9. Forage production following hand chopping of juniper and pinyon in the 17 inch (43 cm) rainfall zone (Arnold and Schroeder, 1955).

Original Tree Density (trees/acre)	Forage Yield (lbs/acre)	
	Before Clearing	After Clearing
50	630	612
150	196	686
240	74	298
475	51	550

Mountain Mahogany-Oak Scrub

Gambel oak and mountain mahogany dominate the dense to open stands of deciduous or semideciduous shrubs which characterize the mountain mahogany-oak scrub ecosystem. The herbaceous understory includes slender wheatgrass, mountain brome, Idaho fescue, Kentucky bluegrass, and streambank wheatgrass. The oak type occurs throughout Colorado at elevations ranging from 4,000 to 10,000 feet (1219-3048 m) and receives from 16 to 22 inches (41-56 cm) of precipitation annually. Fall and winter snowfalls account for approximately 50% of the yearly precipitation.

Deep well developed loamy soils are another characteristic of the mountain mahogany ecosystem. The soils usually have favorable fertility and high production potentials; however, steep and rough terrain coupled with rock outcrops restricts the potential for mechanical manipulations of the soil and vegetation.

Total forage production in the mountain mahogany-oak scrub ecosystem in Colorado averaged 346 pounds per acre (388 kg/ha) due to the dense shrub stands and utilization averaged only 24% according to Brown (1958); therefore, shrub control has received considerable attention. Tordon at two pounds per acre (2.2 kg/ha) has provided the best chemical control of Gambel oak (Marquiss, 1969 and 1973). Chemical brush control has increased forage production from 325 pounds per acre (364 kg/ha) to as much as 728 pounds per acre (815 kg/ha) or 74 to 125% (Jefferies and Norris, 1965; Marquiss, 1969, 1972, and 1973) and has brought utilization up to the 50% level (Jefferies and Norris, 1965; Marquiss, 1969). Jefferies and Norris (1965) reported similar results after undercutting brush at least 12 inches (31 cm) below the soil surface and seeding crested wheatgrass. Bartel, Davis and Cook (1973) controlled sagebrush with one application of 2,4-D and controlled oak with two applications, three years apart, of a 2,4,5-TP and picloram mixture (Table 10).

Table 10. Six year average forage production following brush control on an oak scrub range (Bartel, Davis and Cook, 1973).

Grassland Type	Yield (lbs/acre)	
	Control	Sprayed
Open grassland	825	1147
Sagebrush-grass	666	990
Oak-grass	633	1115

Grass seeding in the mountain mahogany-oak ecosystem should be done only on well prepared seedbeds (Doran, 1951). Forage yields ranging from 1,900 to 3,300 pounds per acre (2128-3696 kg/ha) were reported by Doran (1951) following the establishment of introduced grasses in cleared mountain brush. Seeded species included crested, intermediate, slender, and tall wheatgrasses, big bluegrass, tall oatgrass, timothy, smooth brome, orchard grass, and red fescue. Davis, Bartel and Sims (1973) seeded oak scrub ranges to various mixtures of russian wildrye, intermediate wheatgrass and aflalfa to increase forage production (Table 11). In a similar study Davis, Bartel and Cook (1975) reported three year average productions of 561 pounds per acre (628 kg/ha) on native oak brush range, 626 pounds per acre (701 kg/ha) on cleared range, and 1661 pounds per acre (1860 kg/ha) on cleared range seeded with a russian wildrye, intermediate wheatgrass and alfalfa mix.

Table 11. Six year average yields on seeded oak scrub rangeland (Davis, Bartel and Sims, 1973).

Species	Yield (lbs/acre)
Native (no seeding)	800
Russian wildrye	1477
Russian + alfalfa	2355
Intermediate wheatgrass	2292
Intermediate + alfalfa	2934

Great Basin Sagebrush

Fairly dense to open vegetation of low to medium-tall shrubs dominated by big sagebrush characterize the Great Basin Sagebrush ecosystem. The understory is sparse and contains western wheatgrass, cheatgrass, lupines, and various annual forbs. This sagebrush ecosystem occurs at elevations around 4,500 feet (1372 m) in western Colorado and receives from eight to twelve inches (2-131 cm) of moisture annually. Although snowfall accounts for most of the precipitation, summer rains are intense and highly erosive.

The soils found in the Great Basin Sagebrush type are derived from Tertiary volcanic material and may be low in nitrogen, phosphorus, and organic matter making nutrient cycling important. Carbonate accumulation is also common in these soils at depths of 12 to 18 inches (31-46 cm).

Grazable forage production in the Great Basin Sagebrush ecosystem depends on the amount of brush present; therefore, brush control has usually improved the carrying capacity. Chemical control using 2,4-D at two to three pounds per acre (2.2-4.5 kg/ha) has been shown to be the simplest brush control technique. Eckert, Bruner, and Klomp (1972) obtained 96 to 100% control and increased forage production 300 pounds per acre (301 kg/ha) over the original 143 pounds per acre (160 kg/ha) on fair condition sites. Anderson (1969) reported a 200 pound per acre (224 kg/ha) increase six years after sage spraying. Burning increased forage production by 238 to 336% within two years (hanson, 1929); however, mechanical treatments provided better conditions for broadcast seeding. Cook (1958) reported that plowing and seeding with crested or pubescent wheatgrass increased the production of low condition sites to over 180 pounds per acre (202 kg/ha). Frischnecht and Baker (1972) reported that during a cyclic population peak voles killed 59% of the sage on a sagebrush rangeland.

Saltbush-Greasewood

Open stands of low and dwarf shrubs dominated by shadscale and greasewood are found in the saltbush-greasewood ecosystem. Native grasses commonly found in the saltbush region include bottlebrush squirreltail, Sandberg bluegrass, alkali sacaton, and inland saltgrass.

Annual forbs are common, and halogeton quickly invades disturbed areas. The saltbush zone occurs at elevations around 3,500 feet (1067 m) where annual precipitation ranges from three to nine inches (8-23 cm).

Soils are poorly developed silty clays derived from soft shales. Low areas are usually extremely saline-sodic due to poor drainage and run-in from surrounding uplands. Salinity is a potential problem with all soils in the saltdesert zone. Also, soil fertility is low, making nutrient cycling an important factor in the ecosystem.

Moisture and soil salinity has restricted the potential for range improvement in the saltbush-greasewood ecosystem. Nichols (1964) managed to increase total production from an original 412 pounds per acre (461 kg/ha) to 973 pounds per acre (1090 kg/ha) by contour-furrowing 10 to 12 inches (25-31 cm) deep and seeding crested wheatgrass in the furrows; however, rainfall was above average during the study. Rollins, Dylla, and Eckert (1968), on the other hand, observed 100% seedling mortality while attempting to reseed silt loam flats with tall wheatgrass. Hull and Vaughan (1951) managed to establish limited stands of various grasses by plowing or grading to remove the native vegetation.

Grazing management appeared to be a viable method for increasing forage production in depleted saltdesert areas. In a study by Aldon and Garcia (1967), a five year program of summer deferment and winter grazing increased production threefold to 319 pounds per acre (357 kg/ha). Hutchings and Stewart (1953) reported a 54% increase in total forage production following 13 years of light intensity grazing on winter sheep range, and a moderately grazed range showed a 46% increase in production. Grazing period and intensity have been, therefore, important management considerations.

Alpine Meadows and Barren

The alpine meadow ecosystem occurs at elevations above 10,500 feet (3200 m) in the Rocky Mountains and is treeless. A growing season of less than 70 days and long periods of subzero temperatures control the vegetation, which usually consists of low growing grasses, sedges, and forbs in dense to very open stands. Extensive barren areas are also common in the ecosystem due to frost and wind action and the occurrence of talus slopes. The dominant species are bentgrass, sedges, tufted hairgrass, alpine fescue, woodrush, mountain timothy, bluegrasses, and spike trisetum.

Average annual precipitation ranges from 19 to 32 inches (48-81 cm). The majority of the precipitation falls as snow which may persist throughout the year on some areas.

Shallow, fine textured soils are characteristic of the alpine ecosystem. A humus layer up to 12 inches (31 cm) thick may cover the four to six inches (10-15 cm) of alpine soil and can result in acid soil conditions. Exposed soils are subject to severe wind and water erosion.

Due to the extreme environmental conditions which exist in the alpine meadow ecosystem, attempts to manipulate or rehabilitate the vegetation have seldom been profitable. Thilenius, Smith and Brown (1974) sprayed an alpine meadow with two pounds per acre (2.2 kg/ha) of 2,4-D and virtually eliminated all forbs. Production dropped from 1,204 pounds per acre (1348 kg/ha) to 1,133 pounds per acre (1269 kg/ha) and protein and carotene content was reduced. Revegetation research is presently being conducted in alpine regions, but conclusive results are not yet available. Until more is known about the alpine ecosystem, the vegetative cover should be disturbed as little as possible, and the only reliable practice is establishing and maintaining proper grazing intensity.

Sagebrush Steppe

The dominants in the sagebrush steppe ecosystem are bluebunch wheatgrass and big sagebrush occurring in dense to open grasslands with dense to open shrub stands. The associated native vegetation includes western wheatgrass, Indian ricegrass, bottlebrush squirreltail, Sandberg bluegrass, and Idaho fescue. This sagebrush ecosystem has a high potential for forage production since it occurs in the 10 to 17 inch 25-43 cm) rainfall zone.

Topsoils are usually 12 to 14 inches (31-36 cm) deep, loamy, and well drained. However, a leached calcium carbonate hard pan layer usually lies just below the topsoil.

The sagebrush steppe ecosystem has provided year-round grazing for cattle and sheep, but forage production has been limited by shrub competition. Reducing the cover of sagebrush using two pounds per acre (2.2 kg/ha) of 2,4-D increased forage production from an original 500 pounds per acre (560 kg/ha) to 2,000 pounds per acre (2240 kg/ha) (Alley, 1964). Hyatt (1966) reported a pretreatment production of 343 pounds per acre (384 kg/ha) and post-spraying productions of 1,143 to 3,046 pounds per acre (1280-3412 kg/ha); however, Thilenius and Brown (1974) reported usable forage increases of only 200 pounds per acre (224 kg/ha). Spraying also left shrub skeletons which trapped snow and reduced moisture losses due to interception by the shrub canopy (Alley, 1964; Mueggler and Blaisdell, 1958). A study by Johnson (1958) found that large numbers of sagebrush seedlings appeared three to four years after spraying.

Burning has also proven an effective and cheap sagebrush control technique; however, burns must be carefully planned and controlled. Greene and Aldworth (1959) observed a 69% increase in forage three years after a controlled burn. Similar results were reported by Mueggler and Blaisdell (1958) with an 89% kill of sagebrush. Twelve years after a controlled burn Harniss and Murray (1973) obtained a production increase of 200 pounds per acre (224 kg/ha), but 30 years after treatment sage had reinvaded and production declined.

Mueggler and Blaisdell (1958) studied the effects of rotobeating and railing in the sage steppe ecosystem. Rotobeating gave an 86% kill of sagebrush resulting in a 66% increase in forage production. Railing, on the other hand, resulted in only a 59% kill and 33% forage increase. Rotobeating had the advantage of leaving the brush on the ground to act as a mulch (Halandras, 1963), but it could only be done on relatively level rock-free sites.

Animals have also been used to manipulate the vegetation. Grazing studies conducted by Laycock (1961, 1962, and 1967) indicated that heavy fall grazing with spring deferment decreased the amount of sage and increased forage production by about 43%. Once the desired range condition is reached, spring grazing can be done on a rotational basis without decreasing production (Laycock, 1962).

Grama-Buffalo Grass

Most of eastern Colorado and much of the entire Great Plains region is covered by the grama-buffalo grass ecosystem. This shortgrass ecosystem includes western wheatgrass, three-awn, side-oats and hairy gramas, scarlet globemallow and prickly pear cactus with blue grama and buffalo grass as co-dominants. Approximately 75% of the 10 to 17 inches (25-43 cm) of annual precipitation falls during the 169 day growing season.

Soils are variable but are mostly loams which are shallow on the ridges and deep in the swales. Moisture intake is moderate but depth of penetration may be limited by hard pan layers.

The grama-buffalo grass ecosystem supports a large portion of the grazing and agriculture in the Great Plains. As a result, many range improvements have been applied in the shortgrass region and a great deal has been learned about the performance of these practices.

Moisture is a limiting factor in the shortgrass region; therefore, many practices, including pitting, furrowing, sub-soiling, water spreading and mulching, have attempted to increase or retain soil moisture in order to increase production. Barnes, Anderson, and Heerwagen (1958) estimated that production could be increased from 30 to 100% by pitting, and in a study which covered 20 vegetation types and a variety of soils Branson, Miller, and McQueen (1966) reported an average increase of 300 pounds per acre (336 kg/ha) from a combination of pitting and seeding. Rauzi (1974) obtained significant production increases by pitting and strip spraying seven inch (18 cm) wide bands with atrazine at 15 inches (38 cm) apart (Table 12). Pitting effects lasted about 15 years and the sprayed strips were effective for five to seven years. Another study of pitting on shortgrass range producing 414 pounds per acre (464 kg/ha) increased production by 220 pounds per acre (246 kg/ha) (Rauzi, Lang, and Becker, 1962). Several studies have shown that contour furrowing can increase forage production by 20 to 30% (Barnes and Nelson, 1945; Branson, Miller and McQueen, 1966; Brehm and Malmsten, 1954; Miles and Bradford, 1943). Barnes and Nelson (1945) also increased production from 372 pounds per acre (417 kg/ha) originally to 415 pounds per acre (465 kg/ha) by sub-soil chiseling. Average forage production of 276 pounds per acre (309 kg/ha) was increased as much as 16 times by water spreading on shortgrass prairie (Hubbard and Smoliak, 1953). Beutner and Anderson (1943) were able to increase blue grama production by 50% and reduce runoff 20% through mulching with grass straw at two tons per acre (4480 kg/ha).

Increasing soil fertility has also improved forage production. Klipple and Retzer (1959) increased herbage yields 15 to 50% by applying ten tons per acre (22,400 kg/ha) of well rotted cattle manure, but commercial fertilizers had no significant effects. Goetz (1969), in contrast, increased production from 838 pounds per acre (939 kg/ha) to over 1,200 pounds per acre (1344 kg/ha) using 67 pounds per acre of nitrogen, and Dwyer (1967) increased production by burning and fertilizing (Table 13).

Some shortgrass ranges have been invaded by fringed sage and may have been cropped and abandoned, both of which seriously reduce usable forage production. Two years of treatment with 2,4-D controlled fringed sage and forage production doubled (Anon, 1967). Some abandoned croplands have been reclaimed by seeding to introduced species. Bement and others (1965) obtained yields ranging from 1,320 to 1,604 pounds per acre (1478-1797 kg/ha) on croplands seeded to crested wheatgrass. Seeding 1.5 pounds per acre (1.7 kg/ha) of russian wildrye with 28 inch (71 cm) row spacing produced from 1,162 to 1,911 pounds per acre (1301-2140 kg/ha) on eroded farmlands (Baize, Mann and Cook. 1973; Bose, Mann and Cook, 1974).

Grazing systems have also been shown to influence forage production. Cook, Mann and Bose (1974) reported increased forage production under both continuous and three pasture rotation summer grazing systems on native blue grama range, range seeded to sideoats grama, blue grama, buffalo grass and sand dropseed and 30 year old go-back range (Table 14). Overall average production increased from 777 pounds per acre (870 kg/ha) in 1970 to 1,780 pounds per acre (1994 kg/ha) in 1973.

Table 12. Effects of pitting and strip spraying with atrazine on shortgrass forage production (Rauzi, 1974).

Treatment	Yield (lbs/acre)
Control	947
Pitted	1258
Sprayed	1049
Pitted and Sprayed	1349

Table 13. Effects of time of year on yield of burned and fertilized blue grama rangeland (Dwyer, 1967).

Month Treatment Applied	Yield Increase (%)		
	Burned only	Burned and Fertilized	Fertilized only
January	11.3	116.9	---
April	56.3	173.6	---
June	15.6	164.4	200
October	9.0	103.0	---

Table 14. Effects of two grazing systems on yields of native, seeded and go-back blue grama rangelands (Cook, Mann and Bose, 1974).

Year	Yield (lbs/acre)					
	Native		Seeded		Go-back	
	Continuous	Rotation	Continuous	Rotation	Continuous	Rotation
1970	1050	650	850	725	1000	900
1971	1200	720	952	1200	1711	1200
1972	1072	1083	1799	1400	1345	1800
1973	1294	1333	2253	1266	1354	2100

Wheatgrass-Needlegrass

The wheatgrass-needlegrass ecosystem supports short to medium-tall grasslands of western wheatgrass, blue grama, and needle-and-thread grass at elevations from 7,000 to 9,000 feet (2134-2743 m) in south-central Colorado. Associated species include Indian ricegrass, Arizona fescue, muttongrass, ring muhly, bottlebrush squirreltail, and green needlegrass. Annual precipitation, of which approximately 50% falls during the growing season, ranges from 10 to 14 inches (25-36 cm) in this relatively small mid-grass ecosystem.

Moderately productive loam to sandy loam soils occur with the wheatgrass-needlegrass ecosystem. Gravel usually occurs throughout the soil profile, and, as a result, infiltration and permeability are always favorable.

Due to its limited extent the wheatgrass-needlegrass ecosystem has not been a major grazing area but does offer good potential for forage production with fertility being the most limiting factor. Houston (1971) recorded production figures of 550 pounds per acre (616 kg/ha) following pitting, 830 pounds per acre (930 kg/ha) after pitting and interseeding alfalfa, 590 pounds per acre (661 kg/ha) after pitting and applying 30 pounds of nitrogen, and 1,140 pounds per acre (1277 kg/ha) following the application of 90 pounds of nitrogen per acre (101 kg/ha) on an overflow site where the original production had been 450 pounds per acre (504 kg/ha). On a sandy site, total forage production was increased from 1,603 pounds per acre (1795 kg/ha) to 2,837 pounds per acre (3177 kg/ha) by fertilizing with 67 pounds per acre (75 kg/ha) of nitrogen (Goetz, 1969). The same fertilizer rate on a silty site increased production from 2,410 pounds per acre (2699 kg/ha) to 3,261 pounds per acre (3652 kg/ha) (Goetz, 1969).

Sandsage-Bluestem Prairie

The sandsage-bluestem ecosystem, which consists of medium-tall, medium-dense grasslands with a strong element of dwarf shrubs, occurs in the extreme eastern portions of Colorado. Little bluestem, sand bluestem, sandsage, and hairy grama dominate in a vegetation type which can include blue grama, buffalo grass, prairie sandreed grass, sand dropseed, needle-and-thread grass, and yucca. Precipitation ranges from 11 to 20 inches (28-51 cm) per annum.

Soils are sands to loamy sands, deep, and often extremely loose. Wind erosion becomes a severe hazard if the vegetation is depleted or removed.

In general, mechanical manipulations, such as pitting, have proven of little value in the sandsage-bluestem ecosystem because of the loose soils. Whitfield and Fly (1939), however, reported that contour furrowing on a poor condition sandy loam site doubled forage production. The furrowed area retained 70% more moisture resulting in an increase in sand bluestem and sideoats grama.

Natural revegetation of depleted sand prairies has proven to be slow. Denham (1973) reported that abandoned cropland was producing only 45 pounds per acre (50 kg/ha) after at least 20 years of natural revegetation. Seeding the area to a mixture of blue grama, sideoats grama, and sand lovegrass increased production to 1,033 pounds per acre (1157 kg/ha), and adding alfalfa to the mixture brought production to 2,000 pounds per acre (2240 kg/ha) (Denham, 1973). In seeding and fertilization trials with six warm-season grasses, Sims (1973) increased production to over 3,000 pounds per acre (3360 kg/ha) (Table 15).

In some cases the wind erosion hazard may preclude complete seedbed preparation. Interseeding provides a method for rapidly improving production without completely destroying the existing ground cover. Hervey (1960) reported increasing production on a dune sand site dominated by sand dropseed to 804 pounds per acre (899 kg/ha) by interseeding sand lovegrass at two foot (61 cm) intervals.

Carrying capacity of bluestem ranges has been increased by a system of deferred grazing. On native range, 5.61 acres (2.27 ha) were required to support six cow-months under continuous grazing; whereas, only 3.18 acres (1.29 ha) were required when the pasture was deferred until July (Anderson, 1940). Animals gained better and plant cover and composition were better on the deferred pasture. Sims and

Denham (1969) reported that a short duration grazing system with a stocking rate of 0.75 acre (0.3 ha) per steer-month provided better gains than continuous grazing and had no ill effects on forage production.

Table 15. Yields of six seeded warm-season grasses at various rates of nitrogen (N) and phosphorous (P) fertilization in the Colorado sandhills (Sims, 1973).

Species	Yield (lbs/acre)			
	0 N-0 P	30 N-0 P	0 N-20 P	30 N-20 P
Blue grama	1031	1225	1122	1193
Sand bluestem	1794	2396	2659	2323
Sand lovegrass	1703	2189	2191	2019
Prairie sandreed	2836	3226	3802	3213
Sideoats grama	1054	1269	1186	1287
Switch grass	1979	1764	1946	1784

DISCUSSION AND CONCLUSIONS

Range resource management is becoming an increasingly important part of the livestock industry. More and more, traditional grazing lands are being diverted to alternate uses, and more pressure is being placed on forage production from the remaining rangeland. Thus, these rangelands must be managed to obtain and maintain high production, and range improvement practices can help achieve these goals.

Range improvement practices do have limitations. Range sites which are in high good to excellent condition usually will not respond significantly to improvement practices, and sites in very poor condition may not have the potential to respond without intensive reclamation measures. Adverse weather conditions, such as unusually low rainfall or unexpected frost, may also reduce the effectiveness of attempted improvements. In some cases, the cost of applying a practice may be very high; therefore, the cost of range improvement should be weighed against the expected benefits.

Once an improvement is implemented, the area should be monitored to determine the effects of the practice. A response may not be noted for several growing seasons, or it may be immediate depending upon the vegetation, weather, and practice. If forage production and condition do improve, the range manager should implement management practices which will maintain the new condition.

Many reports and publications which provide range improvement methods and application guidelines are readily available. Unfortunately, only a relatively few studies report how a practice actually affects forage production. Also, more research on the life expectancy of treatments is needed. In order to sufficiently evaluate an improvement practice, the range manager needs this information on expected benefits and life span.

The information presented in this publication is intended as a guide to range improvement benefits in Colorado. The range manager must use his expertise and judgment in evaluating the site potential and in determining if proper climatic conditions exist before applying a practice. The manager is also responsible for determining which practices should be tried. However, once the practices are selected, the information in this report can be used to evaluate the potential benefits.

LITERATURE CITED

Aldon, Earl F. and George Garcia. 1967. Summer deferred grazing can improve deteriorated semidesert ranges. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Res. Note RM-95. 4 p.

Alley, Harold. 1964. More beef through chemical sagebrush control. Amer. Cattle Prod. 46(5):10.

Anderson, A. E. 1969. 2,4-D, sagebrush and mule deer--cattle use of upper winter range. Colo. Div. Game, Fish and Parks Spec. Rep. 21. 21 p.

Anderson, Kling L. 1940. Deferred grazing of bluestem pastures. Kansas Agr. Exp. Sta. Bul. 291. 27 p.

Anonymous. 1967. Grass doubles production from weedbrush spraying. Amer. Cattle Prod. 49(5):37.

Arnold, J. F. and W. L. Schroeder. 1955. Juniper control increases forage production on the Ft. Apache Indian Reservation. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Paper 18. 35 p.

Aro, Richard S. 1971. Evaluation of pinyon-juniper conversion to grassland. J. Range Manage. 24(3):188-197.

Baize, John C., Herb Mann and C. Wayne Cook. 1973. Establishment, production, and nutritive value of russian wildrye in southeastern Colorado. Colo. State Univ. Exp. Sta. Prog. Rep. PR 73-36. 3 p.

Barnes, O. K. and A. L. Nelson. 1945. Mechanical treatments for increasing the grazing capacity of shortgrass range. Wyo. Agr. Exp. Sta. Bul. 273. 35 p.

Barnes, Oscar K., Darwin Anderson, and Arnold Heerwagen. 1958. Pitting for range improvement in the Great Plains and the Southwest desert regions. USDA Prod. Res. Rep. 23. 17 p.

Barney, Milo A. and Neil C. Frischnecht. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. J. Range Manage. 27:91-96.

Bartel, L. E., G. G. Davis and C. W. Cook. 1973. Production benefits from Gambel oak control in southwestern Colorado. Colo. State Univ. Exp. Sta. Prog. Rep. PR 73-11. 3 p.

Bartlett, E. T. 1976. A western range improvement bibliography. mimeographed. 214 p.

Bement, R. E., R. D. Barington, A. C. Everson, L. O. Hylton, Jr., and E. E. Temmenga. 1965. Seeding of abandoned croplands in the Central Great Plains. J. Range Manage. 18(2):53-59.

Beutner, E. L. and Darwin Anderson. 1943. The effect of surface mulches on water conservation and forage production in some semi-desert grassland soils. J. Amer. Soc. Agron. 35:383-400.

Bose, Den R., Herb Mann and C. Wayne Cook. 1974. Establishment, production, and nutritive value of russian wildrye in southeastern Colorado. Colo. State Univ. Exp. Sta. Prog. Rep. PR-74-15. 4 p.

Bowns, James E. 1972. Low level nitrogen and phosphorous fertilization on high elevation range. J. Range Manage. 25(4):273-276.

Branson, F. A., R. F. Miller, and I. S. McQueen. 1966. Contour furrowing, pitting, and ripping on rangelands of the western United States. J. Range Manage. 19(4):182-190.

Brehm, C. D. and H. E. Malmsten. 1954. Contour furrows on pasture and rangeland. J. Soil and Water Conserv. 9(3):111-114.

Brown, Harry E. 1958. Gambel oak in west-central Colorado. Ecology. 39(2):317-327.

Chilson, E. W. 1964. Increasing livestock production through juniper control. Proc. 8th Annual Ariz. Watershed Symp: 28-30.

Christensen, M. Dale, James A. Young, and Raymond A. Evans. 1974. Control of annual grasses and revegetation in ponderosa pine woodlands. J. Range Manage. 27(2):143-145.

Cook, C. Wayne. 1958. Sagebrush eradication and broadcast seeding. Utah Agr. Exp. Sta. Bul. 404 . 23 p.

Cook, C. Wayne. 1965. Plant and livestock responses to fertilized rangelands. Utah Agr. Exp. Sta. Bul. 455. 35 p.

Cook, C. Wayne, Herbert O. Mann and Dan R. Bose. 1974. The history of range research at the Southern Colorado Research Center. Colo. State Univ. Exp. Sta. Prog. Rep. PR 74-16. 3 p.

Cronin, E. H. 1974. Evaluation of some herbicide treatments for controlling tall larkspur. J. Range Manage. 27(3):219-222.

Currie, Pat O. 1969. Plant response and cattle gains on Sherman big bluegrass. J. Range Manage. 22(4):258-261.

Currie, Pat O. 1975. Grazing management of ponderosa pine-bunchgrass ranges of the Central Rocky Mountains: the status of our knowledge. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Res. Paper RM-159. 24 p.

Currie, Pat O. 1976. Recovery of ponderosa pine-bunchgrass ranges through grazing and herbicide or fertilizer treatments. J. Range Manage. 29(6):444-448.

Davis, Gary G., Lawrence E. Bartel and C. Wayne Cook. 1975. Range science project report for 1974 San Juan Basin Research Center. Colo. State Univ. Exp. Sta. Prog. Rep. PR 75-3. 4 p.

Davis, G. G., L. E. Bartel and P. L. Sims. 1973. Production on dryland seeded pastures in the San Juan Basin. Colo. State Univ. Exp. Sta. Prog. Rep. PR 73-14. 3 p.

Denham, A. H. 1973. 20 years of research at the Eastern Colorado Research Center. Colo. State Univ. Exp. Sta. Prog. Rep. PR 73-80. 5 p.

Doran, C. W. 1951. Guide for reseeding summer rangelands on Colorado's western slope. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Paper No. 6 18 p.

Dwyer, Don D. 1967. Fertilization and burning of blue grama grass. J. Anim. Sci. 26(4):934.

Eckert, R. E., Jr., A. D. Bruner, and G. J. Klomp. 1972. Response of understory species following herbicidal control of low sagebrush. J. Range Manage. 25(4):290-295.

Eckert, R. E., Jr., A. D. Bruner, G. J. Klomp, and F. F. Peterson. 1973a. Control of Rocky Mountain iris and vegetation response on mountain meadows. J. Range Manage. 26(5):352-355.

Eckert, R. E., Jr., A. D. Bruner, G. J. Klomp, and F. F. Peterson. 1973b. Mountain meadow improvement through seeding. J. Range Manage. 26(3):200-203.

Forsling, C. L. and W. A. Dayton. 1936. Artificial reseeding on western mountain rangelands. USDA Cir. 178. 48 p.

Frischnecht, Neil C. and Maurice F. Baker. 1972. Voles can improve sagebrush rangelands. J. Range Manage. 25(6):466-468.

Goetz, Harold. 1969. Composition and yields of native grassland sites fertilized at different rates of nitrogen. J. Range Manage. 22(6):384-390.

Greene, G. E. and W. R. Aldworth. 1959. Sagebrush or grass? J. Soil and Water Conserv. 14(4):170-172.

Halandras, Gus R. 1963. Range improvement through sagebrush beating. Natl. Wool Grower. 53(6):16-17.

Hanson, H. C. 1929. Improvement of sagebrush range in Colorado. Colo. Agr. Exp. Sta. Bul. 356. 12 p.

Harniss, Roy O. and Robert B. Murray. 1973. 30 years of vegetal changes following burning of sagebrush-grass range. J. Range Manage. 26(5):322-325.

Hervey, D. F. 1960. Improving Great Plains rangelands by interseeding. Proc. 8th Internatl. Grassland Cong. p. 216-220.

Houston, Walter R. 1971. Range improvement methods and environmental influences in the Northern Great Plains. USDA, ARS, Prod. Res. Report No. 130. 13 p.

Hubbard, William A. and Sylvester Smoliak. 1953. Effects of contour dikes and furrows on short-grass prairie. J. Range Manage. 6(1):55-62.

Hull, A. C., Jr., and C. W. Doran. 1950. Preliminary guide to reseeding pinyon-juniper lands of western Colorado. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Res. Note No. 4. 16 p.

Hull, A. C., Jr., and W. M. Johnson. 1955. Range seeding in the ponderosa pine zone in Colorado. USDA Cir. No. 953. 44 p.

Hull, A. C., Jr., and W. T. Vaughan. 1951. Kill undesirable native vegetation for successful range reseeding. USDA For. Serv. Res. Note No. 8.

Hutchings, Selor S. and George Stewart. 1953. Increasing forage yields and sheep production on intermountain winter ranges. USDA Cir. No. 925. 63 p.

Hyatt, S. Wesley. 1966. Sagebrush control. . .costs, results and benefits to the rancher. J. Range Manage. 19(1):42-43.

Jefferies, Ned. W. and J. J. Norris. 1965. Management and improvement of Gambel oak ranges, San Juan Basin Branch Station, Hesperus, 1965. Colo. Agr. Exp. Sta. Prog. Report 147. 2 p.

Johnson, W. M. 1958. Reinvasion of big sagebrush following chemical control. J. Range Manage. 11(4):169-172.

Klipple, G. E. and John L. Retzer. 1959. Response of native vegetation of the Central Great Plains to application of corral manure and commercial fertilizer. J. Range Manage. 12(5):239-243.

Küchler, A. W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society, Special Publication No. 36. 116 p. and map.

Lavin, Fred and H. W. Springfield. 1965. Seeding in the southwestern pine zone for forage improvement and soil protection. USDA Agr. Handbook No. 89. 52 p.

Laycock, William A. 1961. Improve your range by heavy fall grazing. Nat. Woolgrower. 51(6):16, 30.

Laycock, William A. 1962. Rotation allows heavier grazing of sagebrush-grass range. Nat. Woolgrower. 52(6):16-17.

Laycock, William A. 1967. How heavy grazing and protection affect sagebrush-grass ranges. J. Range Manage. 20(4):206-213.

Ludwick, A. E. and C. B. Rumberg. 1975. Nitrogen sources and rates for meadow hay production. Colo. State Univ. Exp. Sta. Prog. Rep. PR 75-33. 3 p.

Ludwick, A. E. and C. B. Rumberg. 1977. Nitrogen fertilizers for meadow hay production. Colo. State Univ. Exp. Sta. Prog. Rep. PR 77-6. 2 p.

Marquiss, R. W. 1969. Studies on Gambel oak at the San Juan Branch Station. Colo. Agr. Exp. Sta. PR 69-38. 2 p.

Marquiss, Robert W. 1972. Soil moisture, forage and beef production benefits from Gambel oak control in southwestern Colorado. J. Range Manage. 25(2):146-150.

Marquiss, Robert W. 1973. Gambel oak control studies in southwestern Colorado. J. Range Manage. 26(1):57-58.

Miles, Wayne H. and Harold W. Bradford. 1943. Contour furrows on buffalo and blue grama range. The Cattleman. 30(3):18,20.

Minnich, Don W. 1969. Vegetative response and pattern of deer use following chaining on pinyon and juniper forest. ASRM, Abstract of Papers. 22nd Annual Meeting. p. 35-36.

Mueggler, W. F. and J. P. Blaisdell. 1958. Effects on associated species of burning, rotobeating, spraying and railing sagebrush. J. Range Manage. 11(2):61-66.

McConnell, B. R. and J. G. Smith. 1965. Understory response three years after thinning pine. J. Range Manage. 18:129-132.

Nichols, James T. 1964. Cover, composition, and production of contour furrowed and seeded range as compared to native saltsage range. Wyo. Range Manage. 187:27-38.

Nickerson, Mona F., Glen E. Brink, and Charles Feddema. 1976. Principal range plants of the central and southern Rocky Mountains: names and symbols. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Gen. Tech. Rep. RM-20. 121 p.

Paulsen, Harold A., Jr. and John C. Miller. 1968. Control of Parry rabbitbrush on mountain grasslands of western Colorado. J. Range Manage. 21(3):175-177.

Phillips, T. A. 1977. An analysis of pinyon-juniper chaining projects in the intermountain region 1954-1975. USDA For. Serv. Range Improvement Notes. 20 p.

Plummer, A. P. 1958. Restoration of juniper-pinyon ranges in Utah. Proc. Soc. Am. For., Salt Lake City, Utah.

Rauzi, Frank. 1974. Mechanical and chemical range renovation in southeastern Wyoming. J. Range Manage. 27(1):49-52.

Rauzi, F., R. L. Lang, and C. G. Becker. 1962. Mechanical treatments on shortgrass range. Wyo. Agr. Exp. Sta. Bul. 396. 16 p.

Robinson, M. E. and D. H. Matthews. 1955. Aspen cutting may increase feed resources in southern Utah. Utah Farm and Home Sci. 16(2): 28-29, 44.

Rollins, M. B., A. S. Dylla, and R. E. Eckert, Jr. 1968. Soil problems in reseeding a greasewood-rabbitbrush range site. J. Soil and Water Conserv. 23:138-140.

Sims, Phillip L. 1973. Adaptability and fertilization response of improved varieties of warm-season grasses for the eastern Colorado sandhills. Colo. State Univ. Exp. Sta. Prog. Rep. PR 73-73. 4 p.

Sims, Phillip L. and A. H. Denham. 1969. Grazing systems on sandhill rangeland. Colo. State Univ. Exp. Sta. Prog. Rep. PR 69-56. 4 p.

Skovlin, John M. 1965. Improving cattle distribution on western mountain rangelands. USDA Farmer's Bul. 2212. 14 p.

Smith, Dixie R. and Harold P. Alley. 1966. Chemical control of alpine avens. J. Range Manage. 19(6):376-378.

Smith, Dixie R. and R. L. Lang. 1958. The effect of nitrogenous fertilizers on cattle distribution on mountain range. J. Range Manage. 11(5):248-249.

Smith, Dwight R. 1967. Effects of cattle grazing on a ponderosa pine-bunchgrass range in Colorado. USDA Tech. Bul. 1371. 60 p.

Thilenius, John F. and Gary R. Brown. 1974. Longterm effects of chemical control of big sagebrush. J. Range Mange. 27(3):223-224.

Thilenius, John F., Dixie R. Smith and Gary R. Brown. 1974. Effect of 2,4-D on composition and production of an alpine plant community in Wyoming. J. Range Manage. 27(4):140-142.

Thompson, Wesley W. and F. Robert Gartner. 1971. Native forage response to clearing low quality ponderosa pine. J. Range Manage. 24(4):272-277.

Torell, Paul J. and Robert H. Haas. 1963. Herbicidal control of tall larkspur. Weeds. 11(1):10-13.

Whitfield, C. J. and C. L. Fly. 1939. Vegetational changes as a result of furrowing on pasture and rangelands. J. Amer. Soc. Agron. 31:413-417.

Willhite, F. M. 1963. How to improve mountain meadows in the West. Plant Food Review. 9:5-8.

APPENDIX

Common Name	Scientific Name
Grasses and Grasslike Plants	
Alkali sacaton	*Sporobolus airoides*
Alpine fescue	*Festuca brachyphylla*
Arizona fescue	*Festuca arizonica*
Beardless wheatgrass	*Agropyron inerme*
Bentgrass	*Agrostis spp.*
Big bluegrass	*Poa ampla*
Blue grama	*Bouteloua gracilis*
Bluebunch wheatgrass	*Agropyron spicatum*
Bottlebrush squirreltail	*Sitanion hystrix*
Buffalo grass	*Buchloe dactyloides*
Cheatgrass, downy brome	*Bromus tectorum*
Creeping (meadow) foxtail	*Alopecurus pratensis*
Crested wheatgrass	*Agropyron desertorum*
Green needlegrass	*Stipa viridula*
Hairy grama	*Bouteloua hirsuta*
Idaho fescue	*Festuca idahoensis*
Indian ricegrass	*Oryzopsis hymenoides*
Inland saltgrass	*Distichlis stricta*
Intermediate wheatgrass	*Agropyron intermedium*
Kentucky bluegrass	*Poa pratensis*
Little bluestem	*Andropogon scoparius*
Medusahead	*Taeniatherum asperum*
Mountain brome	*Bromus marginatus*
Mountain muhly	*Muhlenbergia montana*
Mountain (alpine) timothy	*Phleum alpinum*
Muttongrass	*Poa fendleriana*
Needle-and-thread grass	*Stipa comata*
Orchard grass	*Dactylis glomerata*
Prairie sandreed grass	*Calamovilfa longifolia*
Pubescent wheatgrass	*Agropyron trichophorum*
Red fescue	*Festuca rubra*
Ring muhly	*Muhlenbergia torreyi*
Russian wildrye	*Elymus junceus*
Sandberg bluegrass	*Poa sandbergii*
Sand bluestem	*Andropogon hallii*
Sand dropseed	*Sporobolus cryptandrus*
Sand lovegrass	*Eragrostis trichodes*
Sedges	*Carex spp.*
Siberian wheatgrass	*Agropyron sibiricum*
Sideoats grama	*Bouteloua curtipendula*
Slender wheatgrass	*Agropyron trachycaulum*

Common Name	Scientific Name
Smooth bromegrass	*Bromus inermis*
Spike trisetum	*Trisetum spicatum*
Streambank wheatgrass	*Agropyron riparium*
Switch grass	*Panicum virgatum*
Tall oatgrass	*Arrhenatherum elatius*
Tall wheatgrass	*Agropyron elongatum*
Three-awn	*Aristida spp.*
Thurber fescue	*Festuca thurberi*
Timothy	*Phleum pratense*
Tufted hairgrass	*Deschampsia caespitosa*
Western wheatgrass	*Agropyron smithii*
Woodrush	*Luzula spp.*

Forbs

Alfalfa	*Medicago spp.*
Alpine avens	*Geum rossii*
Fringed sage	*Artemisia frigida*
Halogeton	*Halogeton glomeratus*
Lupine	*Lupinus spp.*
Povertyweed	*Iva axillaris*
Prickly pear cactus	*Opuntia spp.*
Rocky Mountain iris	*Iris missouriensis*
Scarlet globemallow	*Sphaeralcea coccinea*
Sneezeweed	*Helenium spp.*
Tall larkspur	*Delphinium occidentale*
Yellow blossom sweetclover	*Melilotus officinalis*

Trees and Shrubs

Aspen	*Populus tremuloides*
Big sagebrush	*Artemisia tridentata*
Bitterbrush	*Purshia tridentata*
Douglas fir	*Pseudotsuga douglasii*
Englemann spruce	*Picea engelmannii*
Fourwing saltbush	*Atriplex canescens*
Gambel oak	*Quercus gambelii*
Greasewood	*Sarcobatus vermiculatus*
Mountain mahogany	*Cercocarpus spp.*
Oneseed juniper	*Juniper monosperma*
Parry rabbitbrush	*Chrysothamnus parryi*
Pinyon pine	*Pinus edulis*
Ponderosa pine	*Pinus ponderosa*
Rabbitbrush	*Chrysothamnus spp.*
Sandsage	*Artemisia filifolia*
Shadscale	*Atriplex confertifolia*
Subalpine fir	*Abies lasiocarpa*
Utah juniper	*Juniperus utahensis*
Yucca	*Yucca glauca*