Species Adapted for Planting Arizona Pinyon-Juniper Woodland

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Highlight: Species adaptation trials were observed over periods varying from 21 to 28 years at ten Arizona pinyon-juniper sites. Fifty-nine species and varieties developing fair to excellent stands and persisting five or more years were considered adapted to one or more of the sites. Fifty-four of these were still present at the last rating. Thirty have reproduced themselves and are spreading naturally. Most widely adapted species are *Agropyron desertorum, A. intermedium, A. smithii, A. trichophorum, Atriplex canescens, Bothriochloa ischaemum, Bouteloua curtipendula, Muhlenbergia wrightii,* and *Tridens elongatus*. Moisture variation caused some cool season grasses to fluctuate more widely in growth and stand than the other adapted species, especially shrubs. Warm-season growers were generally sensitive to low temperatures and cool-season growers to high temperatures. Complete protection from livestock appeared to have detrimental effects on some species. Sites are described and classified to help identify planting potential and facilitate wide application of results. Guidelines are suggested for shortening the time period needed to evaluate species adaption.

Successful improvement of pinyon-juniper rangelands by revegetation depends on the use of adapted species. Species and variety adaptation trials were begun in 1945 at 10 pinyon-juniper sites in Arizona. The plantings varied from 21 to 28 years in age when last evaluated. The long duration of these trials makes them especially useful for selecting species and varieties best suited to different range sites and planting needs. The accompanying site descriptions and classifications will help to identify potential planting sites and facilitate wide application.

Results apply to similar sites within the 13.5 million acres of pinyon-juniper rangeland in Arizona, including many areas invaded by juniper. Additional areas occur within the 37.5 million acres of pinyon-juniper in New Mexico, Colorado, and Utah. Other work on species adaptation in the pinyon-juniper woodland has been reported by Renney (1972), Judd (1966), Judd and Judd (1976) for Arizona; Springfield (1965) for New Mexico; McGinnies, et al. (1963) for Colorado; and Plummer et al. (1968) for Utah.

The study was initiated by the former Southwestern Forest and Range Experiment Station (now Rocky Mountain Forest and Range Experiment Station), Forest Service, U.S. Department of Agriculture, and transferred to the Agricultural Research Service, U.S. Department of Agriculture, in 1954.

Site Descriptions and Classifications

Ten study sites were established at the locations shown in Figure 1. Buckhead Mesa is 5 miles southeast of Pine; Dog Knobs, 36 miles northwest of Flagstaff; Drake, 2 miles north of the town of Drake; Moritz Lake, 6 miles northeast of Spring Valley; Mud Tanks, 25 miles east of Camp Verde; Perkinsville, 1 mile south of the town of

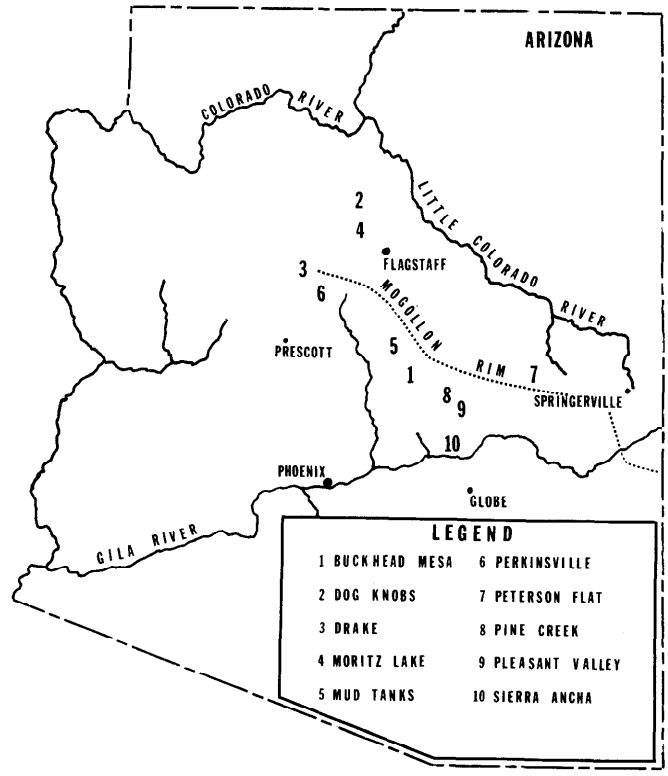

Fig. 1. *Location of the ten pinyon-juniper sites used to study species adaptation.*

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Table 1. Classification and description of Arizona pinyon-juniper study sites.

Subtype and study site	Elevation (ft above sea level)	Precipitation (inches)[1]		Temperature (°F)[1]		Soils		Dominant trees and shrubs[2]
		Annual	Nov.-Apr.	Annual	Jan.	Series	Texture	
Cold-moist								
Moritz Lake	6,600	16	7	49	30	Sponsellor, warm varient	Silt loam	Jumo, Juos, Pied
Peterson Flat	6,500	17	7	49	29	Jacques	Loam	Jude, Jumo, Pied
Cold-dry								
Dog Knobs	6,400	12	4	49	31	Thunderbird	Clay loam	Jumo, Pied
Cool-moist								
Mud Tanks	5,900	18	9	52	32	Thunderbird	Gravelly clay loam, clay loam	Jude
Warm-moist								
Pine Creek	5,200	20	10	53	36	Showlow	Gravelly loam	Jude, Jumo
Pleasant Valley	5,000	19	9	53	36	Lynx	Loam	Jude, Jumo
Buckhead Mesa	4,700	20	10	54	36	Thunderbird	Clay loam	Jude, Jumo
Warm-dry								
Drake	4,600	13	5	54	36	Tajo	Gravelly loam	Juos
Perkinsville	4,000	13	6	57	39	Abra, Partri	Loam, clay loam	Juos
Hot-moist								
Sierra Ancha	4,600	17	9	60	43	White House	Very gravelly loam	Qutu, Jumo, Jude

[1] All precipitation and temperature data are means.
[2] Jude = *Juniperus deppeana*, Jumo = *J. monosperma*, Juos = *J. osteosperma*, Qutu = *Quercus turbinella*, and Pied = *Pinus edulis*.

Perkinsville; Peterson Flat, 1 mile southeast of Pinedale; Pine Creek, 10 miles north of Young; Pleasant Valley, 2 miles east of Young; and Sierra Ancha, 3 miles southeast of the Sierra Ancha Experimental Forest Headquarters.

Elevations, precipitation amounts and seasonal distribution, temperatures, and soils and vegetation of the sites represent a wide range of conditions (Table 1). Detailed site descriptions have been reported by Lavin and Johnsen (1977).

The study sites are placed in six pinyon-juniper subtypes based on precipitation and temperature. Information from nearby weather stations (Sellers and Hill 1974) was adapted for seven sites. A combination of data from the nearest station and more distant stations with similar elevation, physiography, and vegetation was used to extrapolate information for the other three sites, namely Buckhead Mesa, Moritz Lake, and Mud Tanks.

Sites with 15 inches or less mean annual precipitation are classed as dry; those with 16 inches or more, as moist. All sites received 7–10 inches of summer precipitation, mainly in July and August. Cool season precipitation was more variable. The Arizona pinyon-juniper woodland has distinct periods of summer and winter rainfall, with dry springs and falls. Also, there is a gradual reduction of summer rainfall from south to north and of winter rainfall from west to east (Jameson 1969).

Comparisons of available temperature data and survival indicated that mean annual and mean January temperatures apparently were the most significant. Relative temperature groupings, therefore, were delineated on this basis. Sites are classed as: (1) cold, with mean annual temperature 49°F or less and mean January temperature 31°F or less; (2) cool, with 50 to 53°F annual and 32 to 35°F January; (3) warm, with 54 to 58°F annual and 36 to 39°F January; and (4) hot, with 59°F or more annual and 40°F or more January.

Study sites are all relatively level so that slope and aspect effects on temperature and moisture are minimal. Dominant trees and shrubs may have some use as site indicators because they appear to have a relationship to the climate. Alligator juniper grows on the moister sites, while Utah and one-seed juniper dominate the drier sites.

Soils were described from on-site examination by a soil scientist experienced with Arizona pinyon-juniper soils. Nine soil series were found on the study sites (Table 1). Buckhead Mesa, Dog Knobs, Moritz Lake, Mud Tanks, Perkinsville, and Pine Creek all have the same or similar soils classed as Aridic Argiustolls. Peterson Flat and Pleasant Valley have similar Cumulic Haplustolls soils. Drake, with a Petrocalcic Paleustoll, and Sierra Ancha, with a Ustollic Haplargid, have soils different from the other sites. All the soils are loamy, ranging from gravelly to clay loams, with depths varying from moderately deep to deep.

Procedure

Plantings were made from 1945 through 1952 with a total of 240 species and varieties. Several accessions were planted for many of the species. Only results for species and recognized varieties adapted to one or more sites are given here. A listing of all species planted has been made by Lavin and Johnsen (1977).

Plantings were: (1) initial nursery plots of three 12-foot rows, spaced 1-foot apart, and then (2) larger plots up to an acre in size for the more promising species. All plantings were replicated at least twice in separate blocks at each location. Many species and varieties, especially those that did not attain a fair or better stand or were destroyed by some biotic agent, were replanted several times in attempts to establish them.

Juniper and pinyon were clear cut and removed from the planting sites as required. Seed beds were plowed, disked, harrowed, and cultipacked, except at Buckhead Mesa and Pine Creek, which were disked and harrowed only, and at Moritz Lake, which was plowed with a Wheatland plow only. Nursery seedbeds replanted because of initial failure were prepared by hand hoeing and raking.

Rows were formed, seeded, and covered by using handtools for the small nursery plantings. On the larger plots, seed was either drilled or broadcast. Broadcast seed was covered by harrowing or cultipacking. Seed rates were 20–40 pure live seed per linear foot for row plantings and 30–50 per square foot for broadcasting.

Seed was planted from ¼–1 inch deep, depending upon seed size and known species requirements. Most of the plantings were made from late June through July. During a few years plantings also were made at Peterson Flat in September, and at Dog Knobs in September and October. Weeds were not controlled except when replanting.

All sites were fenced against livestock except Moritz Lake. Additional fencing with 1-inch mesh wire was used for protection against rabbits at all nursery plantings except Buckhead Mesa and Pine Creek. Cattle grazed the plantings at Dog Knobs, some of them heavily, during August, 1947, when the fence was being replaced. Fencing was removed from some of the larger plantings at Mud Tanks in the fall of 1959 and they have been heavily grazed each year since that time. Moritz Lake had heavy cattle use from June 1 to October 31 starting the year after planting until 1967, and since then has received heavy year-long use.

All plantings were rated at least twice a year from 1945 through 1953, once in 1954, and at irregular intervals thereafter. The last rating was made the fall of 1973. Numerical relative ratings on a scale from one to 10 representing the actual stand in relation to the best possible stand were used to record planting success (Hull 1974). These ratings consider the number, distribution, and vigor of the seeded plants. To simplify presentation, numbers have been converted to adjectives as follows: 0 = failure, 1–2 = very poor, 3–4 = poor, 5–6 = fair, 7–8 = good, and 9–10 = excellent. Other information, such as natural spread, disease, and animal activity, was also recorded.

Table 2. Final and maximum ratings[1] for species and varieties surviving at least 10 years and attaining a rating of fair or better on one or more study sites.

	Cold-moist		Cold-dry	Cool-moist	Warm-moist			Warm-dry		Hot-moist
Species and variety	Peterson Flat	Moritz Lake	Dog Knobs	Mud Tanks	Pine Creek	Pleasant Valley	Buckhead Mesa	Drake	Perkins-ville	Sierra Ancha
Agropyron cristatum	O/E	O/F	O/G	*V/E*[2]	–	O/P	–	O/G	V/E	O/O
A. desertorum	*G/E*	P/G	*F/E*	*G/E*	*F/G*	V/E	*P/G*	V/F	V/E	O/P
A. elongatum	*F/E*[*3]	O/F	*E/E**	*G/E**	–	V/E	–	O/E	O/E	–
A. intermedium	*O/E*	O/G	*F/E**	*G/E**	*O/E*	*F/G**	O/E	O/G	O/E	O/O
A. intermedium-Amur	O/E	–	O/G	*V/G*	–	O/G	–	O/F	O/E	–
A. intermedium-Ree	*G/E**	–	O/G	*F/E**	–	V/G	–	O/F	–	O/O
A. popovii	O/G	–	P/G	*G/G*	–	*F/E**	–	*O/G*	*G/E**	–
A. sibiricum	O/E	O/G	V/E	*F/E***[3]	–	O/F	–	O/G	–	O/O
A. smithii	*E/E**	*F/F**	*E/E**	*E/E**	*E/E**	*E/E**	*E/E**	*G/E**	*E/E**	O/O
A. trichophorum	*G/G**	V/G	*O/G*	*E/E**	*E/E**	*F/E**	*O/E*	*F/G**	P/E	O/O
Andropogon hallii	O/V	–	O/F	O/O	–	*E/E**	–	O/F	O/G	–
Atriplex canescens	P/G	*F/G*	*E/E*	*G/E*	O/O	*G/E*	O/O	*G/E*	*E/E*	–
Bothriochloa barbinodis	O/O	–	O/G	O/F	–	*V/F*	–	O/F	O/E	O/V
B. caucasica	O/V	–	O/V	*O/G*	–	*O/E*	–	O/O	O/G	*O/E*
B. ischaemum	*F/F***	–	*O/F*	*E/E***	O/O	*E/E***	*E/E***	*G/G***	*E/E***	*G/G***
Bothriochloa ischaemum-King Ranch	O/F	–	O/G	*G/E***	–	*G/E***	–	O/G	O/G	*O/G*
Bouteloua curtipendula	O/V	–	O/E	*V/E*	O/P	*F/E***	*P/E*	*G/G*	–	*P/G*
B. curtipendula-Tucson	O/E	–	O/F	O/G	–	*O/E*	–	*P/E*	*G/E*	*P/G*
B. curtipendula-Vaughn	*F/G*	–	–	–	–	*O/E*	–	*E/E*	*E/E***	–
B. eriopoda	*P/G*	–	O/G	O/E	O/F	*O/G*	O/F	P/F	P/G	O/V
B. gracilis	*G/E*	O/F	O/G	P/G	*O/G*	*F/E*	*F/G*	*G/E*	*V/E*	P/G
B. gracilis-Lovington	*O/E*	O/P	O/G	P/G	–	*F/E*	–	*F/E*	*G/E*	–
Bromus erectus	*O/G*	–	O/F	–	–	O/P	–	–	–	O/V
B. inermis	*F/G*	–	O/G	O/O	O/G	O/F	O/G	–	–	–
B. inermis-Achenbach	P/E	–	–	*F/G*	–	O/F	–	–	–	–
Buchloe dactyloides	O/G	–	O/G	*E/E**	–	*O/G*	–	*E/E**	*F/E**	–
Ceratoides lanata	O/O	–	*E/E***	O/O	–	O/V	–	*F/F***	*E/E***	O/O
Digitaria eriantha	–	–	O/O	O/E	–	*V/E*	–	O/O	O/E	O/O
Elymus junceus	*O/E*	*F/E*	P/E	*E/E***	–	O/F	–	O/F	*F/E***	O/O
Eragrostis chloromelas	O/G	–	O/F	O/G	–	*O/E*	–	O/G	O/F	*E/E***
E. curvula	O/E	–	O/E	O/E	*G/E*	*F/E*	*F/E*	O/G	O/F	O/P
E. lehmanniana	–	–	–	O/O	O/P	–	–	O/V	–	*O/E*
E. superba	–	–	–	–	–	O/O	–	O/O	–	*G/E***
Festuca ovina-duriuscula	V/F	–	–	*E/E***	–	O/V	–	–	–	–
F. ovina-sulcata	*F/F*	–	–	*E/E***	–	O/V	–	–	–	–
Hilaria jamesii	O/G	O/V	O/F	O/P	–	*G/E*	–	O/V	–	–
H. mutica	O/V	–	O/V	–	–	*F/F*	–	O/O	–	–
Koeleria cristata	*F/F***	–	O/P	O/V	–	–	–	–	–	–
Medicago falcata	P/G	–	O/G	*F/E*	–	O/E	–	–	–	–
Melilotus alba	*E/E***	–	O/E	O/E	*E/E***	O/E	–	–	–	–
M. officinalis	O/E	–	O/E	O/E	*E/E***	O/E	–	–	–	–
Menodora scabra	–	–	O/V	–	–	*E/E*	–	O/G	O/E	O/O
Muhlenbergia wrightii	*E/E***	*F/G***	*E/E***	*E/E***	*G/G***	*E/E***	–	P/G	O/F	O/O
Panicum hallii	O/G	–	O/F	–	–	O/E	–	*F/G***	O/E	O/F
P. obtusum	O/P	–	O/F	O/V	O/P	O/F	*O/E*	*O/E*	O/F	*P/E**
P. virgatum	O/F	–	O/G	O/F	–	*E/E**	–	*F/F**	O/G	–
Poa pratensis	*F/G*	–	–	–	–	–	–	–	–	–
Purshia tridentata	*F/G*	–	O/F	O/O	O/O	O/O	O/O	*V/G*	O/O	O/O
Sanguisorba minor	O/F	–	O/P	O/E	–	*P/E***	–	O/G	O/E	–
Schizachyrium scoparium	O/V	–	O/F	O/O	–	*F/F*	–	O/O	–	–
Sitanion hystrix	*F/G*	–	O/F	O/E	–	O/P	–	*F/G*	O/F	–
Sorghastrum nutans	*O/F*	–	O/P	–	–	–	–	O/O	–	–
Sorghum halepense	O/P	–	O/F	–	*G/G**	O/E	–	O/E	–	–
Sporobolus airoides	O/P	–	O/F	O/G	–	*O/G*	–	O/F	*F/F*	O/O
S. cryptandrus	O/G	O/P	O/V	*O/G*	–	O/E	–	O/G	V/G	*V/F*
S. wrightii	O/O	–	O/O	O/F	–	*E/E***	–	O/O	*O/F*	–
Stipa viridula	O/F	–	O/P	*O/G*	–	V/P	–	O/F	O/F	O/V
Tridens albescens	O/F	–	O/F	O/G	O/P	O/E	*O/G*	O/G	*O/F*	*O/G*
T. elongatus	O/G	–	O/G	*F/F***	*O/G*	*G/G***	*O/F*	*O/G*	*F/G*	*V/F*

[1] Final rating/maximum rating: O = failure, V = very poor, P = poor, F = fair, G = good, E = excellent, – = not planted.
[2] Italic indicates sites where species and varieties survived 10 or more years and attained a relative rating of fair or better.
[3] Spreading at time of final observation: * = vegetative spread, ** = spread by natural seeding.

Results and Discussion

Adaption

Fifty-nine of the 240 species and varieties tested were adapted to one or more sites. Fifty-four of these were still present in 1973 (Table 2), 45 with stands rating fair or better. The five species adapted but not present in 1973 had all survived for at least 10 years and some as long as 20 years.

Based on our observation, species adaptation might be considered as persistence for at least 5 years and attainment of relative rating of fair or better. This time period, which is shorter than has generally been accepted in the past, appears to be adequate if it includes at least one prolonged drought. The shorter time interval would be especially important for judging small, test plantings because factors other than site adaptability can affect species survival in them.

Forty percent of the species planted in the cool-moist subtype were adapted. Thirty-four percent were adapted to the warm-moist subtype, and 29% to the warm-dry and to the cold-moist subtypes. Only 13% were adapted to the cold-dry and 9% to the hot-moist subtypes. This indicates that the cool-moist and warm-moist subtypes are most favorable for revegetation with the species tested. All species were not planted on all sites because it was initially known that some were not adapted to certain sites.

The most widely adapted species were crested wheatgrass (*Agropyron desertorum*), intermediate wheatgrass (*A. intermedium*), western wheatgrass (*A. smithii*), pubescent wheatgrass (*A. trichophorum*), fourwing saltbush (*Atriplex canescens*), yellow bluestem (*Bothriochloa ischaemum*), sideoats grama (*Bouteloua curtipendula*), spike muhly (*Muhlenbergia wrightii*), and rough tridens (*Tridens elongatus*) (Table 2). These nine species show the best potential for use on Arizona pinyon-juniper rangelands.

Yellow bluestem, the most widely adapted species, did best in the warmer subtypes where it rated excellent on four sites. It is long-lived and forms a dense ground cover. At Buckhead Mesa it has invaded the native vegetation and dominates the study area. Fourwing saltbush probably is just as widely adapted as yellow bluestem, but was not tested in the hot-moist subtype. Western wheatgrass, rated excellent at seven sites, is outstanding in forming a heavy protective cover. Its main disadvantage is slow establishment. Pubescent wheatgrass rated excellent at Mud Tanks and Pine Creek, but at both sites was stemmy with few basal leaves. Crested wheatgrass at Pine Creek grew in large clumps with wide bare interspaces. This type of growth provides poor protection against both raindrop splash and surface runoff erosion. Spike muhly had a final rating of excellent at four sites. It established slowly but, once established, was vigorous, aggressive, and produced a large volume of foliage. Sideoats grama is widely adapted, apparently doing better on the warmer sites. The difference in responses of the Vaughn and Tucson varieties indicates the need for variety tests on specific sites. Rough tridens was adapted to all but the cold sites. This was a native seed source whose potential is not understood.

Winterfat (*Ceratoides lanata*) became established at only three sites and rated excellent at two. It is probably more widely adapted than our results indicate, but is difficult to establish because the planting techniques used are not reliable. Russian wildrye (*Elymus junceus*) maintained an excellent to fair stand at Moritz Lake despite 22 seasons of extremely heavy cattle use. The sweet clovers (*Melilotus* spp.) maintained excellent stands at Peterson Flat and Pine Creek. Boer lovegrass (*Eragrostis chloromelas*) persisted only at Sierra Ancha. There, however, it dominated the study site, invading bare areas where other species had failed.

Weed competition occurred at all sites but was especially heavy at Pleasant Valley where the study was located on an old cultivated field that had been abandoned for many years. Among the species adaptation characteristics for this site was an ability to overcome weed competition.

Establishment and Survival

Establishment, growth and development of the seedling after initial emergence, was excellent in five of the six subtypes, ranging from 88 to 98%. Poorer establishment, 61%, occurred in the hot-moist subtype. Survival, persistence of living plants from initial emergence to time of the last observation, was 40 to 48% of the planted species in the four most favorable subtypes. Only 27%, however, survived in the hot-moist and 19% in the cold-dry subtypes.

Natural Spread

Thirty species and varieties spread naturally (Table 2). The most vigorous spreaders were western wheatgrass, winterfat, yellow bluestem, and spike muhly. The panicums (*Panicum* spp.), sweetclovers, spike muhly, yellow bluestem, Boer and weeping lovegrass (*Eragrostis curvula*) tended to establish better and spread more rapidly in low-lying areas, such as drainages, swales, and other depressions. Yellow bluestem was the only species observed invading native vegetation. Winterfat was difficult to establish, but, once established, spread widely. It may be practical to transplant winterfat as widely spaced plants and let the interspaces fill in by natural seeding. Fourwing saltbush did not reproduce itself in any of the plantings, although it is widely adapted and long-lived. The sweetclovers, though only biennials, persisted and spread by natural seeding. Buffalograss (*Buchloe dactyloides*) spread vigorously and formed good ground cover where adapted, but produced little foliage. Burnet (*Sanguisorba minor*) established easily and spread aggressively at Pleasant Valley but was short-lived. At nearby Young it is a lawn weed. Some plants originally identified as tall wheatgrass (*Agropyron elongatum*) were spreading by rhizomes. Possibly they had hybridized with pubescent wheatgrass.

Drought

All surviving species and varieties have persisted through severe, extended droughts. For example, a prolonged regional drought occurred from 1950 through 1957. It was especially severe in 1950–53; also 1956 was the driest year on record in Arizona (U.S. Weather Bureau 1956). In 1963 drought was so severe at several sites that fourwing saltbush lost its leaves.

In general, size, vigor, and stand seemed to fluctuate more widely in response to varying moisture conditions for the grasses than for the shrubs. The greatest variation occurred in the cool season grasses. Crested wheatgrass and, to a lesser degree, intermediate, pubescent and western wheatgrass almost disappeared during drought and improved markedly with favorable moisture. For the hot-moist subtype, low effective precipitation during the growing season, because of high temperatures and shallow-soil moisture penetration from high intensity thunderstorms, may have been the reason for poor establishment.

Temperature

Frost damage and winter kill were observed at all sites. Warm season species apparently were more limited by low temperatures than cool season species. Differences in cold resistance

among varieties were also observed. For example, yellow bluestem survived lower temperatures better than the King Ranch variety (*Bothriochloa ischaemum*-King Ranch).

Seedlings of some warm-season species were apparently more sensitive to cold than the mature plants at the colder limits of their tolerance. For example, yellow bluestem established at Dog Knobs, Boer lovegrass at Pleasant Valley, and Lehmann lovegrass (*Eragrostis lehmanniana*) at Sierra Ancha during warmer years. All these stands then survived for several years before dying out. Weeping lovegrass seedlings were highly susceptible to frost heaving in the colder subtypes, especially on heavy textured soils.

Low survival in the hot-moist subtype may have been caused by drought and lethal high temperatures. High mortality in the cold-dry subtype may have resulted from slow growth rate, drought and winter kill. Some of the cool-season species, such as Amur (*Agropyron intermedium*-Amur), crested, intermediate, and tall wheatgrass, became established in the warm subtypes but were relatively short-lived there. These results agree with those of Decker (1974), who found that high soil temperatures adversely affected stand persistence for some cool-season species.

Animal Effects

Animal activity was observed at all sites. This is of special concern because animals from neighboring areas concentrating on small plantings often exert disproportionately heavy foraging pressure. This effect is especially detrimental to seedling establishment.

Rabbit-proof fences were beneficial wherever they were used. Rabbit (*Lepus* spp. and *Sylvilagus* spp.) use was heaviest in early spring when other green feed was scarce and in depressions where foliage was most succulent. Shrub seedlings and legume plantings were the most severely damaged. Mice (*Peromyscus* spp.) dug up freshly planted seed at Drake and removed seedheads at Dog Knobs. Gopher (*Thomomys* spp.) damage was extremely heavy at Pleasant Valley, contributing to the decline of weeping lovegrass and the failure of alfalfa (*Medicago sativa*) plantings. Damage from ants, grasshoppers, and beetles was observed at all sites. Large areas of several plantings were denuded by harvester ants at Dog Knobs.

Big game grazed the test plantings at most locations. Heavy spring use of cool-season species was made by elk (*Cervus canadensis*) and deer (*Odocoileus hemionus*) at Mud Tanks and Moritz Lake and by deer at Peterson Flat. Antelope (*Antilocapra americana*) grazed the plantings at Dog Knobs. Although fencing was used to exclude livestock, some cattle grazing, as previously described, did occur.

Fourwing saltbush on heavy soils was especially large and vigorous where gophers were active, indicating plants benefited from the loosened soil that possibly allowed deeper moisture penetration. Greater growth and vigor have also been observed on light textured soils than on heavy ones.

Limited or Nonuse by Livestock

The effects of limited or nonuse by livestock may be important in considering species adaptation. It is generally known that species and varieties differ in grazing tolerance. Also, weed and native plant competition can be modified by the relative palatability and grazing tolerance of the planted species.

Ungrazed bunch grasses often develop large, dense clumps that gradually become senescent and die, apparently because of the dead, ungrazed foliage. This effect is especially common with ungrazed weeping lovegrass. When clumps are kept small by grazing or burning, weeping lovegrass retains a full, vigorous stand. Loss of vigor also was observed on yellow bluestem, sideoats grama, Boer and Wilman lovegrass, spike muhly, and sacaton, all bunch grasses. Some bunch grasses, therefore, may have declined because of nonuse rather than lack of site adaptation.

Fourwing saltbush became unthrifty at all sites where it was protected from livestock grazing. Plants became woody with many dead branches, and most stands had a relatively high mortality. Unprotected fourwing saltbush at Moritz Lake and Mud Tanks heavily grazed for many years is smaller but more vigorous, less woody, and with fewer dead branches than ungrazed plants, and the stands contain few or no dead plants. Winterfat showed similar, but less marked, responses to prolonged protection from livestock grazing. It may be that livestock grazing on forage shrubs prunes back excessive foliage, providing a stimulation which otherwise might not occur for replacement of the old growth. This would indicate a need for moderate grazing beginning about the third year after establishment to encourage optimal production of these plants.

Conclusions

Species and varieties that germinated, established, and survived in satisfactory stands over a 21- to 28-year period under a wide array of adverse conditions are adapted to the different sites as shown in Table 2. Adaptation to Southwestern pinyon-juniper rangeland conditions might be determined sooner than the 10 to 20 years generally accepted if at least one prolonged drought occurs within the shorter period.

Species failure is not, by itself, conclusive proof that plants are not adapted. Some species may require special seed treatment or planting techniques; others, might survive in larger plantings with less severe animal depredation. The reaction to livestock grazing is still undetermined. Moderate livestock grazing may be essential to some bunch grasses and shrubs for long-time persistence with good vigor.

Persisting species and varieties have survived harsh environments and might provide a genetic pool for obtaining new accessions better adapted for seeding ranges of the Southwestern pinyon-juniper type. Further work is needed, especially on the nine most widely adapted species, to refine selection of varieties to specific situations and encourage their use for revegetation.

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