Analysis of direct seeding methods for establishment of native shrub and forb species on minesoils in southeastern Montana

by Joseph William Clarke III

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Land Rehabilitation
Montana State University

Abstract:
Shrubs form an integral part of many semiarid and arid western ecosystems. Replacement of a diverse vegetation cover after mining consisting of shrubs, forbs and grasses is mandated by legislation in several western states. Direct seeding of shrub species has been partially successful on minesoils.

A study was initiated on topsoiled stripmine spoils in southeastern Montana during Fall, 1978 to develop methods for establishment of certain shrub species on minesoils. The major objectives of this study were to evaluate the effectiveness of high shrub seeding rates on establishment and growth with and without perennial grass competition and (for two of the shrub species seeded) to evaluate the performance of locally collected versus commercially purchased ecotypes.

Five native shrub and one forb species were selected for evaluation: big sagebrush, cudweed sagewort, Nuttall's saltbush, winterfat, rubber rabbitbrush and skunkbush sumac. Nuttall's saltbush and Winter-fat were the species for which different ecotypes were evaluated. Treatments included seeding of each shrub/forb species, both alone and with a mixture of six native perennial grass species. The locally collected ecotypes of Nuttall's saltbush and winterfat were seeded alone. Vegetation and physical monitoring took place over a two year period (1979-1980).

All species germinated and were present in 1979, but establishment and subsequent growth of the shrubs were adversely affected by below average precipitation during the 1979 and 1980 growing seasons.

Initial establishment and ultimate survival of Nuttall1s saltbush and skunkbush sumac were best when these species were seeded alone. Use of local ecotypes appeared to benefit initial establishment and ultimate survival success of Nuttall's saltbush and winterfat. Highest seedling survival after two years of drought was obtained from commercially purchased and locally collected Nuttall's saltbush, big sagebrush and locally collected winterfat seed lots. All other shrub/forb species and/or ecotypes exhibited complete drought-induced mortality at the end of this period.

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ANALYSIS OF DIRECT SEEDING METHODS FOR ESTABLISHMENT

OF NATIVE SHRUB AND FORB SPECIES ON MINESOILS

IN SOUTHEASTERN MONTANA

by

JOSEPH WILLIAM CLARKE III

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Land Rehabilitation

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June, 1982

ACKNOWLEDGEMENTS

I wish to express appreciation to Western Energy Company for providing a study site, technical assistance and funding for my research project.

Special thanks and sincere appreciation is extended to Dr. Edward DePuit, my major advisor, for his sound technical assistance, wise counsel and constructive criticisms; to Loren Wiesner for his guidance and use of laboratory facilities; to Chester Skilbred, Joe Coenenberg, and members of my graduate committee for their helpful advice and assistance; to Ron Thorson for computer programming and data analysis; and most of all, to my wife Carol, for her patience and understanding.

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ABSTRACT

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INTRODUCTION

Background

Shrubs form an integral part of many rangeland ecosystems. They are widely distributed and are present in most natural plant communities, many times occurring as principal constituents in arid and semiarid regions (Monsen and Christensen, 1975; Packer and Aldon, 1978).

Shrubs are important in many ways to both plant and animal communities. The various benefits they provide include: 1) substantial herbage production, hence providing forage and cover for wildlife and livestock; 2) niche diversification; and 3) ground cover for effective soil stabilization.

Many studies have shown that an association of shrubs with grasses and forbs (in proper proportions) has been more productive than shrubs or grasses/forbs alone (Robinette, 1972; Vallentine, 1971; Plummer, Christensen and Monsen, 1968; Monsen and Plummer, 1978).

Shrubs may be a valuable source of forage for both wildlife and livestock (Dietz, 1969; Julander, Robinette and Jones, 1961; Martinka, 1967; MacArthur, Plummer and Davis, 1978). This is especially true during periods of dormancy or drought. Browse species usually possess deeper root systems than grass and forb species, and tend to store food reserves in stems as well as in roots (Stoddart, Smith and Box, 1975; Coyne and Cook, 1970). Hence, protein, vitamin A and carbohydrates are not reduced as much in above ground portions of shrubs compared to grasses during non-growing periods (Stoddart et al., 1975; Sindelar, Hodder and Majerus, 1973). Taller growing shrubs also may constitute the only forage available for the grazing animal during periods of deep snow accumulation. Besides big game species and livestock, many species of birds and small mammals also utilize shrubs as a source of food (Robinette, 1972). Shrubs also provide wildlife with protective cover from the elements and from predators (Williamson and Wanerud, 1980). Birds and small mammals may use shrubs for nesting and/or roosting sites (Robinette, 1972; Vallentine, 1971).

The presence of shrubs in plant communities provides for greater numbers of ecological niches due to height stratification and increased plant cover. Birds are especially influenced by stratification and are often restricted to narrow vertical ranges (Odum, 1971). Thus, without shrubs many species of birds could not be present. Lack of necessary shrub cover may also preclude the presence of many small mammal species.

Shrubs, especially those which are "bushy", provide excellent ground cover. According to Van Dersal (1938), the bushier the shrub and the denser its foliage, the more it will protect the soil from wind and water erosion. Many shrubs meet these criteria. Most shrubs possess deep root systems. Such root systems serve in erosion control mainly by holding the shrub in place rather than holding the topsoil

(Van Dersal, 1938). However, deep root systems may help to hold subsoil in place.

Nature of the Problem

The demand for coal as a source of relatively inexpensive energy has increased in recent years. This demand will probably continue to expand as other sources of fossil fuel become more costly and unavailable. Most of the increase in coal development will occur in the western United States, where many rich, surface mineable deposits are located (DePuit, Coenenberg and Willmuth, 1978). Montana is one state impacted by this development (Paone, Struthers and Johnson, 1978).

The need for suitable and successful means of reclaiming surface mined lands is urgent. The revegetation of such lands is a critically important facet of reclamation. The state of Montana provided strict regulations concerning revegetation in its Strip and Underground Mine Reclamation Act of 1980. This act requires that vegetation established on mined lands provide a suitable, permanent, diverse cover capable of regeneration under existing climatic conditions, and which is able to support livestock and wildlife as well as control erosion in a manner comparable to that preceding mining.

The phrase "diverse vegetative cover" is significant in many cases. A plant cover of this type should include shrubs, forbs and grasses. Although it is important to establish a cover of perennial grass species initially to stabilize the soil, it is equally important ultimately to establish a shrub and forb association. An association of grasses, forbs and shrubs will provide a diverse habitat for many species of wildlife and livestock (DePuit and Coenenberg, 1979; Thornburg, 1974; Williamson and Wanerud, 1980).

One approach for establishing a diverse vegetation cover involves seeding mined lands with broad mixtures of grass, forb and shrub species (DePuit and Coenenberg, 1979). This technique has also been used in the renovation of deteriorated rangeland, especially winter game ranges (Plummer et al., 1968). Usually this technique has met with limited success (Monsen and Christensen, 1975; Plummer et al., 1968; Dollhopf and Majerus, 1975; Frischknecht, 1978).

There are many factors contributing to the success or failure of seeding shrubs and grasses together in a seed mixture. Only a few shrub species have seedlings which are sufficiently vigorous and aggressive to compete with concurrently establishing perennial grass seedlings. Shrub species which have sometimes successfully competed with perennial grasses include antelope bitterbrush (Purshia tridentata), sulfur eriogonum (Eriogonum umbellatum), snowbrush ceanothus (Ceanothus velutinus), rubber rabbitbrush (Chrysothamnus nauseosus), big sagebrush (Artemisia tridentata), and fourwing saltbush (Atriplex canescens) (Monsen and Christensen, 1975). Differences in competition tolerance between shrubs and grasses are related to lifeform differences such as different seedling morphologies and growth rates. Grasses tend to mature more rapidly than shrubs and thus provide frequently stifling competition for young shrubs (Blaisdell, 1949; Frischknecht, 1978; Anderson and Brooks, 1975; Hubbard, Zusman and Sanderson, 1962; Hubbard, 1957). The growing points of shrub seedlings are usually above ground, which exposes them to spring frost and grazing animals. Conversely, grass seedlings have growing points at or below the ground, and thus have a greater tolerance to these two factors (Plummer, Christensen and Monsen, 1965). Other problems with concurrent seeding of grasses and shrubs include: 1) grasses may provide habitat for small mammals that girdle and kill shrubs; and 2) grasses may carry fire that kills susceptible shrubs (Frischknecht, 1978).

An alternative to seeding of uniformly applied grass-shrub mixtures is to seed shrubs and grasses in alternate rows, thus reducing competition between the two (Plummer et al., 1968; Frischknect, 1978). This method has proven fairly successful when seeding shrubs that possess low seedling vigor. An advantage of this technique, if successful, is the shelter belt effect of shrubs planted in this manner. Soil moisture may be increased through snow trapping (Frischknecht, 1978).

Interspecific competition will not be entirely removed when shrubs are seeded alone. Seeds of annual forbs, grasses, and other perennial and biennial species may be present in the seedbed, and may ultimately produce plants which will compete with seeded shrubs

(Holmgren, 1956; Guinta, Christensen and Monsen, 1975). This is especially true on mined lands which have been topsoiled (King, 1980).

Low germination of seed is another factor which makes establishment of shrubs difficult from direct seeding (Sindelar et al., 1974; Monsen and Christensen, 1975). Research has also shown that low seeding rates of shrubs in comparison to perennial grasses has resulted in poor shrub establishment (DePuit and Dollhopf, 1978; Dollhopf and Majerus, 1975; Plummer et al., 1968).

Monsen and Christensen (1975) utilized three criteria in the selection of shrub species for restoration of disturbed range sites: 1) The species must be adapted to the site; 2) The species must provide forage, ground cover and protection to animals; and 3) The seedlings must be able to establish and reach maturity under existing site conditions. They believed that species adaptability was the most important criterion and that locally collected seed of species native to the area best met this criterion. Other authors have also stressed the importance of locally collected ecotypes of plant species for revegetation of disturbed areas (Plummer et al., 1968; Vallentine, 1971; Thornburg and Fuchs, 1978). Thornburg and Fuchs (1978) for example, believed that selection of the proper ecotype is as important as selection of proper species.

Another method used to establish shrubs on disturbed sites, besides direct seeding, is transplantation of bareroot, containerized stock, and stem and root cuttings (Monsen and Christensen, 1975). Transplantation, although sometimes successful, is usually considered unfeasible as a practical approach to extensive shrub establishment due to its excessive cost (Monsen and Christensen, 1975; Stevens, 1980).

Objectives

The general goal of this study was to develop methods for establishment of several shrub and forb species on topsoiled stripmine spoils by direct seeding.

Specific Objectives included:

1) Evaluation of effectiveness of high seeding rates in promotion of shrub and forb establishment and growth.
2) Determination of effects of presence and absence of competition from concurrently seeded perennial grasses on shrub and forb establishment and growth.
3) Comparison of responses of five selected shrub and one forb species seeded to above treatments (presence and absence of competition from concurrently seeded perennial grasses) in terms of establishment and growth.
4) Evaluation of the performance of locally collected versus commercially purchased seed of two species.

STUDY AREA

The study area was located in southeastern Montana near Colstrip (Figure 1). This town is approximately 48 kilometers south of Forsyth, Montana in Rosebud County.

This area overlies rich deposits of sub-bituminous coal within the Fort Union geologic formation (DePuit, Coenenberg and Skilbred, 1980). Stripmining of this area to extract coal is practical, and is being conducted by both the Peabody Coal Company and Western Energy Company.

The pre-mining topography of the Colstrip area consists of gently rolling hills and valleys, with scattered sandstone and porcelainite outcrops (Wyatt, Dollhopf and Schafer, 1980). Most of the streams present are intermittent in nature and dissect the hills and valleys (Sindelar, Hodder and Majerus, 1973). The elevation ranges between 1100 and 1833 meters (Gomm, 1974). Soils in this area are usually poorly developed and have sandy or loamy textures (DePuit et al., 1980). Major soil sub-groups include Ustic Torriorthents, Borollic Camborthids and Aridic Haploborolls (Schafer, Nielsen and Dollhopf, 1977).

Vegetation is primarily characteristic of the Eastern Montana Ponderosa Pine Savannah Type, with ponderosa pine (*Pinus ponderosa*) on the ridgetops grading into mixed prairie grassland below (Payne, 1973;

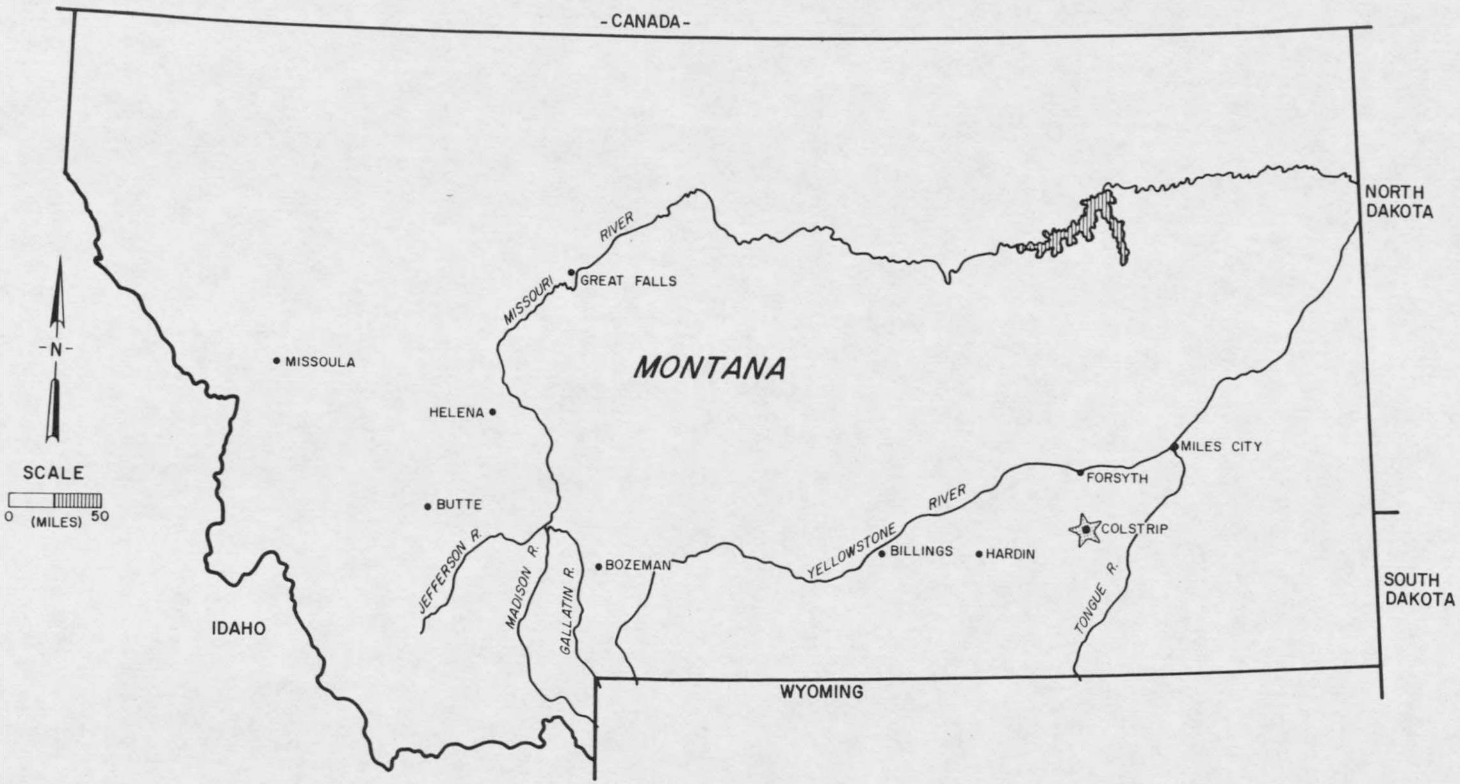


Figure 1. Location of Colstrip, Montana

Wyatt et al., 1980; Sindelar et al., 1973). Dominant understory grass species on the ridgetops include bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), and little bluestem (*Schizachyrium scoparium*). Important grass species of the mixed prairie grassland community include western wheatgrass (*Agropyron smithii*), thickspike wheatgrass (*Agropyron dasystachyum*), green needlegrass (*Stipa viridula*), needle-and-thread (*Stipa comata*), Sandberg bluegrass (*Poa sandbergii*), prairie junegrass (*Koeleria cristata*) and blue grama (*Bouteloua gracilis*). Other common plant species include the shrubs, skunkbush sumac (*Rhus trilobata*) and western snowberry (*Symphoricarpos occidentalis*), needleleaf and threadleaf sedges (*Carex eleocharis* and *C. filifolia*, respectively) and the forbs, phlox (*Phlox* spp.), wild buckwheat (*Eriogonum* spp.) and lupine (*Lupinus* spp.). Overgrazed and otherwise degraded sites are characterized by a predominance of increaser and invader plant species such as cheatgrass brome (*Bromus tectorum*), Japanese brome (*Bromus japonicus*), lupine, big sagebrush and silver sagebrush (*Artemisia cana*).

The climate of the Colstrip area is continental, characterized by warm summers and cold winters (NOAA, n.d.). Mean temperatures during July (typically the warmest month) and January (typically the coldest month) are 23.9 C and -6.7 C, respectively (Munshower and DePuit, 1976). Average annual precipitation is 40.12 cm, three-fourths of which falls as rain from April through September (NOAA, n.d.). The frost-free growing season varies from 95 to 135 days (Sindelar et al., 1973).

METHODS AND PROCEDURES

Shrub and Forb Seeding Field Study

Study Site Description

The study site was located approximately 1.2 kilometers southeast of Colstrip in Area E of Western Energy Company's Rosebud mine (Figures 2 and 3). The topography of the area was nearly level. A portion of the area 0.18 hectares in size was selected for field plot establishment.

Direct take topsoil was utilized as "coversoil" over the entire area (Schafer, 1979). This "coversoil" was placed over the spoil material to a depth of 60 centimeters by Western Energy Company in April, 1978. The "coversoil" was disced immediately following its placement and seeded to a mixture of 16 grass, forb and shrub species (Coenenberg, personal communication, 1981). These species included "Critana" thickspike wheatgrass, "Luna" pubescent wheatgrass (*Agropyron trichophorum*), "Sodar" streambank wheatgrass (*Agropyron riparium*), western wheatgrass, slender wheatgrass (*Agropyron trachycaulum*), "Fairway" crested wheatgrass (*Agropyron cristatum*), "Lincoln" smooth bromegrass (*Bromus inermis*), "Remont" sainfoin (*Onobrychis viciaefolia*), cicer milkvetch (*Astragalus cicer*), green needlegrass, Indian ricegrass (*Oryzopsis hymenoides*), prairie sandreed (*Calamovilfa longifolia*), alkali sacaton (*Sporobolus airoides*), blue grama, sideoats grama

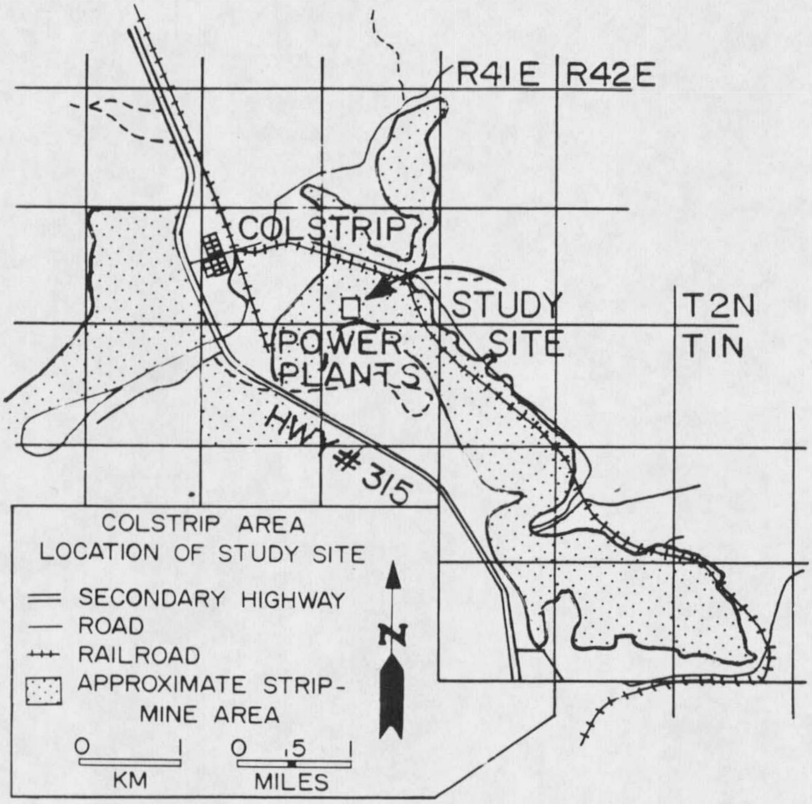


Figure 2. Location of shrub and forb direct seeding study (after Schafer, Nielsen and Dollhopf, 1976).

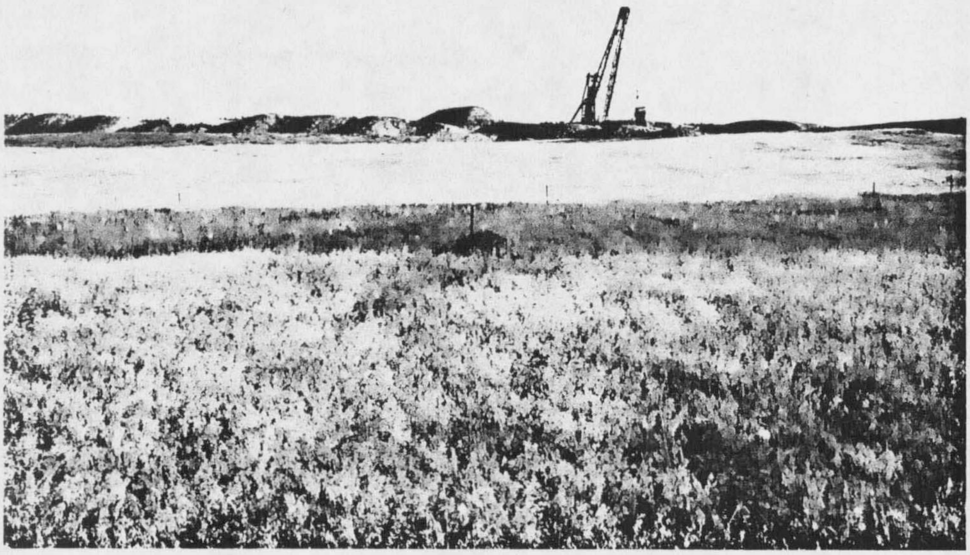


Figure 3. Study site, shrub and forb direct seeding study, Colstrip, Montana, June 7, 1979.

(Bouteloua curtipendula) and fourwing saltbush (Atriplex canescens). Wintergraze was also seeded as a cover crop. Wintergraze is a sterile hybrid developed by DeKalb Agresearch and is a cross between wheat (Triticum aestivum) and Agrotricum (a wheat wheatgrass cross) (DePuit et al., 1978).

Experimental Design

Five xerophytic shrub and one forb species native to the Colstrip region were seeded in small (5x5 m) plots, alone and with a mixture of six native perennial grass species. Locally collected ecotypes of two of the shrub species, winterfat (Ceratoides lanata) and Nuttall's saltbush (Atriplex nuttallii) were also included to determine if there were any differences in establishment between these and seed obtained commercially. The seeding rate and characteristics of the shrub, forb and grass species making up the mixture are presented in Tables 1 and 2. Literature derived number of seeds per kilogram were used to calculate the shrub and forb species seeding rates. This information was obtained from the USDA Forest Service (1974) for all species except cudweed sagewort and from Eddleman (1977) for the latter species.

A completely randomized design was utilized. This design was chosen because it was believed that the study site was homogeneous (Steel and Torrie, 1960).

Table 1. Shrub and forb species evaluated in shrub and forb direct seeding study, Colstrip, Montana.

Species	Estimated[1] Seeds/kg	Seeding Rate (Kg/ha)	Amount of Seed for each .002 Hectare Plot (Kg)	Total Amount Needed (Kg)	Estimated # of Seeds per sq. m.
big sagebrush (Artemisia tridentata)	5,425,200	4.5	.011	.065	2,441.3
cudweed sagewort (Artemisia ludoviciana)	5,489,000	4.5	.011	.065	2,470.1
skunkbush sumac Rhus trilobata)	44,660	51.6	.125	.750	230.5
rubber rabbitbrush (Chrysothamnus nauseosus)	1,524,600	12.3	.030	.179	1,875.3
winterfat (Ceratoides lanata)	244,200	13.5	.033	.196	329.7
winterfat (local) (Ceratoides lanata)	244,200	13.5	.033	.098	329.7
Nuttall's saltbush (Atriplex nuttallii)	245,300	22.4	.054	.326	549.5
Nuttall's saltbush (local) (Atriplex nuttallii)	245,300	22.4	.054	.163	549.5

[1]From literature sources; actual seed/kg and pure live seed data for seed lots used were determined following seeding (see Table 7)

Table 2. Perennial grass seed mixture utilized in shrub and forb direct seeding study, Colstrip, Montana.

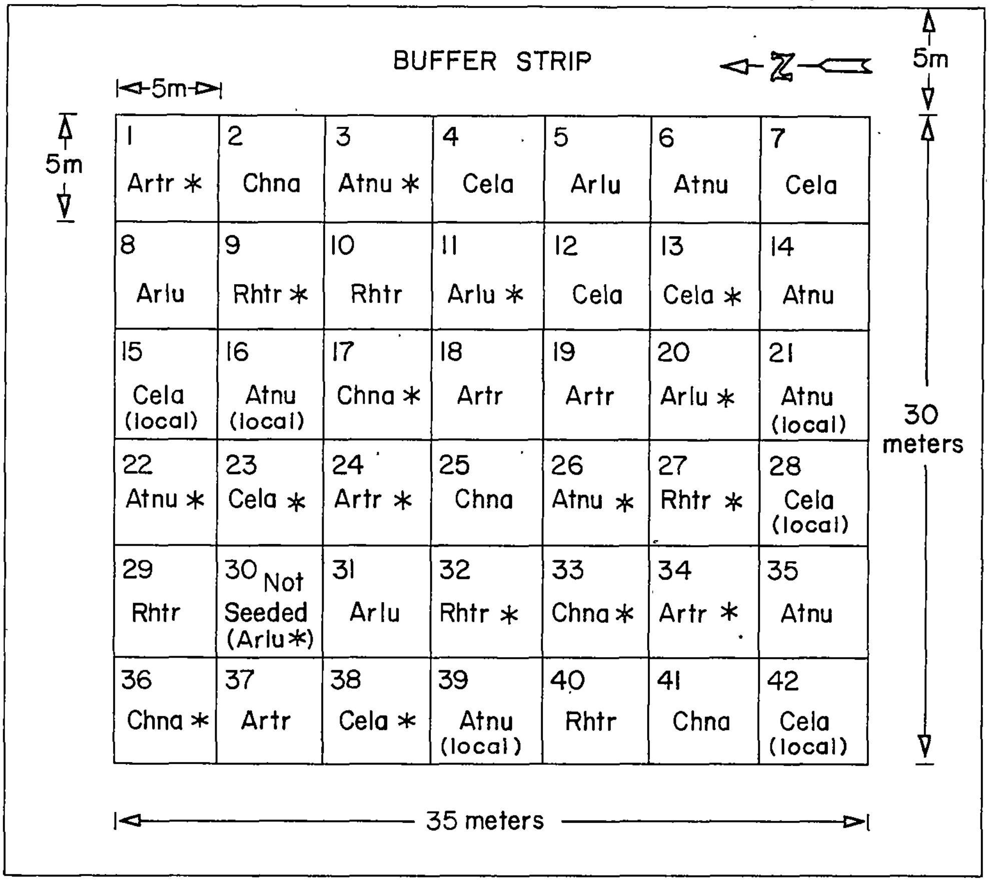
Species	Seeding Rate Kg(Bulk)/ha	Seeding Rate Kg (PLS)/ha	Estimated[1] Seeds/kg	Total Bulk Seed Needed (Kg)	Amount of Bulk Seed for each .002 Ha Plot (Kg)	# Pure Live Seeds per sq. m.
Rosanna western wheatgrass (*Agropyron smithii*)	14.7	11.6	242,506	1.8	.036	277.4
Sodar streambank wheatgrass (*Agropyron riparium*)	8.0	7.4	374,782	1.0	.019	275.3
Reuben's Canada bluegrass (*Poa compressa*)	1.8	1.6	?	0.2	.002	?
Goshen prairie sandreed (*Calamovilfa longifolia*)	5.9	4.5	604,060	0.7	.014	282.8
Paloma Indian ricegrass (*Oryzopsis hymenoides*)	7.9	5.2	518,081	1.0	.019	269.9
Blackwell switchgrass (*Panicum virgatum*)	7.4	3.7	612,879	0.9	.018	226.9
Total	45.6	34.0				

[1]From literature sources

Two major treatments were evaluated: 1) shrub and forb species seeded alone, and 2) shrub and forb species seeded with a mixture of perennial grass species. The two major treatment effects multiplied by the six shrub and forb species to be evaluated provided twelve possible treatment interactions. Each treatment was replicated three times giving a total of thirty-six experimental plots. The locally collected ecotypes of two of the shrub species were also replicated three times (seeded alone only) giving an overall total of forty-two experimental plots. A buffer strip seeded to a perennial grass mixture was established so that the study would be isolated from the adjacent area which, as mentioned previously, was seeded at an earlier date (April, 1978) by Western Energy Company. The experimental design and complete treatment applications are shown in Figure 4.

Seedbed preparation and seeding took place on September 29 and 30, 1978. The study site was first chisel plowed to a 25 cm depth to provide a loose, moderately rough seedbed and to destroy antecedent vegetation (Figure 5). Plots were then hand seeded by broadcasting and raking to simulate harrowing. The entire study site, including the buffer strip, was fenced.

DePuit et al. (1980) found that broadcast seeding into a moderately rough seedbed enhanced the establishment of a diverse mixture of native plant species. This was attributed to effects of variable seed



*- Plots with concurrently seeded perennial grass mixture

Arlu = *Artemisia ludoviciana*, Artr = *Artemisia tridentata*, Atnu = *Atriplex nuttalli*, Cela = *Ceratoides lanata*, Chna = *Chrysothamnus nauseosus*, Rhtr = *Rhus trilobata*

Figure 4. Experimental design of shrub and forb direct seeding study, Colstrip, Montana.

Figure 5. Study site undergoing chisel plowing, shrub and forb direct seeding study, Colstrip, Montana, September 30, 1978.

depth placement achieved under broadcast seeding. In a diverse seed mixture, a large amount of variability exists with respect to seed size, shape and preferred seeding depth among species. Under broadcast seeding at least some seed of each species will be sown at an optimal seeding depth, thus promoting some germination of all species seeded. Also, many plant species have seeds which are small and/or chaffy, making drill seeding difficult. Broadcast seeding was employed in this study because one of the treatments required the use of a diverse seed mixture, and because four of the shrub species had seeds that were small and chaffy.

Many shrub species have difficulty in overcoming seed dormancy, and often require lengthy stratification periods which naturally occur during the winter months (Monsen and Christensen, 1975). Therefore, a fall seeding date was utilized so that dormancy could be broken naturally (Sindelar et al., 1973; Stevens, 1980; Plummer et al., 1968). Certain species, such as skunkbush sumac, require some additional type of seed pre-treatment to increase the permeability of hard, impervious seedcoats and thus enhance germination (Brinkman, 1974; Heit, 1970; Plummer et al., 1968). Seed of skunkbush sumac was scarified for one hour in 90% sulfuric acid at room temperature prior to seeding (Brinkman, 1974).

Plot 30 (Figure 4) was intended for seeding of the forb, cudweed sagewort (Artemisia ludoviciana) with the grass seed mixture concurrently, but there was insufficient seed available to complete the seeding of this forb in Plot 30.

All study plots were uniformly fertilized at 29.6 kg/ha actual nitrogen and 16.3 kg/ha actual phosphorus (185 kg/ha bulk 16-20-0) in May, 1979. The use and rates of these fertilizers were based upon results of another study conducted in the Colstrip area (DePuit and Coenenberg, 1979).

Measurements of Physical Characteristics

Soil samples were collected at three points within the study site enclosure on April 20, 1979. Using an Oakfield sampling tube, each point was sampled at the following depths: 0-3 cm, 3-5 cm, 5-10 cm, and 10-15 cm resulting in 12 samples. These samples were tested at the Montana State University Soil Testing Laboratory. Tests conducted included percent sand, silt and clay, pH, organic matter (%), extractable NO_3N (ppm), NH_4-N (ppm), P (ppm) and K (ppm), exchangeable Ca (meq/100g), Mg (meq/100g) and Na (meq/100g), and electrical conductivity (mmhos).

Soil moisture content was determined using the neutron scattering method (Brady, 1974). The smallness of the study plot and buffer strip area prohibited the collection of the number of soil samples required for determination of soil moisture content by standard gravimetric methods (e.g., Reynolds, 1970). The neutron scattering method provided a rapid, low-impact means of determination of soil moisture content in the field.

In 1979, soil moisture content was measured at bi-weekly intervals from July 16 to September 5. A Troxler surface-moisture density probe was utilized with a 3.0 millicurrie Radium 226 source emitting gamma radiation (Dollhopf, Jensen and Hodder, 1977). Twelve surface samples (0-20 cm) were taken per interval, three at each side of the study site in the buffer strip. This instrument measures soil moisture content on a percent water by volume basis. This information was later calibrated based on laboratory derived percent water by volume from soil samples collected in the field. The equation used to calibrate the probe-collected data was Y = 6.55 + 1.2665X, where Y = percent water by volume derived in the lab and X = percent water by volume derived from the probe (DePuit and Young, 1981).

An aluminum neutron access tube 90 cm long was installed in December, 1979. It was located in the buffer strip at the northeast corner of the study site. Soil moisture content by volume was measured at the following depths: 15 cm, 30 cm, 45 cm, 60 cm, 75 cm, 90 cm, 120 cm, 150 cm, 180 cm and 210 cm. A Troxler neutron emission probe was utilized with a 100 millicurrie Americium-Beryllium source which emits high speed neutrons (Dollhopf et al., 1977). These data were collected on a monthly basis from May 1, 1980 to October 21, 1980. The access tube was installed so that soil moisture content could be measured to a greater depth than was possible with the surface probe. Calibration of this instrument's field data was also required. The calibration equation utilized was Y = 2.4 - 33.93X, where Y = percent water by volume derived in the lab and X = percent water by volume derived from the probe. Dollhopf et al. (1979) derived this calibration equation for use of the probe in sandy loam and sandy clay loam soils in a study conducted in the Colstrip area.

A standard eight inch National Weather Service precipitation gauge was also installed within the study site in December, 1979. Precipitation data were collected on a monthly basis beginning in December, 1979 and ending in October, 1980. An altar-type windshield was constructed around the gauge so that wind movement would not interfere with precipitation collection. Oil was added to the gauge to decrease evaporation and antifreeze was added in the winter so that collected snow would melt thus allowing liquid measurements (DePuit et al., 1978). Unfortunately, precipitation data were not collected at the study site prior to December, 1979. However, precipitation data collected from other studies located nearby were utilized to approximate study site precipitation prior to December, 1979.

Vegetation Analysis Within Shrub and Forb Study Site

Vegetation sampling in this study was designed to gather as much information as possible concerning the success or failure of the shrub and forb species. The following characteristics were measured within each plot: 1) density; 2) canopy cover; 3) frequency, and 4) aerial biomass. Sampling within each plot was conducted systematically, so that all portions of the plot would be adequately sampled. Sampling for density and canopy cover was conducted along three permanently marked 5m long transect lines established within each plot. These lines were marked with wire flags placed at 1.25 meter intervals along the north and south ends of the plots. The two outside lines were also placed 1.25 meters from the east and west side of the plots so that any edge effects between plots would be eliminated. A metric tape was stretched between two flags and sampling proceeded along the tape. The location of these lines and the sampling techniques used to measure the four parameters within a plot are presented in Figure 6.

Canopy cover data were collected from July 23 to August 5, 1979 and from June 11 to June 21, 1980. Canopy cover was estimated for all individual species (using the polygon method described by Daubenmire, 1970) and for litter and bare ground. Cover was estimated to the nearest percentage point. Any cover estimate less than 1% in value was designated a trace. Also, the highest bare ground cover attainable was arbitrarily set at 95%. The aim of this modification was to account for the stems of the plants occupying the quadrat, which were arbitrarily assigned a cover value of 5%. Three 2x5 dm quadrats were sampled along each of the transect lines at 1.25 meter intervals,

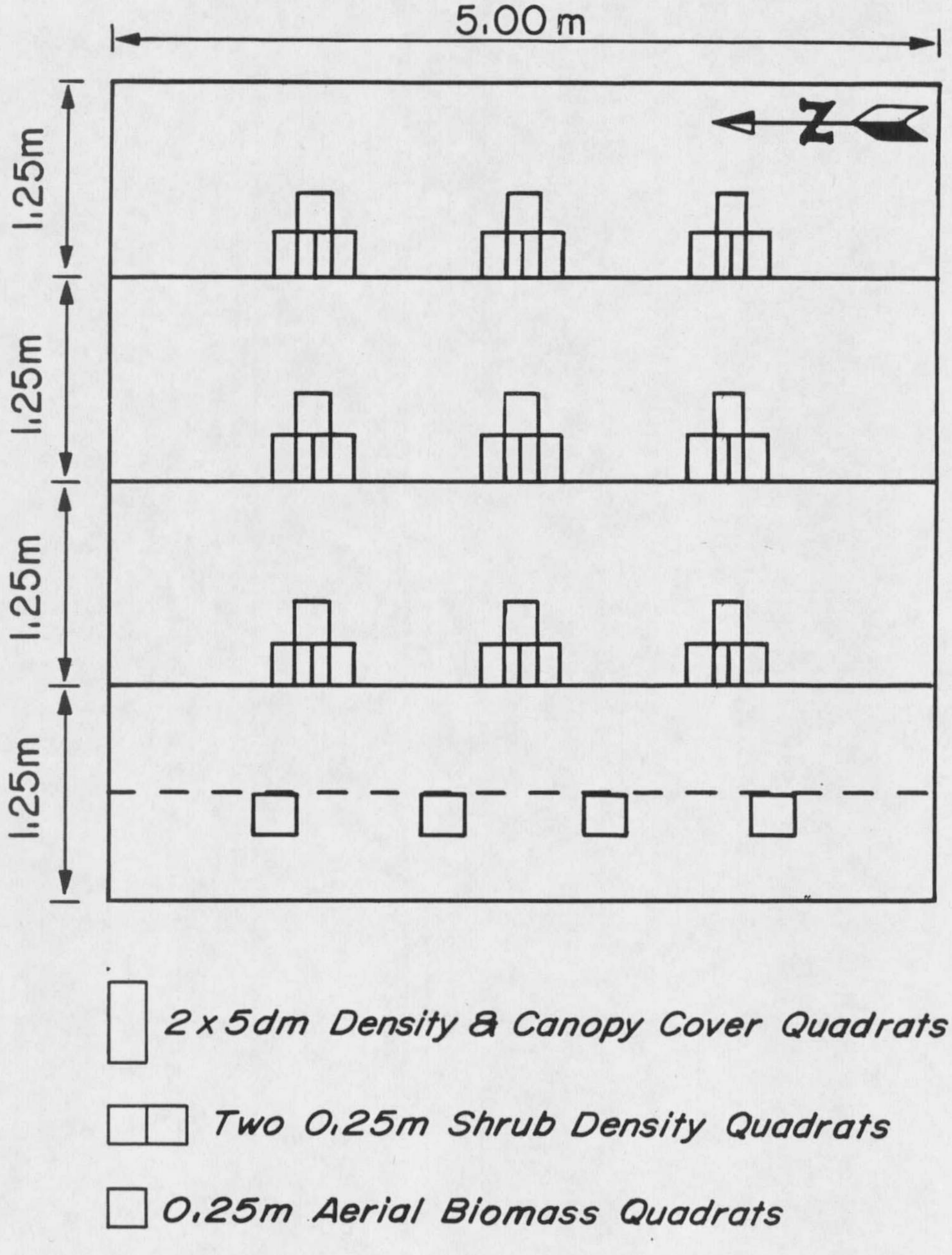


Figure 6. Representative study plot showing locations of transect lines and sampling quadrats, shrub and forb direct seeding study, Colstrip, Montana.

beginning 1.25 meters from the north end of each line. A total of nine quadrats were sampled in each plot. Frequency data for each species were derived from the canopy cover information. Canopy cover provided information on relative growth and vigor of each plant species, and vegetation composition.

Density was measured for each species concurrently with canopy cover estimates. Counts were made for each species present within each 2x5 dm quadrat.

Supplemental density data for the five shrub and one forb species seeded were collected utilizing two 0.25 meter-square quadrats placed side by side at the sampling points described above. The larger quadrat size was chosen because of the anticipated possibility of lower, more widely spaced densities of seeded shrubs in comparison to perennial grasses and annual forbs. According to Mueller-Dombois and Ellenberg (1974), quadrat size must be related to size and spacing of plant individuals. Shrub and forb density data were collected twice during the 1979 and 1980 growing seasons, i.e. on June 11-19 and August 18-23, 1979, and on May 27-30 and July 30-August 1, 1980. This characteristic provided information concerning establishment and survival for each of the six shrub and forb species.

Above ground biomass data were collected from June 21 to July 6, 1980. Four 0.25 meter-square quadrats were sampled per plot at one meter intervals along a transect line, beginning 1 meter from the line's northern end. The biomass sampling transect line was distinct from density/cover transects, being located on the western side of each plot (Figure 6). Each species present within a quadrat was clipped to ground level. Dead vegetation, standing and laying on the ground, was collected. These components were bagged separately, oven dried and weighed. Biomass data were not collected in 1979 because the smallness of the plots and resultant limited sampling area prohibited this type of destructive sampling two years in a row. Biomass sampling was timed to coincide as nearly as possible to the peak production period, which for the Colstrip area usually occurs from late June to early July (DePuit et al., 1980).

All plant species observed within the enclosure were identified throughout the 1979 and 1980 growing seasons. Scientific nomenclature followed Hitchcock (1950) for grasses, and Hitchcock and Cronquist (1974) for all other species.

Phenological data were collected for all observed plant species within the enclosure throughout the 1979 and 1980 growing seasons. These data were collected at approximate bi-weekly intervals (from July 1 to September 1) in 1979 and at monthly intervals (from June 2 to September 22) in 1980. The phenological patterns exhibited by different plant species were documented using a modification of techniques described by West and Wein (1971) and Munshower and DePuit (1976). These techniques strive to quantify phenological data by using a series of numerical and/or letter ratings assigned to each phenological stage. The rating system used is presented in Table 3. Plants were assigned a letter and corresponding number depending on their life form, developmental category and phenological stage at time of observation.

Heights of individual plants selected at random were measured for the six shrub and forb species seeded. These data were collected from sample plots representing both treatments described for each species. Height data collection was conducted three times during the 1979 growing season (July 1, August 16 and September 5), and once during the 1980 growing season (August 17).

Supplemental Vegetation Analyses

Vegetation Analysis of Area Immediately Outside Shrub and Forb Study Site

As previously mentioned, Western Energy Company seeded the entire area (including the study site) to a mixture of 16 grass, forb and shrub species in April, 1978. The present study was implemented by recultivating and seeding a portion of this area. Vegetation of the area surrounding the study site was sampled on August 30, 1979 to provide a basis for evaluation of the nature and maximum degree of "volunteer" plant establishment occurring from the previous seeding.

Plant frequency was selected as a vegetation parameter to characterize this area due to rapidity of data collection (King, 1980).

Table 3. Phenological pattern rating system, shrub and forb direct seeding study, Colstrip, Montana.

Shrubs and forbs

V. Vegetative development
1. Cotyledons showing
2. Seedling
3. Early green-up
4. Vegetative growth
5. Vegetative maturity
6. Die-back
7. Late regrowth
8. Winter dormancy
9. Dead

R. Reproductive development
0. Nothing present
1. Flower buds appearing
2. Flower buds opening, flowering
3. Fruit developing
4. Fruit formed
5. Fruit disseminating

Grasses

V. Vegetative development
1. Early vegetative sprouting
2. Seedling
3. Early green-up
4. Vegetative growth
5. Vegetative maturity
6. Fall green-up
7. Winter dormancy
8. Dead

R. Reproductive development
1. Boot stage
2. Shooting seed stalk
3. Flowering, anthesis
4. Seed-head maturity
5. Hard seed
6. Seed shatter, dehiscence

Three transect lines were utilized. One line, 100 m in length, was established parallel to the eastern border of the study site. Two more lines, each 50 meters in length were established perpendicular to the study site on its southern border. A series of 20x20 cm quadrats placed at 1 meter intervals along these lines were evaluated. A total of 200 quadrats was sampled. Each species (dead or alive) rooted within the quadrat or which had canopy coverage in the quadrat was counted as a hit. Plot size has a very important influence on frequency data. Daubenmire (1968) stated that ideal plot size is achieved when only one or a few species attain a frequency value of 100 percent. A 20x20 centimeter-square quadrat was selected because it met these criteria.

Canopy cover was also sampled in this area on August 31, 1979, so that the abundance of plant species could be estimated. Three transect lines arranged in the same manner as described for frequency were utilized. These data were collected in the same manner described for canopy cover inside the study site. Each line was 50 m long. Two of the lines were stretched perpendicular to the study site boundary on its southern border. The third line was established parallel to the eastern border of the study site. Sampling occurred at 5 meter intervals along these lines for a total of 30 quadrats.

Annual grasses (Japanese brome and cheatgrass) were noticeably more abundant in the area outside the enclosure than inside. To document this difference, annual grass density data were collected for this area on July 11, 1979. Two transect lines, each 40 m long, were established perpendicular to the study site boundary, one on the southern border and one on the northern border of the site. A 20x20 cm quadrat placed at 2 m intervals along these lines was evaluated. A total of 40 quadrats were sampled.

Density data taken in 1979 and 1980 revealed big sagebrush plants to be uniformly distributed throughout the study site enclosure. There were no greater amounts in plots seeded with this species than those not seeded. It was suspected that this species' distribution and presence within the enclosure was due to volunteering from seed sources present in the coversoil. To test this hypothesis, sagebrush frequency data were collected for the area outside the enclosure on July 15, 1980. Seven paced transect lines were examined in the area south of the enclosure. Sampling was achieved using a 20x20 cm quadrat placed by the right foot every two paces for a total of 320 quadrats. All species (dead or alive) rooted or hanging over a quadrat were counted as hits.

Species lists were compiled for this area during the 1979 and 1980 growing seasons.

Vegetation Analysis of Irrigation Study. An on-going irrigation study conducted by the Montana Agricultural Experiment Station, Reclamation Research Unit (see Young and DePuit, 1981) provided an opportunity to evaluate the response of winterfat to three different seeding seasons (i.e. fall, spring and summer) in terms of establishment and growth. Densities were collected for this species from plot 5 (spring seeded non-irrigated control) and plot 1 (summer seeded non-irrigated control). These densities were then compared to those derived from the present study (fall seeding, no irrigation). Winterfat densities were collected for each plot along four permanently marked transect lines, each 16m in length. Two 0.25 meter-square quadrats placed side by side were used at 1.25 meter intervals along each line for a total of 48 quadrats sampled per plot. In 1979 these data were collected on July 16 and again on September 2 for plot 5 (spring seeded non-irrigated control), and on September 3 for plot 1 (summer seeded non-irrigated control). In 1980, sampling occurred on July 28 for both plots. Heights of individual plants selected at random were also determined on the following dates: July 16 and September 2, 1979 and July 28, 1980.

Laboratory Shrub and Forb Seed Measurements

Purity and viability tests were conducted in the laboratory during 1979 and 1980 to ascertain the seed quality (percent pure live seed) of the six shrub and forb species. The multiplication of percent purity and percent viability results in percent pure live seed.

Normally, germination rather than viability is used to determine percent pure live seed (Vallentine, 1971). The former method was not used in this study because dormancy breaking procedures have not been developed for several of the species being evaluated. All the species, except skunkbush sumac, require long periods of cold stratification and/or after ripening to overcome dormancy and germinate (Eddleman, 1977).

The tetrazolium (2,3,5-triphenyl-2H-tetrazolium chloride) staining method was used to determine seed viability (Delouche et al., 1962; Grabe and Delouche, 1959). This method provides a fast, simple way to determine viability, but does not distinguish between dormant and non-dormant seed (Weber and Wiesner, 1980). Tetrazolium in aqueous solution is reduced by dehydrogenase enzymes (present only if the seed is metabolically active) to form formazan. Formazan is a red colored, insoluble dye which stains the seed embryo if viable. The intensity and topography of the resulting embryo coloration were used to determine seed viability (Copeland, 1976).

Weber and Wiesner (1980) have developed procedures for tetrazolium viability testing for three of the species evaluated in this study (i.e. skunkbush sumac, winterfat and big sagebrush). Their procedures were used when testing these species. Rubber rabbitbrush and cudweed sagewort have achenes which are similar to those of big sagebrush. Nuttall's saltbush and winterfat also possess utricles which are similar (USDA Forest Service, 1974). Therefore, the procedures for the species listed by Weber and Wiesner (1980) were modified and used for those species with similar fruit types. The procedures developed by Weber and Wiesner (1980) and the modified procedures are presented in Table 4.

Four replicates, containing 25 seeds each were used to determine seed viability for each species. A lactophenol clearing solution was used for some species to remove the pigmentation from the seed coat to allow evaluation of the embryo. Viable embryonic structures (cotyledon, hypocotyl and radicle) stained light red; non-viable structures failed to stain. For all the species except cudweed sagewort, seeds in which both the hypocotyl and radicle were stained were considered viable. Cudweed sagewort possessed seeds that were too small to distinguish embryonic structures; therefore, if a red staining was visible, the seed was considered viable.

Purity testing procedures for the six shrub and forb species evaluated in this study have not been developed (Association of Seed Analysts, 1978). Sample sizes for these species were based primarily on seed size and/or weight (i.e. the larger and/or heavier seeded species had larger sample sizes than the smaller and/or lighter seeded species). Percent purity was obtained by dividing the weight of pure seed by the total weight of seed plus inert matter, following their separation.

Table 4. Procedures used in viability testing of shrub and forb species, shrub and forb direct seeding study, Colstrip Montana (portions of table from Weber and Wiesner, 1980).

Species	Precondition	Preparation	TZ Conc. %	Staining Time (hrs) at Room Temp.	Remarks
Big sagebrush	None	None	1	16	Clear 2 hours with lacto-phenol
Rubber rabbitbrush	Moist blotters overnight	Cut fruit at distal end and remove embryo	1	48	
Cudweed sageword	Moist blotters overnight	Puncture fruit and seed wall	1	6-8	
Winterfat	Moist blotters overnight	Puncture seed-coat over perisperm area	0.1	4	Remove bracts initially
Nuttall's saltbush	Moist blotters overnight	Puncture seed-coat over perisperm area	0.1	6-8	Remove bracts initially and clear 2 hours with lacto-phenol
Skunkbush sumac	Soak in water 24 hours	Bisect laterally	0.1	4	

Sample sizes used in purity testing were as follows: 1) Nuttall's saltbush, 5.0 grams; 2) skunkbush sumac, 10 grams; 3) winterfat, 2.0 grams; 4) rubber rabbitbrush, 1.0 gram; 5) cudweed sagewort, 0.1 gram; and 6) big sagebrush, 0.5 gram. Four replicates were used for each species when determining purity percentage.

Two of the species, rubber rabbitbrush and big sagebrush, had seeds which were very chaffy and contained large amounts of inert matter. To facilitate purity testing of these species, small cleaning screens were used to separate the chaff and other inert matter from the samples prior to testing. This chaff was saved and added to the total inert matter.

Four interlocking metal screens were used to clean seed of rubber rabbitbrush. The screens sizes (top to bottom) were a 1/16 inch X 1/2 inch rectangular slot; a 1/17 inch diameter round hole; a 1/18 inch diameter round hole and a 1/25 inch diameter round hole. An interlocking plate was placed on the bottom. Following the placement of the sample, the screens were shaken vigorously as a unit. Each screen was then emptied of its contents individually and seed separated from inert matter.

The same procedures were followed for big sagebrush, except the samples were processed through a series of four steps, each step consisting of a series of screens or just one screen. These steps and their screens or screen were: Step 1) a 1/16 inch diameter round hole, a 6 X 24 wire mesh, a 6 X 32 wire mesh and a bottom plate; Step 2) a 1/16 inch diameter round hole, a 1/18 inch diameter round hole, a 1/25 inch diameter round hole and a bottom plate; Step 3) a single brass wire mesh screen and Step 4) a very fine gold wire mesh screen.

The number of seeds per pure sample for each species were counted and the number of seeds per kilogram calculated.

RESULTS

Shrub and Forb Seeding Field Study

Supporting Data

Physical Data.

Precipitation. The average annual precipitation for Colstrip is 40.10 cm, 1/2 of which falls as rain from April through July, coinciding with the period of peak plant production for this area (Hurtt, 1951). Table 5 presents a comparison of monthly precipitation amounts and percentages of the long term average for the years 1978, 1979 and 1980, plus the long term average (1940-1971) for the Colstrip area.

The year of seeding, 1978, was marked by precipitation in excess of the long term average (l.t.a.). Total precipitation in 1978 was 57.76 cm as compared to the l.t.a. of 40.10 cm, or 144 percent of average. During September (the month of seeding), precipitation was 275 percent of the l.t.a. for this month. This was followed by October, which was 18 percent of average, and November and December which were 150 percent and 167 percent of average, respectively.

Only 22.34 cm of precipitation (56 percent of average) fell during 1979, the year of initial seedling establishment and growth. During the April through July period of 1979, 10.89 cm of rain was recorded, which was only 49 percent of average (22.40 cm).

Table 5. Comparison of monthly precipitation (cm) for the years 1978, 1979 and 1980 with long term monthly precipitation averages (1941-1970), shrub and forb direct seeding study, Colstrip, Montana.

Month	Long Term Averages (LTA) (1941-1970)	1978		1979		1980	
		Precip.	% LTA	Precip.	% LTA	Precip.	% LTA
January	1.42	2.11	149	3.45	243	1.30	92
February	1.42	2.54	179	1.85	130	1.68	118
March	1.88	0.81	43	0.84	45	2.26	120
April	4.72	2.03	43	3.45	73	0.79	17
May	6.27	23.14	369	4.01	64	1.55	25
June	8.41	3.91	47	1.91	23	6.02	72
July	3.00	5.23	174	1.52	51	0.94	31
August	3.53	2.62	74	0.66	19	4.43	126
September	3.51	9.65	275	0.38	11	4.85	138
October	2.64	0.48	18	2.87	109	0.99	38
November	1.70	2.57	150	0.84	49	0.58	34
December	1.60	2.67	167	0.56	35	1.50	94
Total annual	40.10	57.76	144	22.34	56	26.89	67

The abnormally low precipitation of 1979 was repeated in 1980, the second year of plant growth. In 1980, 26.89 cm of annual precipitation was recorded, which was 67 percent of average. Only 9.3 cm fell as rain from April through July, 42 percent of average.

Soils. Table 6 presents mean soil test data collected at the various soil depths indicated. No large differences existed between data collected at the various soil depths with respect to individual properties measured. The physical and chemical properties of the soil were similar to those of other coversoils in the Colstrip area (DePuit and Coenenberg, 1979; DePuit, Coenenberg and Skilbred, 1980).

No deleterious chemical and physical soil properties were apparent based upon these analyses. The pH was 8.3, which is relatively high, but since exchangeable salts and electrical conductivity were low the soil was nonsaline/nonsodic. The soil possessed a sandy loam texture. It should be noted that the soil was sampled prior to fertilization and that nitrogen and phosphorus contents presented here should be lower than those present in the soil following fertilization.

Volumetric soil moisture collected periodically on the study site in 1979 and 1980 is presented in Tables 19 and 20, Appendix A. Soil moisture desorption characteristics and corresponding curves were not determined.

Phenology. Phenological data for all observed plant species inside the study site enclosure in 1979 and 1980 are presented in

Table 6. Mean soil test data for the soil depth intervals: 0-3 cm, 3-5 cm, 5-10 cm and 10-15 cm, shrub and forb direct seeding study, Colstrip, Montana, April 20, 1979[2].

	Soil Depth (cm)			
Soil Parameter	0-3[1]	3-5[1]	5-10[1]	10-15[1]
% Sand	60.1	59.1	57.5	57.2
% Silt	22.6	23.3	24.8	24.4
% Clay	17.3	17.6	17.7	18.4
pH	8.3	8.3	8.3	8.4
Organic Matter (%)	1.9	1.7	1.6	1.3
NO_3N(ppm)	5.8	11.3	10.9	10.1
NH_4-N (ppm)	5.7	0.0	1.7	0.0
P(ppm)	6.0	5.7	5.0	3.7
K(ppm)	158.0	162.7	166.7	141.3
Ca(meq/100g)	25.1	24.7	30.6	32.8
Mg(meq/100g)	2.8	2.9	3.2	3.3
Na(meq/100g)	T[3]	T	T	T
EC(mmhos)	0.4	0.6	0.6	0.6

1 Sample size (n) = 3

2 Soil sampling conducted prior to fertilization

3 T = trace (<0.1 meq/100g)

Tables 21 and 22, Appendix A. These data are not presented by treatment due to lack of any appreciable phenological differences between treatments. All phenological stages observed for each plant species are presented, with appropriate comments addressing overall plant condition and phenological stage.

Vegetation

Seed Analysis. Table 7 presents laboratory seed analysis results for shrub and forb species utilized in this study. Skunkbush sumac exhibited the highest overall percent pure live seed (95.6), and rubber rabbitbrush the lowest (0.7). Locally collected winterfat and Nuttall's saltbush seed demonstrated higher percent pure live seed than commercially purchased seed.

Plummer et al. (1968) stated what they believed were acceptable percent purities for all shrub and forb species of the present study except cudweed sagewort. These were 10 percent for big sagebrush and rubber rabbitbrush, 90 percent for skunkbush sumac and Nuttall's saltbush, and 50 percent for winterfat. Seed lots for all shrub/forb species of this study except Nuttall's saltbush had higher percent purities, with the latter species approximately 5 to 10 percent lower.

No information was available in the literature on either acceptable percent viability or percent pure live seed for the shrubs and forbs seeded. It would appear, however, that percent viabilities were

Table 7. Laboratory seed analysis results for shrub and forb species utilized in shrub and forb direct seeding study, Colstrip, Montana.

Species	Percent Purity	Percent Viability	Percent Pure Live Seed	Seed Number Per Kilogram
Big Sagebrush	20.1	42.4	8.5	5,165,415
Cudweed sagewort	34.3	34.6	11.9	40,255,482
Skunkbush sumac	99.6	96.0	95.6	59,804
Rubber rabbitbrush	14.8	4.5	0.7	2,621,386
Winterfat	45.5	19.9	9.1	281,761
Winterfat (local)	61.2	44.6	27.3	232,076
Nuttall's saltbush	84.0	40.8	34.3	389,857
Nuttall's saltbush (local)	80.7	45.4	36.6	368,536

low for all species except skunkbush sumac, with rubber rabbitbrush and commercially purchased winterfat seed viability especially poor. These low viabilities resulted in low pure live seed, especially for commercially purchased winterfat, big sagebrush, rubber rabbitbrush, and cudweed sagewort.

Table 8 presents actual seeds per kilogram and pure live seeding rate data derived from laboratory seed analysis as opposed to initially estimated seeds per kilogram and bulk seeding rates based upon literature information. Actual number of seeds per kilogram derived from laboratory analysis were higher for all shrub and forb species than values estimated from literature information, with the exception of big sagebrush and locally collected winterfat which exhibited slightly lower values.

The pure live seed (PLS) results substantially lowered kilogram per hectare PLS seeding rates from levels originally desired for all shrub/forb species except skunkbush sumac.

Although laboratory-derived numbers of seeds per kilogram were higher than literature-based numbers, for certain species these differences were not sufficient to offset the low pure live seed percentage. This resulted in lower numbers of pure live seed per square meter for both locally collected and commercially purchased winterfat and nuttall's saltbush, big sagebrush and rubber rabbitbrush than initially

Table 8. Shrub and forb species seeding rates: actual seeding rates derived from laboratory seed analysis versus initially estimated seeding rates based on literature information, shrub and forb direct seeding study, Colstrip, Montana.

Species	# Seeds/kg Actual	# Seeds/kg Literature	Seeding Rate Actual kg/(PLS)/ha	Seeding Rate Literature kg/ha	Seed #/Unit Area Actual # Seeds(PLS) per sq. m.	Seed #/Unit Area Literature # Seed per sq. m.
Big sagebrush	5,165,415	5,425,200	0.4	4.5	206.6	2441.3
Cudweed sagewort	40,255,482	5,489,000	0.5	4.5	2012.8	2470.1
Skunkbush sumac	59,804	44,660	49.3	51.6	294.8	230.5
Rubber rabbitbrush	2,621,386	1,524,600	0.1	12.3	26.2	1875.3
Winterfat	281,761	244,200	1.2	13.5	33.8	329.7
Winterfat (local)	232,076	244,200	3.7	13.5	85.9	329.7
Nuttall's saltbush	389,857	245,300	7.7	22.4	300.2	549.5
Nuttall's saltbush (local)	368,536	245,300	8.1	22.2	298.5	549.5

desired. All other species had numbers of pure live seed per square meter similar to those initially desired.

Relative Field Performance Among Shrub and Forb Species. The overall field performance among seeded shrub/forb species in 1979 and 1980 was evaluated utilizing mean plant density (plants/m^2). This information is presented in Table 9.

Locally collected Nuttall's saltbush exhibited the highest initial establishment density (17.04) followed by commercially purchased saltbush (7.33) and skunkbush sumac (3.85). All other species had statistically similar densities, which were significantly lower than these two species.

Initial establishment percentages for each shrub and forb species were calculated by dividing the initial establishment densities (Table 9) by the actual seeding rate (# of pure live seeds/m^2, Table 8). All species exhibited very low establishment percentages. Locally collected Nuttall's saltbush exhibited the highest percentage (5.71) followed by commercially purchased Nuttall's saltbush (2.44), rubber rabbitbrush (1.41) and skunkbush sumac (1.31). All other species demonstrated establishment percentages lower than one (i.e. locally collected winterfat: 0.51, commercially purchased winterfat: 0.21, big sagebrush: 0.15, and cudweed sagewort: 0.01).

Following initial establishment, certain species decined in density, the degree of which was variable among species. Big sagebrush

Table 9. Field performance evaluation (in terms of mean[1] plant density (plants/m^2)) of shrub and forb species (commercially purchased (without perennial grass mixture treatment only) and locally collected seed) in 1979 and 1980, shrub and forb direct seeding study, Colstrip, Montana[2].

Species	1979 Date 1 (June 11-19)		1979 Date 2 (Aug. 18-23)		1980 Date 1 (May 27-30)		1980 Date 2 (July 30-Aug.1)	
Big sagebrush	0.30	d	0.22	c	0.30	c	0.22	b
Rubber rabbitbrush	0.37	d	0.37	c	0.00	c	0.00	b
Winterfat	0.07	d	0.00	c	0.00	c	0.00	b
Cudweed sagewort	0.22	d	0.44	c	0.15	c	0.00	b
Nuttall's saltbush	7.33	b	6.89	b	6.81	b	4.89	b
Skunkbush sumac	3.85	c	0.15	c	0.00	c	0.00	b
Nutall's saltbush (local)	17.04	a	16.96	a	8.96	a	4.74	a
Winterfat (local)	0.44	d	0.44	c	0.30	c	0.30	b

[1] Of 3 replications, each containing a sample size (n) of 9

[2] Values within a column followed by different letters are significantly different at 5% level (Duncan's Multiple Range Test)

and locally collected winterfat, however, maintained original densities throughout the sampling periods. Skunkbush sumac suffered near complete mortality by Date 2, 1979 and complete mortality by Date 1, 1980. Commercially purchased winterfat, rubber rabbitbrush and cudweed sagewort suffered complete mortality by 1980. Commercially purchased and locally collected Nuttall's saltbush exhibited steady declines in density, and by 1980, Date 2 were approximately 1/4 and 1/2 their original densities, respectively.

Survival percentages were calculated for each shrub and forb species. This was accomplished by dividing final sampling densities by initial establishment densities. Survival percentages were: big sagebrush 73, winterfat (locally collected) 68, Nuttall's saltbush (commercially purchased) 67, and Nuttall's saltbush (locally collected) 28. All other species failed to survive.

In terms of initial establishment densities, locally collected Nuttall's saltbush performed best, followed by commercially purchased Nuttall's saltbush and skunkbush sumac. However, by the last sampling date, commercially purchased and locally collected Nuttall's saltbush showed the highest densities. These densities were approximately equal and were significantly higher than all other species' values. However, in view of the high density reduction of locally collected Nuttall's saltbush, it would appear that commercially purchased Nuttall's saltbush performed the best following initial establishment.

Competition Effects on Vegetation Establishment. Tables 10, 11, 12 and 13 present comparisons of seeded shrub and forb species mean density by treatment and by species for two sampling dates in each of 1979 and 1980. Data for locally collected winterfat and Nuttall's saltbush were not included in this analysis due to the fact that the perennial grass mixture treatment was not applied to these species ecotypes.

Table 10 reflects initial shrub and forb species establishment in terms of density. Only one species, cudweed sagewort, exhibited a significant with and without perennial grass mixture treatment difference. This species possessed a significantly higher mean density when seeded concurrently with the perennial grass mixture. Nuttall's saltbush and skunkbush sumac established in higher densities when seeded alone than when concurrently seeded with the perennial grass mixture. However, these differences were not significant. Nuttall's saltbush, skunkbush sumac, and cudweed sagewort showed highest overall mean densities. The other species possessed very low overall mean densities and exhibited no significant differences between treatments.

During the next three sampling dates, (Tables 11, 12, and 13, respectively) all shrub and forb species exhibited density reductions under both treatments. Rates of density loss were accelerated when seeded with the perennial grass mixture. This is demonstrated best by cudweed sagewort. By 1980, date 1, this species no longer showed a

Table 10. Comparison of shrub and forb species mean[1] seedling density (plants/m^2) by treatment (with and without concurrently seeded perennial grass mixture), shrub and forb direct seeding study, Colstrip, Montana, Date 1 (June 11-19) 1979[2].

Species	With Perennial Grass Mixture	Without Perennial Grass Mixture
Big sagebrush	0.37	0.30
Rubber rabbitbrush	0.44	0.37
Winterfat	0.00	0.07
Cudweed sagewort	2.00 a	0.22 b
Nuttall's saltbush	5.63	7.33
Skunkbush sumac	2.52	3.85

1 Of 3 replications, each containing a sample size (n) of 9

2 Values within a row followed by different letters are significantly different at 5% level

Table 11. Comparison of shrub and forb species mean[1] seedling density (plants/m^2) by treatment (with and without concurrently seeded perennial grass mixture), shrub and forb direct seeding study, Colstrip, Montana, Date 2 (August 18-23) 1979[2].

Species	With Perennial Grass Mixture	Without Perennial Grass Mixture
Big sagebrush	0.37	0.22
Rubber rabbitbrush	0.30	0.37
Winterfat	0.00	0.00
Cudweed sagewort	1.11 a	0.44 b
Nuttall's saltbush	5.26	6.89
Skunkbush sumac	0.59 a	0.15 b

1 Of 3 replications, each containing a sample size (n) of 9

2 Values within a row followed by different letters are significantly different at 5% level

Table 12. Comparison of shrub and forb species mean[1] plant density (plants/m^2) by treatment (with and without concurrently seeded perennial grass mixture), shrub and forb direct seeding study, Colstrip, Montana, Date 1 (May 27-30), 1980[2].

Species	With Perennial Grass Mixture	Without Perennial Grass Mixture
Big sagebrush	0.30	0.30
Rubber rabbitbrush	0.07	0.00
Winterfat	0.00	0.00
Cudweed sagewort	0.00	0.15
Nuttall's saltbush	3.56 b	6.81 a
Skunkbush sumac	0.00	0.00

1 Of 3 replications, each containing a sample size (n) of 9

2 Values within a row followed by different letters are significantly different at 5% level

Table 13. Comparison of shrub and forb species mean[1] plant density (plants/m^2) by treatment (with and without concurrently seeded perennial grass mixture), shrub and forb direct seeding study, Colstrip, Montana, Date 2 (July 30 to August 1) 1980[2].

Species	With Perennial Grass Mixture	Without Perennial Grass Mixture
Big sagebrush	0.30	0.22
Rubber rabbitbrush	0.00	0.00
Winterfat	0.00	0.00
Cudweed sagewort	0.00	0.07
Nuttall's saltbush	2.96	4.89
Skunkbush sumac	0.00	0.00

[1] Of 3 replications, each containing a sample size (n) of 9

[2] Values within a row followed by different letters are significantly different at 5% level

significant difference between treatments. Complete mortality occurred with the perennial grass mixture by 1980, date 2. The rate of density loss for the species when seeded alone was much less rapid, and complete mortality never occurred. Nuttall's saltbush maintained higher densities without the perennial grass mixture throughout 1979 and 1980. This higher density became significant by 1980, Date 1. Skunkbush sumac showed no difference in rate of density loss between the treatments during this period. Density responses of other species under the two treatments were impossible to ascertain due to very low initial establishment densities.

Table 23, Appendix B presents comparisons of seeded shrub and forb species' mean plant heights by treatment in 1979 and 1980. No statistical analyses were conducted for these data due to low sample numbers for most of the shrub and forb species. However, differences in plant height between treatments were generally negligible, suggesting that statistical analysis would have yielded no significant differences.

Table 14 summarizes plant canopy cover, density and biomass by treatment (with and without concurrently seeded perennial grass mixture) for all seeded shrub and forb species plots in 1979 and 1980. Table 14 is derived from the complete, detailed canopy cover, density and biomass data set presented in the following Appendix B tables: Tables 24 and 25 (cover, 1979 and 1980, respectively), Tables 26

Table 14. Summary of plant canopy cover (%), biomass (kg/ha) and density (plants/m^2) by treatment (with and without concurrently seeded perennial grass mixture) over all shrub and forb species plots[2] in 1979 and 1980, shrub and forb direct seeding study, Colstrip, Montana[2].

	Density				Canopy Cover				Biomass[3]	
	1979		1980		1979		1980		1980	
Plant Species/Class	With	Without	With	Without	With	Without	With	Without	With	Without
Thickspike Wheatgrass	94.7a	5.3b	56.6a	6.4b	17.9a	2.6b	26.0a	5.4b	156.1a	33.2b
Western Wheatgrass	18.6a	2.5b	38.4a	5.2b	4.3a	0.9b	8.5a	1.9b	42.5a	9.8b
Prairie Sandreed	0.8	0.1	0.0	0.0	0.1a	Tb	0.0	0.0	0.0	0.0
Indian Ricegrass	30.4a	7.1b	13.4a	4.0b	7.1a	2.4b	7.6a	3.5b	30.6a	17.8b
Switchgrass	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Canada Bluegrass	5.6	0.3b	0.8a	0.0b	0.8	0.1	0.2a	0.0b	2.3a	0.0b
Total seeded perennial grasses	150.1a	15.3b	109.5a	15.6b	30.2a	6.1b	42.4a	10.8b	231.5a	60.8b
Total non-seeded perennial grasses	17.0	22.8	14.6b	22.6a	10.7b	15.7a	12.7b	21.0a	117.1	157.5
Total perennial grasses	167.1a	38.1b	124.1a	38.2b	40.9a	21.8b	55.1a	31.8b	348.6a	218.3b
Total sedges	0.0	0.0	0.1	0.0	0.0	0.0	T	0.0	0.0	0.0
Total annual grasses	1.2	1.7	5.8	13.4	1.9	4.3	0.6b	1.7a	9.8	15.1
Total perennial forbs	1.9	2.4	0.6	0.3	0.3	0.7	0.1	T	1.3	0.9

Table 14. (continued)

Plant Species/Class	Density 1979 With	Density 1979 Without	Density 1980 With	Density 1980 Without	Canopy Cover 1979 With	Canopy Cover 1979 Without	Canopy Cover 1980 With	Canopy Cover 1980 Without	Biomass[3] 1980 With	Biomass[3] 1980 Without
Total biennial forbs	0.3b	1.4a	0.3	0.6	0.3	0.7	T	0.1		
									928.1b[5]	1094.0a[5]
Total annual forbs	49.1	43.9	1560.8	1574.0	77.9	82.7	64.3	70.7		
Total half-shrubs (seeded and non-seeded)	1.1	1.6	0.8	2.1	0.1	0.3	0.2	0.3		
									5.9[6]	4.3[6]
Total shrubs (seeded and non-seeded)	0.1	0.4	0.2	0.2	0.1	0.1	0.1	T		
Total vegetation	220.8a	89.5b	1692.7	1628.8	121.5a	110.6b	120.5a	104.7b	1293.7	1432.6

1 For detailed information concerning mean plant canopy cover, density and biomass for each selected shrub/forb species by treatment (with and without concurrently seeded perennial grass mixture) in 1979 and 1980, see Appendix B, Tables 24 and 25 (canopy cover, 1979 and 1980, respectively), 26 and 27 (density, 1979 and 1980, respectively) and 28 (biomass, 1980 only)

2 Treatment values followed by different letters significantly different at 5% level (T-test)

3 Biomass was collected in 1980 only

4 Thickspike wheatgrass (Agropyron dasystachyum) + streambank wheatgrass

5 Total includes both annual and biennial forb values

6 Total includes both shrub and half-shrub values

and 27 (density, 1979 and 1980, respectively) and Table 28 (biomass, 1980 only).

As expected, in 1979, significantly higher densities of seeded perennial grass species were present in plots seeded with the perennial grass mixture than in plots not seeded with this mixture. Of seeded perennial grass species, thickspike wheatgrass, Indian ricegrass, western wheatgrass, and Canada bluegrass exhibited highest densities (in that order) and significantly greater densities in plots seeded with the perennial grass mixture. Prairie sandreed and switchgrass (*Panicum virgatum*) exhibited very low densities and no significant differences between treatments.

The presence of seeded species in plots not seeded with the perennial grass mixture was due to the presence of these species in the coversoil prior to study implementation. Western Energy Company seeded the entire area with their own seed mixture in April, 1978. The company seed mixture contained four of the six species utilized in the present study: thickspike wheatgrass, Indian ricegrass, western wheatgrass and prairie sandreed. Frequency and cover data collected for the area outside the study site showed the presence of all species except Canada bluegrass, prairie sandreed and switchgrass (see Tables 29 and 30, Appendix B).

Total non-seeded perennial grasses exhibited higher densities in plots not seeded with the perennial grass mixture, but this difference was not significant. Again, the presence of all unseeded species was due in part to the company's prior seeding effort, although volunteering of species originally present in the coversoil no doubt also occurred. Information concerning species present outside the study site can be found in Tables 29, 30 and 31, Appendix B.

Except for annual forbs, other life form categories exhibited much lower densities than did perennial grasses. These categories generally exhibited higher densities (although not significantly except for biennial forbs) in plots not seeded with the perennial grass mixture. Annual forbs, however, did not show greatly higher densities in plots not seeded to the perennial grass mixture.

Both total perennial grass and total vegetation categories had significantly higher densities in plots seeded with the perennial grass mixture. This was due to the performance of seeded perennial grasses in these plots.

Canopy cover data collected in 1979 exhibited similar trends to those of density with respect to plant species/classes and treatments. The higher density of total non-seeded perennial grasses in plots not seeded with the perennial grass mixture was mirrored by significantly higher canopy cover of such species under that treatment. However, annual forbs showed slightly higher cover values in plots not seeded with the perennial grass mixture, somewhat in contrast to density data relationships.

The trends established in 1979 with respect to plant species/classes and treatments were maintained in 1980 in terms of density. There were, however, density decreases in the total seeded perennial grass category in plots seeded with the perennial grass mixture. All seeded perennial grass species showed marked density decreases, except western wheatgrass, which showed an increase.

Total non-seeded perennial grasses maintained their densities in plots not seeded with the perennial grass mixture from 1979 to 1980, but exhibited a slight density decrease in plots seeded with the mixture. In 1980, plots not seeded with the perennial grass mixture showed a significantly higher non-seeded perennial grass density than plots seeded with the mixture.

Therefore, from 1979 to 1980 total perennial grass densities were maintained in plots not seeded with the perennial grass mixture while decreasing in plots seeded with the mixture.

Total annual forb density increased greatly in both treatments from 1979 to 1980. There were no significant differences in annual forb density between treatments in 1980. Total annual grasses also increased in density from 1979 to 1980 in both treatments, and exhibited higher densities under the without perennial grass mixture treatment. The other plant categories generally did not exhibit any marked increases or decreases from one year to the next.

The total vegetation category exhibited large increases in density from 1979 to 1980 in both treatments due to the influence of the annual forbs, and no significant difference between treatments was apparent by the second growing season.

Canopy cover data from 1979 to 1980 indicated that all perennial grass species/classes exhibited slight increases in cover from 1979 to 1980 over both treatments, while the other categories showed slight decreases. This resulted in total vegetation cover values which were very similar for both years.

Biomass data collected in 1980 generally supported density and cover relationships for that year. Total perennial grass biomass was significantly higher in plots seeded with the perennial grass mixture. This was due again to surviving seeded perennial grasses, which all showed significantly higher biomass under this treatment. In agreement with cover/density data, total non-seeded perennial grasses exhibited greater biomass in plots not seeded with the perennial grass mixture, although not significantly. Annual forb biomass in 1980 was significantly higher in the without perennial grass treatment. Due to this, total vegetation biomass was not significantly different between treatments.

Complete plant species lists for both inside and outside the study site enclosure in 1979 and 1980 are presented in Table 31 of Appendix B. Mean plant frequency comparisons by treatment for all species in 1979 and 1980 are presented in Tables 32 and 33, respectively, in Appendix B.

Shrub Ecotype Performance. Table 15 presents mean plant densities of commercially purchased (CP) versus locally collected ecotypes of winterfat and Nuttall's saltbush for 1979 and 1980.

In 1979 date 1, the locally collected Nuttall's saltbush ecotype showed significantly higher initial density than the commercially purchased ecotype. Densities for both the locally collected and commercially purchased ecotype were maintained through the second sampling date in 1979. The locally collected ecotype still showed significantly higher density than the commercially purchased ecotype in 1980 at date 1; however, it had suffered a much greater reduction in density. Density of the commercially purchased ecotype was better maintained from 1979 to 1980. This trend continued through the second (July) sampling date in 1980, by which time there was no significant difference in density between the two ecotypes.

There were no significant density differences between locally collected and commercially purchased ecotypes of winterfat in 1979 and 1980. However, despite of the lack of significant differences, the locally collected ecotype of winterfat did consistently exhibit higher densities than the commercially purchased ecotype.

Mean plant density, canopy cover and biomass data for all plant classes in plots seeded to commercially purchased (without perennial

Table 15. Mean plant density (plants/m^2) of commercially purchased (CP) versus locally collected ecotypes of winterfat and Nuttall's saltbush in 1979 and 1980, shrub and forb direct seeding study, Colstrip, Montana.[2].

Species	1979 Date 1 (June 11-19)	1979 Date 2 (Aug.18-23)	1980 Date 1 (May 27-30)	1980 Date 2 (July 30-Aug.1)
Winterfat (CP)[3]	0.07c	0.00c	0.00c	0.00b
Winterfat (local)	0.44c	0.44c	0.30c	0.30b
Nuttall's saltbush (CP)[3]	7.33b	6.89b	6.81b	4.89a
Nuttall's saltbush (local)	17.04a	16.96a	8.96a	4.74a

1 Of 3 replications, each containing a sample size (n) of 9

2 Values within a column followed by different letters are significantly different at 5% level (Duncan's Multiple Range Test)

3 For these species (commercially purchased seed), comparisons made using without perennial grass mixture treatment only

grass mixture treatment only) versus locally collected winterfat and Nuttall's saltbush ecotypes in 1979 and 1980 are presented in Table 16. Appendix B, Tables 34, 35, 36, 37 and 38 present more detailed information concerning density, canopy cover and biomass for 1979 and 1980.

In 1979, there were few significant differences in plant species/class density and cover between plots seeded with commercially purchased versus locally collected ecotypes for either winterfat or Nuttall's saltbush. An exception to this was the significantly higher Nuttall's saltbush densities in plots seeded with the locally collected ecotype. Annual forb (and because of this, total vegetation) cover was also higher in plots seeded to the local Nuttall's saltbush ecotype than in plots seeded to the commercially purchased ecotype.

In 1980, there were no significant differences in plant class density or biomass between plots seeded to commercially purchased and locally collected Nuttall's saltbush ecotypes. However, annual forb canopy cover was still significantly greater in local ecotype plots, which was largely responsible for higher total vegetation cover in those plots.

In contrast to 1979, a number of significant differences in density and canopy cover between commercially purchased and local winterfat ecotype seeded plots became apparent in 1980. Annual forb density and canopy cover were higher in local ecotype seeded plots;

Table 16. Summary of plant density (plants/m^2), canopy cover (%) and biomass (kg/ha) for commercially purchased (CP) versus locally collected (L) winterfat and Nuttall's saltbush in 1979 and 1980, shrub and forb direct seeding study, Colstrip, Montana.[2]

Parameters/Plant Class	1979 Plots Seeded To: Atnu(CP)	Atnu(L)	Cela(CP)	Cela(L)	1980 Plots Seeded To: Atnu(CP)	Atnu(L)	Cela(CP)	Cela(L)
A. Density (plants/m^2)								
Total Perennial Grasses	32.6	29.0	27.6	33.0	36.9	26.7	35.1	40.4
Total Annual Grasses	1.2	1.9	0.4	0.7	6.7	24.8	6.7	20.0
Total Perennial Forbs	1.5	1.4	1.5	1.5	0.4	0.0	0.0	0.0
Total Biennial Forbs	1.4	0.4	0.0	0.4	0.4b	0.0b	0.0b	2.2a
Total Annual Forbs	55.1	49.3	40.8	51.1	1799.7b	1837.8b	1167.8c	2291.1a
Total Half Shrubs	7.4b	14.1a	0.4c	1.1c	8.9a	10.0a	0.8b	0.7b
Total Shrubs	0.4	0.7	0.0	0.8	0.0	0.0	0.0	0.0
Total Vegetation	99.6	96.8	70.7	88.6	1853.0b	1899.3b	1210.4c	2354.4a
B. Canopy Cover (%)								
Total Perennial Grasses	15.9	19.1	16.4	22.7	30.8	20.8	31.2	31.5
Total Annual Grasses	1.4ab	3.8a	0.9b	Tb	0.9	2.7	0.7	1.8
Total Perennial Forbs	0.5	0.2	0.2	0.2	0.1	0.0	0.0	T
Total Biennial Forbs	0.6	0.1	0.0	0.1	Tb	0.0b	0.0b	0.1a
Total Annual Forbs	79.3c	91.6a	90.0ab	81.7abc	67.3b	92.9a	66.2b	88.0a
Total Half Shrubs	0.9a	1.5a	0.1b	0.2b	1.1	1.2	0.5	0.2
Total Shrubs	T	1.0	0.0	T	0.0	0.0	0.0	T
Total Vegetation	98.6b	117.3a	107.6ab	104.9ab	100.2b	117.6a	98.6b	121.6a

Table 16. (continued)

Parameters/Plant Class	1979 Plots Seeded To: Atnu(CP)	Atnu(L)	Cela(CP)	Cela(L)	1980 Plots Seeded To: Atnu(CP)	Atnu(L)	Cela(CP)	Cela(L)
C. Biomass(kg/ha)								
Total Perennial Grasses	--	--	--	--	207.0bc	262.5b	116.8c	430.1a
Total Annual Grasses	--	--	--	--	5.3	41.9	1.5	19.2
Total Perennial Forbs	--	--	--	--	0.0	0.0	0.0	0.9
Total Biennial/Annual Forbs	--	--	--	--	1322.7	1435.4	1272.7	1243.4
Total Shrubs/Half-Shrubs	--	--	--	--	21.1ab	34.6a	1.5b	14.3ab
Total Vegetation	--	--	--	--	1556.1abc	1774.4a	1392.5c	1707.9ab

1 For detailed information concerning mean plant density, canopy cover, and biomass for commercially purchased (CP) versus locally collected (L) winterfat and Nuttall's saltbush in 1979 and 1980, see Appendix B, Tables 31 and 32 (density, 1979 and 1980, respectively), Tables 33 and 34 (canopy cover, 1979 and 1980, respectively) and Table 35 (biomass, 1980 only)

2 Values for each year (1979 and 1980) followed by different letters significantly different at 5% level (Duncan's Multiple Range Test)

3 Biomass was collected in 1980 only

4 T = trace (0.1 % cover)

somewhat surprisingly, this relationship was not reflected in biomass data. This density/cover relationship was largely responsible for higher total vegetation density and canopy cover in plots seeded to the local ecotype. Biomass data revealed another somewhat perplexing difference between winterfat ecotype plots. Although density and cover of perennial grasses were insignificantly different between plots seeded to the two winterfat ecotypes, perennial grass biomass was significantly greater in the local ecotype seeded plots. This was largely responsible for the higher total vegetation biomass in the local ecotype plots. Reasons for these seeming conflicts between density/cover and biomass data patterns between the winterfat ecotype plots are not known, but could involve sampling error.

The plant community data of Table 16 (and Tables 34 - 38, Appendix B) indicate few significant differences in density and canopy cover between plots seeded with commercially purchased and locally collected ecotypes for either species in 1979. In 1980 plots seeded to locally collected winterfat showed significant differences in density, cover and/or biomass of annual forbs and/or perennial grasses, which resulted in higher total vegetation density, cover and biomass. For Nuttall's saltbush, seeded plot differences occurred only in annual forb cover. Reasons for these differences in growth of species other than the seeded shrubs between ecotype plots in 1980 are not known. However, these differences must be kept in mind in interpreting the performance of the two ecotypes of each shrub species. It would appear that the local winterfat ecotype and, to some extent, the local Nuttall's saltbush ecotype were subjected to a greater degree of competition stress from other species in 1980. If this difference in competition stress had not occurred, it is conceivable that the superiority of the local ecotypes would have been accentuated.

Tables 39 and 40, Appendix B present frequency data for plots seeded to commercially purchased versus locally collected Nuttall's saltbush and winterfat in 1979 and 1980, respectively. Mean plant height comparisons between winterfat and Nuttall's saltbush ecotypes are given in Table 23, Appendix B.

Supplemental Field Vegetation Analyses

Comparison of Annual Grass Abundance

Annual grass density data collected in 1979 for both inside and outside the enclosure (Table 17) indicated significantly greater densities of annual grasses outside the enclosure. Of the annual grasses, cheatgrass was most abundant followed by Japanese brome.

Effect of Seeding Date on Winterfat Establishment

The effect of seeding dates on mean winterfat density (plants/m^2) in 1979 and 1980 is presented in Table 18. These data were collected from the present study (fall seeding date) and M.A.E.S. Reclamation

Table 17. Comparison of mean annual grass density (plants/m^2), outside versus inside study site enclosure, shrub and forb direct seeding study, Colstrip, Montana, 1979.

Plant Species/Class	Outside Enclosure[2] (July 11)	Inside Enclosure[2] (July 23 to August 5)
Japanese brome (*Bromus japonicus*)	41.3 a	0.1 b
Cheatgrass (*Bromus tectorum*)	107.5 a	0.8 b
Total annual grasses (*Bromus spp.*)	148.8 a	0.9 b

[1] Values within rows followed by different letters are significantly different at 5% level (T-test)

[2] Of 4 replications, each containing a sample size (n) of 10

[3] Sample size (n) = 396

Table 18. Effect of seeding date[1] on mean winterfat density(plants/m^2), irrigation study, and shrub and forb direct seeding study, Colstrip, Montana, 1979 and 1980.[2, 5]

	Seeding Date		
Year	Spring[3]	Summer[3]	Fall[4]
1979	1.21 a	0.00b	0.11 b
1980	1.17 a	0.00b	0.07 b

1 Spring = April, 1979; Summer = June, 1979; Fall = September, 1978

2 Values within rows followed by different letters signficantly different at 5% level (Studentized-Newman-Keuls Test)

3 Of 3 replications, each containing a sample size (n) of 12 (irrigation study).

4 Sample size (n) = 81 (includes all plots in which winterfat was seeded (shrub direct seeding study)

5 Sampling dates as follows: 1979, Spring = September 2 (Date 2), Summer = September 3, Fall = August 18-23; 1980, Spring = July 28, Summer = July 28, Fall = July 30 - August 1 (Date 2)

Research's Irrigation Study (spring and summer seeding dates) (Young and DePuit, 1981).

In 1979 (the year of establishment for all seeding dates), significantly higher winterfat densities existed in spring than in summer or fall seeded plots. These results occurred despite the fact that higher seeding rates were utilized in the fall-seeded plots (2.45 kg/ha average seeding rate) than in spring seeded plots (0.338 kg/ha). These relationships between fall, spring and summer seeding dates for winterfat persisted during the second (1980) growing season. No difference existed between years in terms of winterfat density by treatment comparisons.

Comparisons of winterfat mean plant heights by seeding date treatment (spring versus summer) for the Irrigation Study in 1979 and 1980 are presented in Table 41, Appendix B; again fall seeded winterfat plant heights are given in Table 13 (Appendix B). No statistical comparisons were conducted for height data by seeding date due to limited sample numbers for fall and summer seeding date treatments.

DISCUSSION

Evaluation of Field Performance Among Seeded Shrub and Forb Species

Initial Establishment

All seeded shrub and forb species exhibited low initial seedling densities and establishment percentages. These unsatisfactory results can be attributed to several factors: 1) absence of favorable environmental conditions for proper seed germination and initial establishment; 2) improper seeding dates; and 3) poor seed quality.

Factor 1) Absence of Favorable Environmental Conditions for Proper Seed Germination and Initial Establishment. Precipitation during the April through July period, the season of characteristically highest precipitation and plant growth (Sindelar et al., 1973; Hurtt, 1951), was abnormally low during both 1979 and 1980. Compounding this low spring precipitation was the fact that sandy soils, such as those at the study site, have relatively high percolation rates and low water holding capacities (Redmann, 1975; Salter and Williams, 1965). In times of limited precipitation, as in 1979 and 1980, such soils are especially droughty.

Fluctuations in precipitation are characteristic of semi-arid areas. Since available soil moisture is the single most limiting factor controlling plant growth in this region, a difference of only one inch of precipitation during the growing season can significantly affect revegetation potential (Packer and Aldon, 1978; Brown, 1977). Several authors (Bjustad, Yamamoto and Uresk, 1980; McKell and Van Epps, 1980) have recommended that direct seeding of shrubs not be implemented in areas receiving less than 25 cm of precipitation, annually. In 1979 the present study area received only 22.34 cm total precipitation, and although there was above average precipitation in September, 1978, it is difficult to say how much of this moisture was stored near the soil surface over winter due to the sandy nature of the soil (Redmann, 1975).

This below average precipitation was one of the factors contributing to the poor initial establishment of seeded shrub and forb species. Adequate water has been demonstrated to be an important requirement for proper germination for at least four of the shrub and forb species, i.e. big sagebrush, winterfat, cudweed sagewort, and Nuttall's saltbush (Vories, 1981; Eddleman, 1977). Adequate water is also important for germination of skunkbush sumac and rubber rabbitbrush, but may not play as large a role as other environmental factors, such as temperature and light (Brinkman, 1974; Deitschman, Jorgensen and Plummer, 1974).

Even if germination is successful, newly developing seedlings are highly susceptible to drought conditions. This is especially true for species possessing small seedlings such as big sagebrush, cudweed sagewort, and rubber rabbitbrush (Plummer et al., 1968). These species exhibited very poor initial establishment in the present study.

In this study, Nuttall's saltbush and skunkbush sumac possessed seedlings which were best able to withstand the conditions of drought during the initial establishment period. This can probably be attributed to the fact that these species possess seedlings which are larger than the other species being evaluated, and therefore are better able to withstand drought conditions. However, for winterfat and rubber rabbitbrush, factors other than drought alone (e.g., seeding date and/or poor seed quality) contributed to poor establishment. Additionally, rubber rabbitbrush characteristically has difficulty overcoming seed dormancy (Deitschman et al., 1974).

Factor 2) Improper Seeding Dates. Seeding date comparisons for winterfat in the present study revealed higher mean plant densities of this species when seeded in early spring (April) than in early fall (September) or summer (June).

Under natural conditions, seeds of winterfat germinate best following an after-ripening period involving exposure to short periods of cool or freezing temperatures (Stevens et al., 1977). Satisfactory germination will also result if the seed has been stored for at least 2 to 3 months prior to seeding (Springfield, 1974). Once after-ripening or aging has occurred, germination studies have indicated that a high rate of germination can occur within 24 hours following short warm periods accompanied by adequate moisture conditions (Stevens et al., 1977). Complicating this precocious seed germinative nature is the fact that subsequent frost will kill newly developing seedlings. The seedlings are highly susceptible to frost damage until leaves develop (Stevens et al., 1977). This precludes seeding in early fall, when such conditions are likely to exist.

Given the nature of seed and newly developing seedlings of winterfat, many authors have suggested either late fall/early winter or early spring as optimal seeding dates (Plummer et al., 1968; Eddleman, 1977; Stevens et al., 1977; Springfield, 1974).

The present study supports the findings of these authors. Fall seeding in this study took place on September 30. It is believed that favorable environmental conditions at this time, i.e. above average precipitation and warm temperatures, may have resulted in high winterfat seed germination during fall. However, following germination, unfavorable environmental conditions (frost, etc.) typical of fall could have ultimately destroyed the newly developing seedlings. This would account for the low mean plant densities observed the following spring for this seeding date.

Late fall/winter or early spring seeding (of seed aged at least 2 to 3 months) will provide the seed with an after-ripening period needed to break dormancy and favorable environmental conditions in spring for germination and early seedling growth. Also, fall seed germination is prevented. Summer seeding is unsatisfactory due to lack of available soil moisture needed for proper germination.

Species other than winterfat were probably not affected by the early fall seeding date because they possess different germinative characteristics. These species require cool, moist stratification periods, necessitating overwintering (Vories, 1981).

Factor 3) Poor Seed Quality. The seed analyses confirmed the necessity of accurate analysis for seed-lots of direct-seeded shrubs prior to definition of bulk seeding rates. In this study, lack of seed analysis data at seeding resulted in widely variable (and often low) actual numbers of pure live seeds per unit area among shrubs and forbs seeded, due both to deviations in numbers of seeds per kilogram from literature values and wide variations among species in percent purity and viability. These results also confirmed the inherently low percent seed purity and/or viability inherent to many native shrub species, which may often necessitate increased seeding rates. This was apparent for commercially purchased and locally collected winterfat, rubber rabbitbrush and big sagebrush which were seeded at an actual rate much lower than initially calculated. This probably contributed to reduced initial establishment densities.

Other Factors. Big sagebrush was found to be uniformly distributed in sagebrush seeded plots as well as those not seeded with this species. Big sagebrush seedlings were also present outside the study site; 61 plants were observed at distances up to 100 meters and farther from the site in 1980, and frequency data collected outside the study site resulted in a value of 1.25 percent (Table 29, Appendix B). Based on this information, it is believed that residual seed of this species was present in the coversoil (topsoil) prior to seeding. The apparent low success of initial germination of applied sagebrush seed is rather perplexing, although several causes for this are possible. Failure to overcome seed dormancy by spring, 1979 may have occurred, or if dormancy was overcome and seeds germinated, seedlings may not have been able to withstand subsequent droughty conditions due to their small size. Another possibility involves the fact that big sagebrush is highly variable genetically (MacArthur, Giunta and Plummer, 1974); the seed utilized in the present study may have been of an ecotype not adapted to the area or unable to withstand the drought conditions present.

It is not unexpected that seed of big sagebrush was present in the coversoil, since direct-take topsoil was utilized, which would tend to promote germination of residual seed of a great many species native to the Colstrip area (King, 1980). On native range sites big sagebrush re-invades burned over sites primarily through seed residual in the topsoil (Mueggler, 1956). Tables 29 and 30 in Appendix B contain information concerning species present in the coversoil.

Subsequent Growth

The dry conditions which prevailed during the two years of the study allowed only the most drought tolerant species and/or ecotypes to survive. By the end of the second growing season, skunkbush sumac, commercially purchased winterfat, rubber rabbitbrush and cudweed sagewort suffered complete mortality. Conversely, big sagebrush, commercially purchased Nuttall's saltbush, locally collected Nuttall's saltbush, and locally collected winterfat all survived and possessed survival percentages of 73, 68, 67, and 28, respectively. Of these species, big sagebrush appeared to have the best performance and was best able to maintain its initial densities under both treatments throughout the droughty period of this study.

Big sagebrush, winterfat and Nuttall's saltbush are highly drought tolerant, once established. These xerophytic species are characteristically able to survive extremely low water potentials for extended periods (Brown, 1977). An interesting phenomenon was observed for all these species as drought conditions intensified beginning in July 1979 (refer to phenological comments presented in Table 21, Appendix A). Larger lower leaves were shed and gradually replaced by smaller leaves which developed at the tops of the plants. This appears to be a drought resistance mechanism. Orshan (1972) and Kozlowski (1971) have observed this phenomenon in desert plant species, and believe it to be a means of increasing water economy through leaf surface area reduction.

Competition Effects on Shrub and Forb Establishment and Growth

Three shrub/forb species, Nuttall's saltbush, skunkbush sumac and cudweed sagewort, exhibited density differences between treatments (with and without the concurrently seeded perennial grass mixture) in terms of initial establishment.

Nuttall's saltbush and skunkbush sumac exhibited higher densities in plots not concurrently seeded with the perennial grass mixture. Although these differences were not statistically significant at the 5 percent level, they were at the 10 percent level suggesting that seeding these species alone rather than with a perennial grass mixture results in better stand establishment.

Cudweed sagewort, conversely, showed significantly better initial establishment when seeded with the perennial grass mixture than when seeded alone. This was not expected, and was probably due to difficulties in direct seeding. The bulk seed contained a great amount of fibrous material which clung to the seeds to such an extent that uniform seed distribution throughout seeded plots was impossible. The seed could not be separated from this material in the field, and clumps of the seed-fiber mass tended to be distributed instead of single seeds. This seed distribution pattern was more pronounced in plots seeded to cudweed sagewort alone, since agitation with concurrently seeded perennial grass seeds tended to improve breakup of shrub seed-fiber masses. Since seed-fiber masses contained many seeds and the seed-fiber mass problem was greater in plots seeded to cudweed sagewort alone, it is highly probable that many seeds never achieved sufficient contact with the soil for proper germination. It is believed that uneven stands of this species in plots where seeded alone was the result, thus accounting for reduced overall seedling densities.

Nuttall's saltbush suffered a gradual reduction in density over the two growing seasons, and by the end of the second season its density was approximately half that of initial establishment for both treatments. However, it still maintained a higher density when seeded alone than when seeded with a perennial grass mixture. This demonstrates the advantage of seeding this species alone rather than with perennial grass mixtures in terms not only of initial establishment, but also in terms of subsequent survival.

Following initial establishment, cudweed sagewort exhibited a much greater rate of density loss in plots seeded with the perennial grass mixture. This can be attributed to increased competition in those plots seeded with the perennial grass mixture, which appears to demonstrate the advantage of seeding this species alone in terms of subsequent growth and survival.

As noted previously, Nuttall's saltbush exhibited the best performance of all species in terms of both initial establishment and subsequent drought tolerance. All other species, except skunkbush sumac, exhibited various problems in initial establishment and were not present in densities sufficient to allow meaningful initial or ultimate comparisons between the seeded alone/ seeded with perennial grass treatments.

Skunkbush sumac appeared to be most severely affected by drought conditions. After its initial establishment, it exhibited a great reduction in density in both treatments, and by the beginning of the 1980 growing season had suffered complete mortality. However, the initial performance of this species when seeded alone may well have persisted if more favorable climatic conditions for subsequent survival and growth had occurred.

Substantially higher perennial grass density, cover and biomass occurred in plots seeded with the perennial grass mixture plus shrubs than in plots seeded with shrubs alone in 1979 and 1980. The increased competitive stress in plots concurrently seeded with both shrubs and grasses no doubt induced the superiority of skunkbush sumac and Nuttall's saltbush initial establishment in plots where seeded alone, as well as the ultimate superiority of Nuttall's saltbush in plots where seeded alone. Lack of such differences in shrub density between seeding method treatments for other species is related to some or all of the following factors: initially poor germination and/or establishment of shrubs due to the absence of favorable environmental conditions for proper seed germination and initial establishment, poor seed quality and improper seeding dates; and excessive shrub mortality due to protracted drought.

Substantial growth of volunteer "weedy" species (most notably Russian thistle (*Salsola kali*) and summer cypress (*Kochia scoparia*)) occurred both in plots seeded to shrubs alone and in plots seeded to shrubs and perennial grasses concurrently. There was also some volunteering from perennial grass species from seeds residual in the coversoil and from prior seeding by Western Energy Company. Volunteer perennial grass species exhibited significantly higher density, cover and biomass in plots seeded to shrubs alone. This was due to the absence of competitive stress from seeded perennial grasses in these plots. "Weedy" annual species also usually exhibited higher density, cover and biomass in plots seeded to shrubs alone, but with the exception of 1980 biomass values these differences were not significant. By 1980, the generally increased volunteer growth in plots seeded to shrubs alone led to no significant differences in total vegetation density and biomass in plots seeded with and without the perennial grass mixture. This may have caused competition stress on seeded shrubs to have been more similar between treatments than desired, and may have been a factor causing the lack of significant differences in shrub performance between treatments.

Density data revealed much higher annual grass (cheatgrass and Japanese brome) values outside as opposed to inside the study site enclosure. Most cheatgrass and Japanese brome seed produced in spring will germinate the following fall, if precipitation is adequate (Robocker, Gates and Kerr, 1965; Hull and Stewart, 1948). It is believed that annual grass seed underwent nearly complete germination during September, 1978 due to that month's above average precipitation.

Western Energy Company seeded the entire area, including the future study site, to its own seed mixture in April, 1978. The present study site was chisel plowed and seeded on the 29th and 30th of September, 1978. Fall plowing is an effective annual grass control method if germination is completed by this time, which explains the difference in annual grass densities outside and inside the enclosure.

Holmgren (1956) studied the competitive effects of broad leaved, summer-annual weeds versus cheatgrass on bitterbrush seedling densities. He found that fall-germinated cheatgrass, because of its advanced development at the time of bitterbrush germination, was a more severe competitor than spring-germinating cheatgrass. He also found that few bitterbrush seedlings were able to survive the first summer in plots with severe cheatgrass competition and that the effect of this competition generally manifested itself early in the growing season coinciding with the period of rapid growth for cheatgrass. Bitterbrush seedlings were better able to compete with broadleaved, summer-annual weeds than cheatgrass. The competitive effect of these broadleaved, summer-annuals manifests itself later in the growing season during their period of active growth. Although broadleaved, summer-annual weeds were less severe competition for bitterbrush seedlings, their inhibiting influence resulted in stands of low-vigor bitterbrush plants that continued to die off for 2 to 3 years. Plummer et al. (1968) stated similar findings. These findings indicate the benefit of reducing annual weed and grass competition in establishing shrub seedlings. They also show that fall-germinating cheatgrass is an especially aggressive competitor compared to spring-germinating cheatgrass and broadleaved, summer-annual weeds. Fortunately, the annual grass population was greatly reduced in the present study due to the cultivation practices employed.

Wali (1980) reported the findings of several studies dealing with plant succession on topsoiled stripmine lands. He reported that the broadleaved, summer-annual weeds summer cypress and Russian thistle showed similar growth patterns. Both species were most dominant the first year, showed sharp declines with time, and were totally eliminated by the fourth year. Robust growth forms and low densities occurred the first year of colonization. This was followed by stunted growth and increased plant density prior to subsequent complete disappearance. This growth pattern was evident in the present study for these species (Table 14). If this study had been monitored for a longer period, it is felt that a large scale reduction of these species would have been observed.

The findings of the present study suggest, at least for certain of the shrubs evaluated, the importance of seeding shrubs alone in terms of promoting initial establishment and subsequent growth. However, results also indicate that it is important not only to remove seeded perennial grass competition, but volunteer winter-annual grass and summer-annual forb competition as well. Fortunately, late fall/early winter seeding of shrubs may reduce winter-annual grass competition through seedbed preparation. Competition from broadleaved, summer-annual weeds is more difficult to remove. This competition may disappear in three to four years (Wali, 1980). It appears that one way to initially compensate for this competition is to apply high numbers of pure live shrub seeds to the soil. This may allow establishment of a number of seedlings sufficient to yield acceptable ultimate shrub densities following the expected initial shrub dieback due to weed competition during the interim period prior to eventual weed elimination.

Performance Evaluation of Local Versus Commercially Purchased Ecotypes

The locally collected Nuttall's saltbush ecotype performed better in terms of initial establishment than the commercially purchased ecotype. However, following initial establishment, the locally collected Nuttall's saltbush ecotype exhibited a much greater rate of density loss, and by the end of the second growing season showed densities equal to the commercially purchased ecotype.

Initially, it was believed that this difference in performance was due solely to adaptation differences that existed between the two ecotypes. The commercially purchased ecotype was obtained from seed sources located in southeastern Montana, but in an area possessing a lower annual precipitation than the experimental area. Therefore, it was felt that the commercially purchased ecotype may have been better adapted to the drought conditions which existed during the two year period of this study.

However, further analysis revealed higher cover values for total vegetation in plots seeded with locally collected Nuttall's saltbush in 1979 and 1980. Annual forbs were primarily responsible for this. Increased competition from annual forbs such as Russian thistle and summer cypress may have resulted in the higher rate of density loss exhibited by the locally collected ecotype. Holmgren (1956), in a study which analyzed the effect of competition from annuals on bitterbush density, found that broadleaf, summer-annuals had an inhibiting influence upon bitterbush seedlings which did not manifest itself until later in the first growing season. The ultimate result of annual forb competition was stands of low-vigor bitterbrush plants that continued to die-off for 2 or 3 years. These findings parallel the results of the present study showing an increased rate of density loss for locally collected Nuttall's saltbush during the second growing season, and suggest that differences in rate of mortality between the two ecotypes may have been due to chance differences in weed invasion/competition rather than to ecotypic differences.

These data patterns suggest the strong benefit of the use of locally collected ecotypes of Nuttall's saltbush in terms of initial establishment. The higher survival of the commercially obtained ecotype under protracted drought was attributed to effects of increased annual forb competition within the local ecotype plots. If annual forb cover had been similar in both locally collected and commercially purchased ecotype plots, the results may have been altered so that the higher initial densities exhibited by the local ecotype would have been maintained during the second growing season.

There were no significant differences in density between locally collected and commercially purchased ecotypes of winterfat in 1979 and 1980. This was considered a result of an early fall seeding date and low numbers of pure live seeds per square foot in both cases. However, although there were no significant differences between the two, the locally collected ecotype of winterfat did appear to perform better than the commercially purchased ecotype. This was partially, but not completely, due to the fact that locally collected seed was inadvertently applied at twice as many pure live seeds per square meter as commercially purchased seed (Table 8). The local winterfat ecotype largely maintained its initial seedling density throughout the drought conditions of 1979 and 1980, whereas the commercial ecotype exhibited complete mortality. This occurred even under conditions of significantly increased volunteer perennial grass and annual forb competition in plots seeded to the local ecotype. Thus, although differences were not statistically significant, the pattern of data tends to support the premise that the use of local shrub ecotypes for direct seeding of winterfat, would benefit initial establishment and ultimate survival.

The results of this study verify the importance of using shrub seed sources that are close to the area of intended seeding. If this is impossible, seed should be obtained from sources that possess similar environmental conditions. Plummer et al. (1968) contend that selecting adapted ecotypes is just as important as choosing the shrub species. These authors have observed shrub seedings that have completely failed due to improper ecotype selection. Four of the species used in the present study, big sagebrush, rubber rabbitbrush, skunkbush sumac and winterfat, have been noted in the literature to possess high numbers of ecotypes, and several authors have recommended the use of locally adapted ecotypes (Plummer et al., 1968; Swenson, 1957; Van Epps, 1974; Stevens et al., 1977).

It is not possible to evaluate the performance of varied ecotypes for the other shrub/forb species used in this study, but based on literature information and results presented here, it does appear that use of locally collected seed can be recommended for these species as well. Certainly, more study into this subject is warranted.

Limitations of Present Study and Future Research Needs

Two of the most serious shortcomings of this study included lack of a low shrub seeding rate control against which to evaluate effects of the elevated seeding rates employed and the unavailability of detailed pure live seed analysis prior to derivation and field implementation of bulk seeding rates. Although it is felt that "heavier" seeding rates may indeed be desirable to promote adequate establishment of certain shrub species on mined lands, more research is obviously needed to substantiate or disprove this. Also, in light of the overriding adverse impacts of drought on results of this study, it is strongly urged that accelerated research evaluations on feasibility and effects of temporary, initial irrigation on success of shrub direct seeding be conducted.

Possible study improvements include the incorporation of low, medium and high seeding rate treatments, i.e. 10, 20 and 40 seeds per square foot, respectively. Locally collected ecotypes would be included as a treatment for all shrub/forb species and pure live seed percentages would be ascertained prior to seeding so that proper (PLS) seeding rates could be obtained. The grasses would be seeded utilizing the same species mixture, seeding rates and competition treatments (with and without concurrently seeded perennial grass species). Larger plots would be used, implementing a split plot design allowing irrigation and its absence to be used as treatments applied to each plot half, respectively. Late fall or early winter seeding dates would be used for all species.

CONCLUSIONS

The following conclusions are possible based on results of this study.

1. For meaningful derivation of shrub direct seeding rates, it is essential to conduct accurate analyses of seedlots for numbers of seeds per pound, seed purity and seed viability. Much variability in the above characteristics can be expected not only among species but also within a given species. Relatively low purity and/or viability may often be expected with many native shrubs, as was the case with big sagebrush, rubber rabbitbrush, winterfat and cudweed sagewort in the present study.

2. For Nuttall's saltbush and (probably) winterfat, use of seed of local ecotypes may be recommended in terms of improved initial seedling establishment and ultimate survival.

3. For Nuttall's saltbush and skunkbush sumac, seeding alone (without concurrently seeded perennial grasses) may be recommended to improve initial seedling establishment; for Nuttall's saltbush, ultimate survival was also enhanced by seeding alone.

4. In terms of initial establishment, among shrub species direct seeded in the fall, locally collected and commercially purchased Nuttall's saltbush exhibited greatest success, followed by skunkbush sumac. Marginal initial establishment was shown by big sagebrush,

winterfat, rubber rabbitbrush and cudweed sagewort.

5. In terms of seedling survival during two years of drought following direct seeding, commercially purchased and locally collected Nuttall's saltbush, big sagebrush and locally collected winterfat exhibited highest numbers of surviving seedlings. Skunkbush sumac, rubber rabbitbrush, cudweed sagewort and commercially purchased winterfat seedlings exhibited complete drought-induced mortality.

6. Late fall/early winter or spring seeding dates are recommended for winterfat. These seeding dates prevent early seed germination, provide an after-ripening period necessary for proper germination and provide the newly developing seedlings with favorable environmental conditions of sufficient duration for establishment.

7. Serious shortcomings of this study included lack of a "low" shrub seeding rate control against which to evaluate effects of the elevated seeding rates employed. Although it is felt by the author that "heavier" seeding rates may indeed be desirable to promote adequate establishment of certain shrub species on mined lands, more research is obviously needed to substantiate or disprove this.

8. In light of the overriding adverse impacts of drought on results of this study, it is strongly urged that accelerated research evaluations on feasibility and effects of temporary, initial irrigation on success of shrub direct seeding be conducted.

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APPENDICES

APPENDIX A

Table 19. Mean surface (0-20 cm) volumetric soil moisture content from July 16 to September 5, 1979, shrub and forb direct seeding study, Colstrip, Montana.

Date	Actual Soil Moisture[1] Content (%)
July 16	10.4
July 31	11.9
August 13	10.9
August 20	11.2
September 5	11.2

[1] Sample Size (n) = 12 for each date; the equation Y = 1.2665 + 6.55 was used to calculate actual soil moisture content from probe collected data

Table 20. Volumetric soil moisture content at various soil depths from May 1 to October 21, 1980, shrub and forb direct seeding study, Colstrip, Montana.

		Actual Soil Moisture Content (%)			
Soil Depth (cm)	May 1	May 28	July 1	Sept. 9	Oct. 21
15	13.9	11.3	7.9	-1.9	19.4
30	21.9	18.8	15.3	0.3	15.1
45	19.9	17.7	16.4	3.1	13.3
60	17.8	16.6	16.0	6.7	14.0
75	17.3	17.4	17.3	12.5	14.4
90	19.9	21.5	21.1	14.4	18.7
120	20.0	19.6	20.3	19.9	18.9
150	23.8	23.0	23.6	19.9	22.7
180	19.7	19.1	19.4	20.9	18.2
210	19.1	18.7	18.9	18.5	18.0

[1] The equation Y = 33.93x - 2.4 was used to calculate actual soil moisture content form probe collected values

[2] Soil moisture was not taken between July 1 and September 9 due to improper probe function

Table 21. Phenological pattern data for all observable plant species in 1979, shrub and forb direct seeding study, Colstrip, Montana.

Plant Species	Date 1 (July 1) Phenological Stage	Comments
Perennial Grasses:		
<u>Agropyron cristatum</u>	V4R0/V5R1-2	
<u>Agropyron dasystachyum</u>	V4R0/V5R0-3	
<u>Agropyron smithii</u>	V4R0/V5R3	
<u>Agropyron trachycaulum</u>	V4R0-1/V5R1-2	
<u>Agropyron trichophorum</u>	V4R0/V5R1-2	
<u>Calamovilfa longifolia</u>	V4R0	
<u>Oryzopsis hymenoides</u>	V4R0-5/V5R0-2	
<u>Poa compressa</u>	V4R0-1/V5R2	

Table 21 (continued)

Plant Species	Date 2 (July 17) Phenological Stage	Comments
Perennial Grasses:		
Agropyron cristatum	V4RO/V5R2-3/V6	plants drying out
Agropyron dasystachyum	V4RO	plants drying out
Agropyron smithii	V4RO/V5R1-3	
Agropyron trachycaulum	V4RO/V5R1-4/V6RO	plants drying out-dying back
Agropyron trichophorum	V5R1-4	leaves drying out
Calamovilfa longifolia	V4RO	
Oryzopsis hymenoides	V4RO/V5RO-5	plants drying out
Poa compressa	4RO/V5R3-4/V6RO	leaves wilting-drying out

Table 21 (continued)

Plant Species	Date 3 (August 7) Phenological Stage	Comments
Perennial Grasses:		
<u>Agropyron</u> <u>Cristatum</u>	V4R0/V5R4-6/V6R4-6	plants showing signs of die-back
<u>Agropyron</u> <u>dasystachyum</u>	V4R0/V6R0	plants showing signs of die-back
<u>Agropyron</u> <u>smithii</u>	V4R0/V6R0	plants showing signs of die-back
<u>Agropyron</u> <u>trachycaulum</u>	V4R0/V5R0-6/V6R0-6	plants dying back
<u>Agropyron</u> <u>trichophorum</u>	V4R0/V5R1-5/V6R0-5	plants dying back
<u>Calamovilfa</u> <u>longifolia</u>	V4R0/V6R0	leaves drying out/ plants starting to die-back
<u>Oryzopsis</u> <u>hymenoides</u>	V4R0/V5R1-6/V6R1-6	leaves drying out/ plants starting to die-back
<u>Poa</u> <u>compressa</u>	V4R0/V5R5/V6R0-6	plants starting to die-back

Table 21 (continued)

Plant Species	Date 4 (September 1) Phenological Stage	Comments
Perennial Grasses:		
Agropyron cristatum	V6R6	plants dying back - entering dormancy
Agropyron dasystachyum	V6R0	plants dying back - entering dormancy
Agropyron smithii	V6R0	plants dying back - entering dormancy
Agropyron trachycaulum	V6R0-6	plants dying back - entering dormancy
Agropyron trichophorum	V6R5, 6	plants dying back - entering dormancy
Calamovilfa longifolia	V6R0	plants dying back - entering dormancy
Oryzopsis hymenoides	V6R0-6	plants dying back - entering dormancy
Poa compressa	V6R0-6	plants dying back - entering dormancy

Table 21. (continued)

Plant Species	Date 1 (July 1) Phenological Stage	Comments
Poa sandbergii	V4R0	
Stipa comata	V4R0	
Stipa viridula	V4R0	
Annual Grasses:		
Bromus japonicus	V4R0-2/V5R1-4	
Bromus tectorum	V5R4-5	
Wintergraze	V4R0-1/V5R1-2	
Perennial Forbs:		
Ambrosia psilostachya	V4R0	
Artemisia dracunculus	V4R0	
Artemisia ludoviciana	V4R0	leaves wilting
Astragalus cicer	V2R0/V4R0	leaves wilting

Table 21. (continued)

Plant Species	Date 2 (July 17) Phenological Stage	Comments
Poa sandbergii	V4R0	
Stipa comata	V4R0/V6R0	plants beginning to die back/leaves drying out
Stipa viridula	V4R0	
Annual Grasses:		
Bromus japonicus	V4R0/V5R4-6/V6R5-6	
Bromus tectorum	V5R5-6	
Wintergraze	V5R1-4	
Perennial Forbs:		
Ambrosia psilostachya	V4R0/V6R0	leaves wilting/plants dying back
Artemisia dracunculus	V4R0	
Artemisia ludoviciana	V4R0	leaves wilting
Astragalus cicer	V4R0/V6R0/V9	plants dying back/ some dead

Table 21. (continued)

Plant Species	Date 3 (August 7) Phenological Stage	Comments
Poa sandbergii	V4R0	
Stipa comata	V4R0/V6R0	plants continuing to dry out and die-back
Stipa viridula	V4R0	plants in good shape, no signs of leaf dry-up or plant die-back
Annual Grasses:		
Bromus japonicus	V9R5, 6	plants dead by this date
Bromus tectorum	V9R5, 6	plants dead by this date
Wintergraze	V5R4-5/V9R4-5	plants dead and/or dying
Perennial Forbs:		
Ambrosia psilostachya	V4R0	leaves severely wilted involute
Artemisia dracunculus	V4R0	leaves wilting
Artemisia ludoviciana	V6R0/V9	plants dead and/or dying
Artragalus cicer	V6R0/V9	plants dead and/or dying

Table 21. (continued)

Plant Species	Date 4 (September 1) Phenological Stage	Comments
Poa sandbergii	V6R0	plants dying back - entering dormancy
Stipa comata	V6R0	plants dying back - entering dormancy
Annual Grasses:		
Bromus japonicus	V9R6	
Bromus tectorum	V9R5-6	
Wintergraze	V9R5-6	plants dead by this date
Perennial Forbs:		
Ambrosia psilostachya	V6R0-1	leaves severely wilting - plants dying back
Artemisia dracunculus	V4R0	leaves severely wilting
Artemisia ludoviciana	V6R0/V9	plants appear to be dying
Astragalus cicer	V9	all plants dead by this date

Table 21 (continued)

Plant Species	Date 1 (July 1) Phenological Stage	Comments
Lactuca puchella	V4RO/V6RO	leaves wilting
Lithospermum incisum	V4RO	
Lygodesmia juncea	V4RO	
Psoralea agrophylla	V4RO/V6RO/V9	leaves wilting
Biennial Forbs:		
Cirsium undulatum	V4RO	
Erysimum asperum	V4RO	
Melilotus officinalis	V4RO	leaves wilting

Table 21. (continued)

Plant Species	Date 2 (July 17) Phenological Stage	Comments
Lactuca puchella	V4R0/V6R0/V9	leaves severely wilted many plants dead
Lithospermum incisum	V4R0	
Lygodesmia juncea	V5R1,2	
Psoralea argophylla	V9	all plants dead by this date
Biennial Forbs:		
Cirsium undulatum	V4R0/V6R0/V9	plants wilting/dying/ some dead
Erysimum asperum	V4R0/V6R0	plants wilting/dying
Melilotus officinalis	V4R0/V6R0/V9	plants dead or dying

Table 21. (continued)

Plant Species	Date 3 (August 7) Phenological Stage	Comments
Lactuca puchella	V9	all plants dead
Lithospermum incisum	V4RO/V6RO	
Lygodesmia juncea	V5/R4	
Psoralea argophylla	V9	some plants showing signs of dying back
Biennial Forbs:		
Cirsium undulatum	V6RO	plants dying
Erysimum asperum	V6RO	basal rosettes wilting
Melilotus officinalis	V9	all plants dead by this date

Table 21. (continued)

Plant Species	Date 4 (September 1) Phenological Stage	Comments
Lactuca puchella	V9	
Lithospermum incisum	V6RO/V9	plants either entering dormancy or dying - some appear dead
Cirsium undulatum	V9	all plants dead by this date
Erysimum asperum	V6RO	basal rosettes severely wilted
Melilotus officinalis	V9	

Table 21. (continued)

Plant Species	Date 1 (July 1) Phenological Stage	Comments
Trapopogon dubius	V4R1/V5R2-3	
Annual Forbs:		
Collomia linearis	V6R0/V9	fruit disseminated, plants dead and/or dying
Descurainia pinnata	V4R0	
Kochia scoparia	V4R0	
Plantago patagonica	V5R2-3	
Salsola kali	V4R0-2	
Sisymbrium altissimum	V4R2/V5R2-3	
Sisymbrium loeselii	V4R2/V5R2-4	
Half-Shrubs:		
Artemisia frigida	V4R0	

Table 21. (continued)

Plant Species	Date 2 (July 17) Phenological Stage	Comments
Tragopogon dubius	V5R4-5/V6R4-5	plants beginning to die
Annual Forbs:		
Collomia linearis	V9	all plants dead by this date
Descurainia pinnata	V9	all plants dead by this date
Kochia scoparia	V4R0	
Plantago patagonica	V9R3-5	plants dead
Salsola kali	V4R1-2	
Sisymbrium altissimum	V5R2-4/V6R4	
Sisymbrium loeselii	V5R2-4/V6R4	
Half-Shrubs:		
Artemisia Frigida	V4R0	

Table 21. (continued)

Plant Species	Date 3 (August 7) Phenological Stage	Comments
Tragopogon dubius	V9	all plants dead by this date
Annual Forbs:		
Collomia linearis	V9	
Descurainia pinnata	V9	
Kochia scoparia	V4R1-2	
Plantago patagonica	V9R4-5	plants dead
Salsola kali	V4R1-2	
Sisymbrium altissimum	V9	all plants dead by this date
Sisymbrium loeselii	V9	all plants dead by this date
Half-Shrubs:		
Artemisia frigida	V4R0	bottom leaves dying but are being replaced at top of plant

Table 21. (continued)

Plant Species	Date 4 (September 1) Phenological Stage	Comments
Tragopogon dubius	V9	
Annual Forbs:		
Collomia linearis	V9	
Descurainia pinnata	V9	
Kochia scoparia	V5R2-3	
Plantago patagonica	V9R4-5	
Salsola kali	V5R2-3	
Sisymbrium altissimum	V9	
Sisymbrium loeselii	V9	
Half-Shrubs.		
Artemisia frigida	V4R0	bottom leaves dying but are being replaced at top of plants

Table 21 (continued)

Plant Species	Date 1 (July 1) Phenological Stage	Comments
Atriplex nuttallii	V4RO	
Ceratoides lanata	V4RO-2	only shrub to produce flowers
Shrubs:		
Artemisia tridentata	V4RO	
Chyrsothamnus nauseosus	V4RO	
Rhus trilobata	V4RO	

Table 21. (continued)

Plant Species	Date 2 (July 17) Phenological Stage	Comments
Atriplex nuttallii	V4RO	bottom leaves dying but are being replaced top of plants
Ceratoides lanata	V4RO-2	bottom leaves dying but are being replaced at top of plants
Shrubs:		
Artemisia tridentata	V4RO	bottom leaves dying, dropping off-replacement by upper leaves
Chrysothamnus nauseosus	V4RO	bottom leaves dying, dropping off-replacement by upper leaves
Rhus trilobata	V6RO, V9	plants dying and/or dead

Table 21. (continued)

Plant Species	Date 3 (August 7) Phenological Stage	Comments
Atriplex nuttallii	V4RO	bottom leaves dying but are being replaced at top of plants
Ceratoides lanata	V4RO-2	bottom leaves dying but are being replaced at top of plants
Shrubs:		
Artemisia tridentata	V4RO	bottom leaves dying but are being replaced at top of plants
Chrysothamnus nauseosus	V4RO	bottom leaves dying but are being replaced at top of plants
Rhus trilobata	V9	all plants dead by this date

Table 21. (continued)

Plant Species	Date 4 (September 1) Phenological Stage	Comments
Atriplex nuttallii	V4RO	bottom leaves dying but are being replaced at top of plants
Ceratoides lanata	V4RO-3	bottom leaves dying but are being replaced at top of plants
Shrubs:		
Artemisia tridentata	V4RO	bottom leaves dying but are being replaced at top of plants
Chrysothamnus nauseosus	V4RO	bottom leaves dying but are being replaced at top of plants
Rhus trilobata	V9	

Table 22. Phenological pattern data for all observable plant species in 1980, shrub and forb direct seeding study, Colstrip, Montana.

Plant Species	Date 1 (June 2) Phenological Stage	Comments
Perennial Grasses:		
Agropyron cristatum	V4RO-3/V5RO-3	leaf tips drying out
Agropyron dasystachyum	V4RO-3/V5RO-3	leaf tips drying out
Agropyron smithii	V4RO	leaf tips drying out
Agropyron spicatum	V5R2	leaf tips drying out
Agropyron trachycaulum	V4RO	leaf tips drying out
Agropyron trichophorum	V4RO-2/V5RO-2	leaf tips drying out
Bromus inermis	V4RO	leaf tips drying out
Hordeum jubatum	V4RO	
Koeleria cristata	V4RO	leaf tips drying out
Oryzopsis hymenoides	V4RO-2/V4RO-2	leaf tips drying out

Table 22. (continued)

Plant Species	Date 2 (July 11) Phenological Stage	Comments
Perennial Grasses:		
Agropyron cristatum	V5R4-6/V6R4-6	leaves drying out
Agropyron dasystachyum	V4R0-6/V5R0-6/V6R0-6	plants starting to dry out and die-back
Agroyron smithii	V4R0/V6R0	plants starting to die-back
Agropyron spicatum	V5R3	leaf tips drying out
Agropyron trachycaulum	V4R0/V5R0-4/V6R0-4	leaf tips drying out
Agropyron trichophorum	V5R1-6/V6R1-6	plants dying back entering dormancy
Bromus inermis	V4R0/V6R0	plants dying back entering dormancy
Hordeum jubatum	V6R6	
Koeleria cristata	V6R0	plants dying back entering dormancy
Oryzopsis hymenoides	V6R0-6/V5R0-6/V6R0-6	plants dying back entering dormancy

Table 22. (continued)

Plant Species	Date 3 (September 22) Phenological Stage	Comments
Perennial Grasses:		
Agropyron cristatum	V6R6/V7R6	
Agropyron dasystachyum	V6R6/V7R6	
Agropyron smithii	V6R6/V7R6	
Agropyron spicatum	V6R6/V7R6	
Agropyron trachycaulum	V6R6/V7R6	
Agropyron trichophorum	V6R6/V7R6	
Bromus inermis	V6R0	
Hordeum jubatum	V6R0	
Koeleria cristata	V6R0	
Oryzopsis hymenoides	V6R6/V7R6	

Table 22. (continued)

Plant Species	Date 1 (June 2) Phenological Stage	Comments
<u>Poa compressa</u>	V4R0-2/V5R0-2	leaf tips drying out
<u>Poa sandbergii</u>	V5R3-4/V6R3-4	plants starting to die-back entering dormancy
<u>Stipa comata</u>	V4R0-1/V5R0-1	leaf tips drying out
<u>Stipa viridula</u>	V4R0-2/V5R0-2	leaf tips drying out
Annual Grasses:		
<u>Bromus japonicus</u>	V4R1-2/V5R1-2	
<u>Bromus tectorum</u>	V5R2-4/V6R4	
<u>Festuca octoflora</u>	V5R4	
<u>Wintergraze</u>	V4R0	leaf tips drying out
Perennial Forbs:		
<u>Ambrosia psilostachya</u>	V4R0	
<u>Artemisia dracunculus</u>	V4R0	

Table 22. (continued)

Plant Species	Date 2 (July 11) Phenological Stage	Comments
Poa compressa	V5R4-6/V6R4-6	plants dying back entering dormancy
Poa sandbergii	V6R6	
Stipa comata	V4R0/V5R0-6/V6R0-6	plants beginning to die-back
Stipa viridula	V4R0/V5R5-6/V6R5-6	plants beginning to die-back
Annual Grasses:		
Bromus japonicus	V6R4-5	
Bromus tectorum	V6R5-6	
Festuca octoflora	V6R6	
Wintergraze	V4R0	
Perennial Forbs:		
Ambrosia psilostachya	V4R0	
Artemisia dracunculus	V4R0	

Table 22. (continued)

Plant Species	Date 3 (September 22) Phenological Stage	Comments
Poa compressa	V6R6	
Poa sandbergii	V6R6	
Stipa comata	V6R6/V7R6	
Stipa viridula	V6R6/V7R6	
Annual Grasses:		
Bromus japonicus	V6R5	
Bromus tectorum	V2R0	fall germination prevalent
Festuca octoflora	V9	
Wintergraze	V6R0	
Perennial Forbs:		
Ambrosia psilostachya	V6R0	
Artemisia dracunculus	V6R0	

Table 22 (continued)

Plant Species	Date 1 (June 2) Phenological Stage	Comments
Artemisia ludoviciana	V4R0	one plant found - appears to be in good condition
Astragalus cicer	V4R0	
Gaura coccinea	V4R2/V5R2-6	
Taraxacum officinale	V6R5	
Biennial Forbs:		
Cirsium undulatum	V2R0	
Erysimum asperum	V4R0-2/V5R0-2	
Grindelia squarosa	V4R0	
Lactuca serriola	V2R0	leaves starting to wilt
Tragopogon dubius	V5R2	

Table 22 (continued)

Plant Species	Date 2 (July 11) Phenological Stage	Comments
Artemisia ludoviciana	V4R0	
Astragalus cicer	V4R0	
Gaura coccinea	V9	all plants dead by this date
Taraxacum officinale	V9	all plants dead by this date
Biennial Forbs:		
Cirsium undulatum	V9R5	plants dead - disseminating seed
Grindelia squarosa	V4R1	
Lactuca serriola	V9	all plants dead by this date
Tragopogon dubius	V5R5	

Table 22 (continued)

Plant Species	Date 3 (September 22) Phenological Stage	Comments
Artemisia ludoviciana	V6R0/V9	plant has either gone dormant or is dead
Astragalus cicer	V9	all plants dead by this date
Gaura coccinea	V6R5	
Taraxacum officinale	V9	
Biennial Forbs:		
Cirsium undulatum	V9	
Erysimum asperum	V2R0	basal rosettes present
Grindelia squarosa	V6R4	
Lactuca serriola	V9	
Tragopogon dubius	V9	

Table 22 (continued)

Plant Species	Date 1 (June 2) Phenological Stage	Comments
Annual Forbs:		
Camelina microcarpa	V4R1	
Chenopodium leptophyllum	V4R0-1/V5R0-1	
Descurainia pinnata	V4R0	
Helianthus annuus	V4R0	
Kochia scoparia	V2R0	
Plantago patagonica	V4R1	
Salsola kali	V2R0	
Sisymbrium altissimum	V4R1	
Thlaspi arvense	V4R0	

Table 22 (continued)

Plant Species	Date 2 (July 11) Phenological Stage	Comments
Annual Forbs:		
Camelia microcarpa	V6R4-5/V9R5	
Chenopodium leptophyllum	V4R1/V5R1	leaves severely wilted
Descurainia pinnata	V6R5	
Helianthus annuus	V4R0	
Kochia scoparia	V4R0	
Plantago patagonica	V6R2	
Salsola kali	V4R0-2	
Sisymbrium altissimum	V6R4/V9	plants disseminating seed - some dead by this date
Thlaspi arvense	V6R4	

Table 22 (continued)

Plant Species	Date 3 (September 22) Phenological Stage	Comments
Annual Forbs:		
Camelia microcarpa	V9	
Chenopodium leptophyllum	V5R1	leaves severely wilted
Descurainia pinnata	V9	
Helianthus annuus	V9	
Kochia scoparia	V6R1	
Plantago patagonica	V9R5	
Salsola kali	V6R3-4	
Sisymbrium altissimum	V9	
Thlaspi arvense	V9R5	

Table 22 (continued)

Plant Species	Date 1 (June 2) Phenological Stage	Comments
Half-shrubs:		
Artemisia frigida	V4R0	
Atriplex nuttallii	V4R0	growth appears to be slow - plants small
Ceratoides lanata	V4R0	plants look vigorous
Xanthocephalum sarothrae	V4R0	
Shrubs:		
Artemisia tridentata	V4R0	plants appear to be in good condition
Chrysothamnus nauseosus	V4R0	small plants - appear stunted - leaf tips yellowed

Table 22 (continued)

Plant Species	Date 2 (July 11) Phenological Stage	Comments
Half-shrubs:		
Artemisia frigida	V4RO	
Atriplex nuttallii	V4RO	growth slow-plants small
Ceratoides lanata	V4RO	
Xanthocephalum sarothrae	V4RO	
Shrubs:		
Artemisia tridentata	V4RO	
Chrysothamnus nauseosus	V6RO	

Table 22 (continued)

Plant Species	Date 3 (September 22) Phenological Stage	Comments
Half-shrubs:		
Artemisia frigida	V4R0	
Atriplex nuttallii	V5R0	
Ceratoides lanata	V6R0	
Xanthocephalum sarothrae	V6R2	
Shrubs:		
Artemisia tridentata	V4R0	
Chrysothamnus nauseosus	V6R0/V9	have either gone dormant or have died by this date

APPENDIX B

Table 23. Comparison of shrub and forb species mean[1] plant heights by treatment (with and without concurrently seeded perennial grass mixture) in 1979 and 1980, shrub and forb direct seeding study Colstrip, Montana.

Species/Treatments	1979 Date 1 (July 1)	1979 Date 2 (Aug. 16)	1979 Date 3 (Sept. 5)	1980 (Aug. 17)[2]
1. Big Sagebrush *Artemisia tridentata*				
With Perennial Grass Mix	3.5 (n=3)	6.9 (n=2)	2.8 (n=3)	6.3 (n=6)
Without Perennial Grass Mix	3.6 (n=4)	5.8 (n=4)	3.0 (n=3)	6.9 (n=10)
2. Rubber rabbitbrush *Chrysothamnus nauseosus*				
With Perennial Grass Mix	3.8 (n=2)		3.7 (n=2)	
Without Perennial Grass Mix	5.3 (n=3)		4.2 (n=3)	17.8 (n=1)
3. Cudweed sagewort *Artemisia ludoviciana*				
With Perennial Grass Mix	2.4 (n=5)		1.3 (n=2)	
Without Perennial Grass Mix	3.3 (n=3)		2.6 (n=3)	1.7 (n=1)
4. Skunkbush sumac *Rhus trilobata*				
With Perennial Grass Mix	3.8 (n=8)		4.8 (n=2)	
Without Perennial Grass Mix	3.3 (n=7)			
5. Nuttall's saltbush *Atriplex nuttallii*				
With Perennial Grass Mix	3.0 (n=22)	5.5 (n=19)	3.2 (n=2)	
Without Perennial Grass Mix	3.4 (n=24)	6.6 (n=17)	3.0 (n=26)	

Table 23 (continued)

Species/Treatments	1979 Date 1 (July 1)	1979 Date 2 (Aug. 16)	1979 Date 3 (Sept. 5)	1980 (Aug. 17)[2]
6. Nuttall's saltbush (Local) *Atriplex nuttallii*	3.6$^{(n=37)}$	5.1$^{(n=5)}$	3.4$^{(n=33)}$	7.4$^{(n=35)}$
7. Winterfat *Ceratoides lanata*				
With Perennial Grass Mix				
Without Perennial Grass Mix	14.5$^{(n=1)}$	15.1$^{(n=1)}$	14.0$^{(n=1)}$	
8. Winterfat (local) *Ceratoides lanata*	10.0$^{(n=2)}$	8.8$^{(n=2)}$	9.8$^{(n=2)}$	9.8$^{(n=1)}$

[1] Sample size (n) is found in parantheses immediately following plant height values

[2] Plant height sampling occurred for only one date in 1980

Table 24. Comparison of mean[1] plant canopy cover (%) by treatment (with and without concurrently seeded perennial grass mixture) for each shrub and forb species in 1979 (July 23 to August 5), shrub and forb direct seeding study, Colstrip, Montana.

Plant Species/Class	Artemisia tridentata With	Artemisia tridentata Without	Chrysothamnus nauseosus With	Chrysothamnus nauseosus Without
Agropyron cristatum	2.4	1.7	0.2 b	2.6 a
Agropyron dasystachyum[3]	17.2 a	2.7 b	18.1 a	2.5 b
Agropyron smithii	4.2 a	0.9 b	5.6 a	1.9 b
Agropyron trachycaulum	2.5	6.1	1.7	5.2
Agropyron trichophorum	7.0	6.2	5.0	7.6
Bromus inermis	0.4	0.1	0.4	0.0
Calamovilfa longifolia	0.1 a	0.0 b	T	0.0
Koeleria cristata	0.0	0.0	0.2	0.0
Oryzopsis hymenoides	7.9 a	0.9 b	6.8 a	2.3 b
Poa compressa	0.7 a	0.0 b	0.4	T
Poa sandbergii	0.0	0.6	0.0	0.0
Stipa comata	0.9 b	4.3 a	2.0	3.0
Stipa viridula	0.4	1.0	1.6 a	0.4 b
Other perennial grasses	T	0.0	0.0	0.0
Total perennial grasses	43.7 a	24.5 b	42.0 a	25.5 b
Bromus japonicus	0.7 b	10.2 a	0.9	2.4
Bromus tectorum	0.8	0.2	0.2	0.2
Festuca octoflora	0.0	0.2	0.0	0.0
Wintergraze[4]	3.5	0.7	0.2	0.4
Total annual grasses	5.0	11.3	1.3	3.0
Ambrosia psilostachya	0.1 b	0.8 a	T	0.1
Artemisia ludoviciana	0.0	0.0	0.0	0.0
Astragalus cicer	0.1	0.0	0.4	0.2
Echinacea angustifolia	0.0	0.0	0.0	0.0
Lactuca puchella	0.0	0.2	0.2	0.0
Lithospermum incisum	0.0	0.1	T	0.0
Lygodesmia juncea	0.0	0.0	0.0	0.0
Medicago sativa	T	0.0	0.0	0.0
Psoralea argophylla	T	0.0	0.0	0.0
Total perennial forbs	0.2	1.1	0.6	0.3
Erysimum asperum	0.2	0.4	0.0	0.4
Melilotus officinalis	0.0	0.2	0.0	0.0
Tragopogon dubius	0.0	0.0	0.0	0.0
Total biennial forbs	0.2	0.6	0.0	0.4