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Causes of Seeding Failure within the Tooele Fire Rehabilitation Project in Northwestern Utah

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CAUSES OF SEEDING FAILURE WITHIN THE TOOELE FIRE REHABILITATION PROJECT IN NORTHWESTERN UTAH

by

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Fire Rehabilitation Project in
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by

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The original purpose of this study was to examine the influences of ecological site, seeding method and planting season on rangeland seeding success within the Tooele Fire Rehabilitation Project (TFRP) in northwestern Utah. The major objective of the TFRP, designed by the USDI Bureau of Land Management, was to establish a permanent cover of 'Nordan' crested wheatgrass (Agropyron desertorum (Fischer ex Link) Schultes), 'Luna' pubescent wheatgrass (Thinopyrum intermedium ssp. barbulatum (Schur) Barkw. and D. R. Dewey) and 'Alkar' tall wheatgrass (Thinopyrum ponticum (Podp.) Barkw. and D. R. Dewey) on approximately 20,000 ha of rangeland burned by a wildfire in July 1983.

Thirteen combinations of site, method and planting season were identified within the study area; each was treated as an experimental unit. There were no significant differences ($P \leq 0.05$) in seedling densities between these treatment combinations. Means ranged from 0 to 1.9 seedlings/m^2. There was significant variation ($P \leq 0.05$) among seedling densities within each treatment combination. Because of low seedling densities and non-uniform seedling establishment patterns, seedings within the study area were failures. Study effort was redirected to identify the causes of seeding failure.

Among planting seasons and seeding methods, spring plantings and broadcast seeding contributed to failure. Most sites within the study area were suitable for seeding, with the exception of desert shallow loam. This site should not have been seeded because of steep topography and shallow soil. Planting during spring, broadcast seeding and the seeding of low potential sites explained only localized failure, however.

The absence of crested wheatgrass seedlings within the study area was a major factor contributing to failure. Only two crested wheatgrass plants were found on a total of 195 permanently established transects. Of the three species seeded, crested wheatgrass was the best adapted to site conditions.

Seeding technique was considered the most important factor causing failure. Contract workers on the project had no rangeland seeding experience. Drills were not properly equipped to control seed placement at the proper soil depth. Seeding was done during periods when site conditions were unfavorable.

There was no evidence suggesting weather, grasshopper damage or cheatgrass competition caused failure.

(95 pages)

INTRODUCTION

On July 5, 1983, a wildfire began in northwestern Utah. By the time it was controlled on July 9, 1983, the fire had consumed approximately 63,800ha of salt-desert shrub and sagebrush steppe vegetation in central Tooele County. Most of the base of the Cedar Mountains was burned, as well as portions of Puddle Valley to the west and Skull Valley to the east.

Land ownership within the burn was varied and included a mixture of federal, state, private, Indian and military lands. About 85% of the burned area was administered by the USDI Bureau of Land Management (BLM).

Prior to the wildfire, these lands were in poor ecological condition. Cheatgrass (*Bromus tectorum* L.) dominated many of the lower elevation sites. Many areas were described as critically eroded and in need of stabilization. Following the burn, a plan was quickly developed by the BLM in which they proposed to rehabilitate 23,000ha.

The Tooele Fire Rehabilitation Plan (TFRP) was a massive project. It included seeding a perennial grass cover on approximately 15,000ha, constructing over 105km of new fenceline, repairing 10km of existing fenceline, establishing 15 spreader dikes and constructing over 40 gully plugs. The objective of this work was to stabilize the condition of the Skull Valley watershed by reducing soil erosion and minimizing other on-site damage within this closed basin. The total estimated cost of the TFRP was $978,650 but the BLM estimated a benefit/cost ratio of 16.7:1 (BLM, unpublished report[1]).

By far the most crucial portion of the TFRP plan was the re-establishment of a permanent vegetal cover. The BLM estimated that about 80% of the perennial plant species within the boundaries of the burn were killed by the fire (BLM, unpublished report). It was feared that a loss of cover of this magnitude would greatly increase soil erosion, reduce wildlife habitat and livestock forage, and allow weedy species, such as cheatgrass, to dominate the burned area. To avoid these undesirable results, a major component of the TFRP was to seed 14,580ha of the burn with perennial grasses. Previous drill seedings that covered about 350ha within the area indicated a high probability of success.

The seeding effort began in October of 1983. A mixture of crested wheatgrass (Agropyron desertorum (Fisch ex. Link) Schult.), pubescent wheatgrass (Thinopyrum intermedium ssp. barbulatum (Schur) Bark. and D. R. Dewey) and tall wheatgrass (Thinopyrum ponticum (Podp.) Bark. and D. R. Dewey) was planted. Both drilling and aerial broadcasting methods were used for planting. The broadcast treatments were followed by either chaining or sheep trampling to cover the seed. Fall seeding work was completed by mid-November. Seeding operations resumed in April of the following year. The same species mixture was planted

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[1]USDI Bureau of Land Management. 1984. Emergency fire rehabilitation plan and environmental assessment for the Tooele Fire #6916. Salt Lake City, Utah.

during the spring as in the fall, but all seeding was done with rangeland drills. By the time the project was finished in mid-May 1984, approximately 15,000ha of the burn had been seeded through the combined efforts of four independent contractors.

The seeding project was fraught with problems throughout its duration. Inexperienced seeding contractors, equipment failure and subsequent work delays, heavy rains and frost were frequently noted in BLM project logbooks. In addition, Utah underwent one of the worst grasshopper population eruptions in recent history during the spring and summer of 1984. Skull Valley was one of the areas that was most severely affected. These problems created doubt within both the State and Salt Lake District BLM Offices as to the success of the rehabilitation seeding. An evaluation was needed.

The Salt Lake District Office contacted Utah State University in an effort to secure some form of support in evaluating the seeded areas within the TFRP. Because a number of different seeding methods were used across a variety of ecological sites in both spring and fall planting seasons, their specific request was to have the most successful treatment combinations identified.

In the fall of 1984, I located several study sites within the seeded area, established permanent transects and collected seedling density data. The study objectives were to determine if there was differential seeding success among: (1) different ecological sites when seeded by the same method during the same season; (2) different seeding methods on the same ecological sites planted during the same season; and, (3) spring and fall planting seasons when seeded by the same method on identical ecological sites.

During the second period of data collection in spring of 1985, it became obvious that the seedings within the study area were failures. Many transects contained no seedlings. When seedlings were present, densities were very low. Variability in seedling densities on all treatments was so large it would be difficult to identify differences among treatments if they existed. As such, any conclusions concerning the study objectives above would be meaningless or, at best, unreliable. This made it necessary to redirect the study effort.

The exact cause(s) for the failure of the seeding was unknown. Many opinions were expressed, ranging from grasshopper-caused seedling mortality to improper seeding technique. A systematic evaluation might be extremely valuable to the BLM if the information gained could be used to plan and conduct future rangeland and fire rehabilitation seeding projects. Therefore, the objectives of this study were to document the failure of the TFRP seeding and to examine possible causes for that failure attributable to weather, site factors and cultural practices.

LITERATURE REVIEW

The research literature concerning range seeding is extensive, both in its geographical coverage and research approach. Most early work was general or descriptive in nature. Prior to about 1950, recommendations for when, where, what and how to seed rangelands were determined more though trial and error approaches than by controlled experiments. More recently, controlled studies have been conducted to determine why certain seasons, methods, species and sites have proven more successful or adapted to seeding than others. Both approaches have been used over a wide area and considerable attention has been given to semiarid rangelands.

Planting Season

Fall and spring have been the two seasons most extensively examined and recommended for seeding in the Intermountain area (Monsen and McArthur 1985). In 20-30cm precipitation zones, fall is generally considered the best season for seeding (Douglas et al. 1960, Hull et al. 1950, Klomp and Hull 1972, Parker 1961, Plummer et al. 1955, Plummer et al. 1968, Rummell and Holscher 1955, Stark et al. 1946, Stewart et al. 1939, Vallentine et al. 1963, Walker and Bracken 1938). In studies that examined differences in seeding success between early fall (September through mid-October) and late fall (mid-October through November), the latter period was reported more successful (Kilcher

1961).

Spring seedings in 20-30cm precipitation zones of the Intermountain area have proven sucessful in some studies. Drawe et al. (1975) found no difference in success between spring and fall plantings of Russian wildrye (Psathyrostachys juncea (Fischer) Nevski) in central Utah. Cook et al. (1967) concluded that spring plantings on the Benmore Experimental Range in west-central Utah produced more crested wheatgrass (Agropyron cristatum (L.) Gaertn. and A. desertorum (Fischer ex Link) Schultes), intermediate wheatgrass (Thinopyrum intermedium (Host) Barkw. and D. R. Dewey ssp. intermedium), pubescent wheatgrass and tall wheatgrass seedlings than fall plantings.

Monsen and McArthur (1985) considered planting during the wrong season as a principal cause of seeding failure. In the 20-30cm precipitation zone of the Intermountain area, the most favorable planting season is dictated largely by seed and seedbed ecology. Seed germination requires favorable temperature and moisture conditions (Ashby and Hellmers 1955, Ellern and Tadmor 1967, Keller and Bleak 1970, Laude et al. 1952, Wilson et al. 1974). These conditions often do not occur simultaneously on arid and semiarid rangelands (Evans et al. 1970). When moisture is most available, often in the winter and early spring, temperatures are too cold for germination. In late spring and early summer, temperatures are high enough for germination, but soil moisture is limiting. Within this general pattern there is only a short period of time when temperature and moisture conditions simultaneously exceed seed germination requirements (Jordan 1983, Young and Evans 1982). Once germination occurs, the seedlings must grow rapidly and establish before the dry summer period or perish.

Late fall seeding offers the best opportunity for seeding success because the seed is in the ground and ready to germinate as soon as environmental conditions are favorable in the spring (Plummer et al. 1955). After germination, the seedlings have a relatively long period in which to become established before moisture becomes limiting (Hull 1960, Parker 1961, Plummer et al. 1955, Plummer et al. 1968).

Seeding in early fall offers many of the potential benefits of late fall seeding, but incurs risk. If temperature and moisture conditions are favorable shortly after seeding, the seeds may germinate. The seedlings are then susceptible to winter kill, either from frost heaving, cold or drought (Hull et al. 1950, Stewart et al. 1939, Vallentine et al. 1963).

The major limitations to spring seeding are practical ones. While conditions for seed germination and seedling establishment are most favorable in the spring, it is often too wet to get the seeding equipment on the ground. Once conditions are suitable, a portion of the most favorable growing period has past and seedlings have less time to establish before the dry summer (Hull et al. 1950, Plummer et al. 1968, Vallentine 1971, Vallentine et al. 1963). Stark et al. (1946) concluded that spring seeding was most successful when rainfall occurred after planting.

Seeding Method

The two most widely used methods to seed rangelands are drilling and broadcasting. Where topography and soil conditions permit, drill seeding is the preferred method of planting (Hull and Holmgren 1964, Keller 1979, Plummer et al. 1955, Vallentine et al. 1963, Walker and Bracken 1938). In studies comparing drill and broadcast seeding methods, drilling produced better grass stands in less time (Douglas et al. 1960, Drawe et al. 1975, Hull and Holmgren 1964, Hull and Klomp 1967, Klomp and Hull 1972, Nelson et al. 1970). Hull and Klomp (1967) found that drilling produced 10 times the number of seedlings and drilled stands reached full production sooner than broadcast seeding.

The reasons drill seeding produces better stands than broadcasting have been summarized by many authors. Keller (1979) stated that drilling distributes seed more uniformly and covers the seed better than broadcasting methods. Better soil coverage of the seed improves moisture relationships (Walker and Bracken 1938). This happens because the seed is less exposed to cycles of wetting and drying than if lying on the soil surface (Plummer 1943) and because the hydraulic conductivity from the soil to the seed is improved (Evans and Young 1970, 1972, Harper 1977, Harper et al. 1965, Young and Evans 1986). Drill seeding requires less seed to produce full stands than broadcasting (Plummer et al. 1955). The drill not only better controls seeding depth, but also more precisely controls the seeding rate (Reynolds and Springfield 1953).

Disks are the most common type of furrow openers used for drill seeding (Vallentine 1971). The standard disk creates a furrow appproximately 2.5cm or less in depth. Deep furrow disks are larger and more concave than standard disks and create furrows from 5-10cm deep.

In areas receiving under 30cm of precipitation or during years of below normal rainfall, deep furrow disks have certain advantages over the standard type. Most noteworthy is that soil moisture is less susceptable to evaporative loss (Vallentine 1971, Vallentine et al. 1963). McGinnies (1959) reported soil moisture content was significantly greater in 10cm deep furrows than in furrows 2.5, 5 and 7.5cm in depth. The number of 'Nordan' crested wheatgrass seedlings was also significantly greater in the 10cm deep furrows. Evans et al. (1970) compared and measured microclimate differences between furrows made with deep furrow and standard disks. They found soil moisture depletion was slower and soil temperature extremes were moderated in deeper furrows. These soil moisture and temperature changes bring the seedbed closer to conditions necessary for seed germination (Young and Evans 1986).

Deep furrow disks can reduce seedling competition with less desirable plant species, such as cheatgrass. Plummer et al. (1955) recommended using deep furrow disks in areas where cheatgrass was common. Klomp and Hull (1972) found that fall drilling with deep furrow disks produced the best stands of crested and Siberian wheatgrasses (Agropyron fragile (Roth) Candargy) in areas with cheatgrass. Evans et al. (1967) reported that deep furrow disks improved intermediate wheatgrass seedling establishment over surface drilling in areas without prior cheatgrass control.

While deep furrow disks generally improve seedling establishment over standard disks in areas with low precipitation or during dry years, certain problems have been reported. Soil sloughing in coarse texture soils can bury the seeds too deeply (Plummer et al. 1955).

Seed burial can also occur during short duration, high intensity periods of rainfall and these wet conditions can reduce soil aeration (Vallentine 1971). For these reasons, deep furrow disks are not recommended for use in coarse texture or unstable soils (Plummer et al. 1955, Vallentine 1971).

Broadcast seeding is often the only method suited for seeding rough or steep areas where drilling is impractical (Cook 1958, Plummer et al. 1955, Vallentine et al. 1963, Vallentine 1971), but this seeding method has produced variable results (Bleak and Hull 1958, Cook 1958, Koniak 1983).

Several factors, operating singly or in combination, can cause broadcast seeding failure. The most universally cited factor is failure to adequately cover the seed with soil (Cook 1958, Pearse et al. 1948, Plummer et al. 1955, Plummer et al. 1968, Vallentine et al. 1963, Vallentine 1971). Nelson et al. (1970) stated the main deterrent to germination of broadcast seed was rapid drying of the soil surface following brief periods of rain. Inadequate removal of competing vegetation prior to broadcasting has also contributed to seeding failure (Cook 1958, Evans 1961, Harris 1967). Nelson et al. (1970) found that bird and rodent depredation of wheatgrass seed significantly reduced the effectiveness of broadcast seeding.

Several ways of covering broadcast seed have been recommended. Seeding in aspen (Populus tremuloides Michx.) and Gambel oak (Quercus gambelii Nutt.) before the leaves fall has given good results (Plummer et al. 1955, Plummer et al. 1968, Vallentine 1971, Vallentine et al. 1963). Pipe harrows, anchor chains and brush drags have all been used to cover broadcast seed (Plummer et al. 1968). Herding livestock through a seeded area has also been recommended (Plummer et al. 1955, Stewart et al. 1939). No studies that compared the relative effectiveness of these methods were found.

Site Suitability

Few studies have attempted to identify, either singly or in combination, the factors that define a site with high potential for seeding. As a result, recommendations of where to and where not to seed have been very general. The most commonly used criteria of site suitability have been the amount of annual precipitation, selected soil characteristics and the presence of "indicator" plant species.

Annual precipitation is considered to be the most limiting factor to seeding success in the Intermountain area. In general, 30cm of annual precipitation is recommended as the lower limit for consistent seeding success (Cornelius and Talbot 1955, Plummer et al. 1955, Plummer et al. 1968, Stewart 1947, Stewart et al. 1939, Vallentine et al. 1963). On areas where a portion of the precipitation comes during the growing season or where infiltration and soil water holding capacity is higher, precipitation requirements for seeding success may be as low as 20cm (Plummer et al. 1955, Plummer et al. 1968, Shown et al. 1969).

The ideal combination of edaphic characteristics for seeding has been summarized by many workers as deep, fertile soils of medium to fine textures, with high amounts of organic matter and moisture holding capacities (Plummer et al. 1955, Rummell and Holscher 1955, Vallentine et al. 1963, Stewart et al. 1939). Few of these recommendations gave any indication as to which of these characteristics were most important in determining seeding success. Rummell and Holscher (1955) considered soils less than 30cm deep too shallow for seeding. Vallentine et al. (1963) stated that sandy or rocky soils were not suitable. Several authors considered sites with greater than 30% slope unsuitable (Cornelius and Talbot 1955, Plummer et al. 1955, Stewart 1947, Stewart et al. 1939). Salt-desert vegetation types or soils with greater than 1% soluable salt were not recommended for seeding (Cook 1961, Haas et al. 1962, Hull 1963, Plummer et al. 1968, Rollins et al. 1968, Vallentine et al. 1963).

There was an early recognition that some species of plants could be used as indicators of site suitability for seeding (Stewart et al. 1939). Rummell and Holscher (1955) recommended seeding on areas where big sagebrush (*Artemisia tridentata* Nutt.) was 60cm or taller. Shown et al. (1969) examined seedings throughout the Intermountain West. They found that a big sagebrush vigor index, based on the height and density of the plants, was valuable for predicting seeding success. Plummer et al. (1955) stated that thick, vigorous sagebrush, cheatgrass or Russian thistle (*Salsola kali* L.) indicated sites that could produce high-yielding stands of forage plants. On disturbed areas where halogeton (*Halogeton glomeratus* (Bieb.) C.A. May), Russian thistle or cheatgrass stands have been invaded by juniper (*Juniperus* sp. L.), precipitation was considered adequate for seeding (Plummer et al. 1968). Vallentine et al. (1963) stated seeding should not be attempted on sites supporting shadscale (*Atriplex confertifolia* (Torr. and Frem.) Wats.), black sagebrush (*Artemisia nova* Nelson) or blackbrush

(Coleogene ramosissima Torr.).

The rationale for using the "indicator" plant approach to predict site suitability for seeding was that plants act as integrators of site climate and soil characteristics. These qualities could then be related to the requirements of the species available for seeding (Plummer et al. 1968, Winward 1983).

An extension of the indicator plant approach has been the use of broad rangeland vegetation types or the ecological site concept as basis for determining site suitability for seeding (Vallentine 1971). This is because each broad vegetation type or ecological site represents a general integration of precipitation, soils, topography, elevation and native plant species information for each site (Plummer et al. 1968, USDA Soil Conservation Service 1976).

Seeded Species

Crested wheatgrass is probably the most widely used grass species for seeding rangelands in the western U.S. It was first introduced from the U.S.S.R. in 1906 (Rogler and Lorenz 1983).

'Nordan' crested wheatgrass, the most widely seeded variety in the U.S., was developed and released in 1953 by the North Dakota Agricultural Experiment Station and the Agricultural Research Service (Hanson 1972, Rogler 1954). This variety has a number of characteristics that made it superior to other strains of standard crested wheatgrass available at the time of its release. These plants have an erect growth habit and are resistant to lodging. Seed is uniform and of high quality. The seeds also have fewer awns, improving cleaning, threshing and drilling qualities. Seedling vigor and first-year growth were greatly improved over other strains. Stands are therefore more uniform and develop rapidly. 'Nordan' crested wheatgrass yields, however, are similar to other varieties (Rogler 1954).

Crested wheatgrass has a wide range of adaptation in terms of precipitation and edaphic requirements. It needs as little as 20cm of annual precipitation to produce successful stands (Plummer et al. 1955, Plummer et al. 1968, Rogler and Lorenz 1983, Thornburg 1982, Weintraub 1953). Where topography or soil moisture holding capacity increases precipitation effectiveness, the moisture requirement can be as low as 18cm (Stevens 1983). Walker and Bracken (1938) stated that crested wheatgrass does well on productive, well drained soils of almost any texture. Jordan (1981) recommended seeding this grass on soils with medium to fine textures. Crested wheatgrass does not produce well on hard clay or coarse sandy soils (Vallentine 1961, Weintraub 1953).

Crested wheatgrass is moderately tolerant of alkaline and salty soils (Forsberg 1953, Weintraub 1953). Dewey (1962) found that the germination of 'Nordan' crested wheatgrass seeds was reduced 1.7% at 6,000ppm (8.5mmhos/cm of conductance of the saturation paste extract) calcium chloride and sodium chloride, 14.4% at 12,000ppm (14.3 mmhos/cm) and 69.7% at 18,000ppm (20.6mmhos/cm). Dewey (1960) calculated a salt tolerance index of 11.3-12.9mhos/cm for 'Nordan' crested wheatgrass. The salt tolerance index was the conductance value at which yields were reduced 50% as compared to yields in unsalinized plots.

Pubescent wheatgrass, the pubescent form of intermediate wheatgrass, is a cool season, rhizomatous grass introduced from the U.S.S.R. in 1934 (New Mexico State University 1964, Schwendiman 1972b).

'Luna' pubescent wheatgrass was developed and released in 1963 by the New Mexico Agricultural Experiment Station and the USDA Soil Conservation Service (Hanson 1972, New Mexico State University 1964). This variety has better seedling vigor, is easier to establish, has greater drought and salt tolerance and higher forage yields than other strains of pubescent wheatgrass available at the time of its release (New Mexico State University 1964).

Pubescent wheatgrass has a wide range of climatic and edaphic adaptation, although it is not as tolerant of low rainfall as crested wheatgrass. Pubescent wheatgrass requires 25-30cm of annual precipitation to produce good stands (Hafenrichter et al. 1968, Jordan 1981, Plummer et al. 1968, Vallentine 1961). This grass does best on well-drained, slightly acid to mildly alkaline soils with medium to fine textures (Jordan 1981, Hafenrichter et al. 1968). Pubescent wheatgrass is not adapted to wet, poorly drained sites, but it is better adapted to infertile and alkaline sites than tall wheatgrass (Weintraub 1953). Dewey (1960) found that pubescent wheatgrass seed germination under salty conditions and its salt tolerance index was about equal to crested wheatgrass.

Tall wheatgrass is a late maturing, tall bunchgrass native to saline meadows and seashores in southeastern Europe and Asia Minor. It was first introduced into the U.S. from the U.S.S.R. in 1932 (Rogler 1973).

'Alkar' tall wheatgrass was developed and released in 1951 by the

USDA Soil Conservation Service and the Washington, Oregon and Idaho Agricultural Experiment Stations (Hafenrichter et al. 1968, Hanson 1972, Schwendiman 1972a). This variety has good seedling vigor and is resistant to stripe and leaf rust.

Tall wheatgrass requires more moisture to remain productive than either crested or pubescent wheatgrasses. Jordan (1981) stated that a minimum of 30cm of annual preciptation was needed in the southwest U.S. Hafenrichter et al. (1968) considered 35cm as the lower requirement, because tall wheatgrass is later maturing and requires moisture season-long either through irrigation or in deep, nonirrigated soils with a high moisture holding capacity. Vallentine (1961) recommended planting this species on sub-irrigated or naturally wet alkaline sites with a relatively high water table but not on dry alkaline sites. In areas that are not sub-irrigated, tall wheatgrass should only be planted where annual precipitation exceeds 30cm. Weintraub (1953) stated that high yields were obtained on sub-irrigated sites, but performance was poor on dry sagebrush and salt-desert shrub range.

Schwendiman (1972a) and Weintraub (1953) stated that tall wheatgrass was well adapted to alkali and saline soils in the western U.S. Vallentine (1961) stated that tall wheatgrass can tolerate up to 1% soluable salt. Dewey (1960) found that tall wheatgrass yields were less affected than either crested or pubescent wheatgrass yields under artificially salinized conditions. He calculated a salt tolerance index of 13.9mmhos/cm for tall wheatgrass compared to 11.3-12.9 mmhos/cm for both crested and pubescent wheatgrasses. There were no differences in the germination ability of tall, crested and pubescent wheatgrass seed under salinized conditions (Dewey 1960).

STUDY AREA

Area Description

The study area was located within a portion of the Tooele Fire Rehabilitation Project (TFRP) along the eastern base of the Cedar Mountains and western edge of Skull Valley, approximately 49km south of Timpie in Tooele County, Utah (Figure 1). Elevation ranges between 1,400m at the valley bottom to 1,700m at the base of the Cedar Mountains. Slope is mostly less than 5% and the aspect is predominately east. The 30-year mean annual precipitation recorded at the Dugway weather station, approximately 10km south of the study area, was 17.6cm distributed evenly throughout the year (Stevens et al. 1983). The mean annual high temperature is 47.1C and the low 3.3C.

Six ecological sites (Range Inventory Standardization Committee 1983) were identified within the study area by BLM and USDA Soil Conservation Service personnel. Selected characteristics of each site are summarized in Table 1 and complete descriptions are provided in the Appendix. The sites differ primarily in precipitation zone and in soil texture and coarse fragment percentages resulting from sediment deposition patterns and fluctuating water levels of historic Lake Bonneville (Holmgren 1983). Generally, soils located on the Stansbury and Provo Terraces at the base of the Cedar Mountains are coarse-textured and gravelly. Valleyward, soil texture becomes finer,

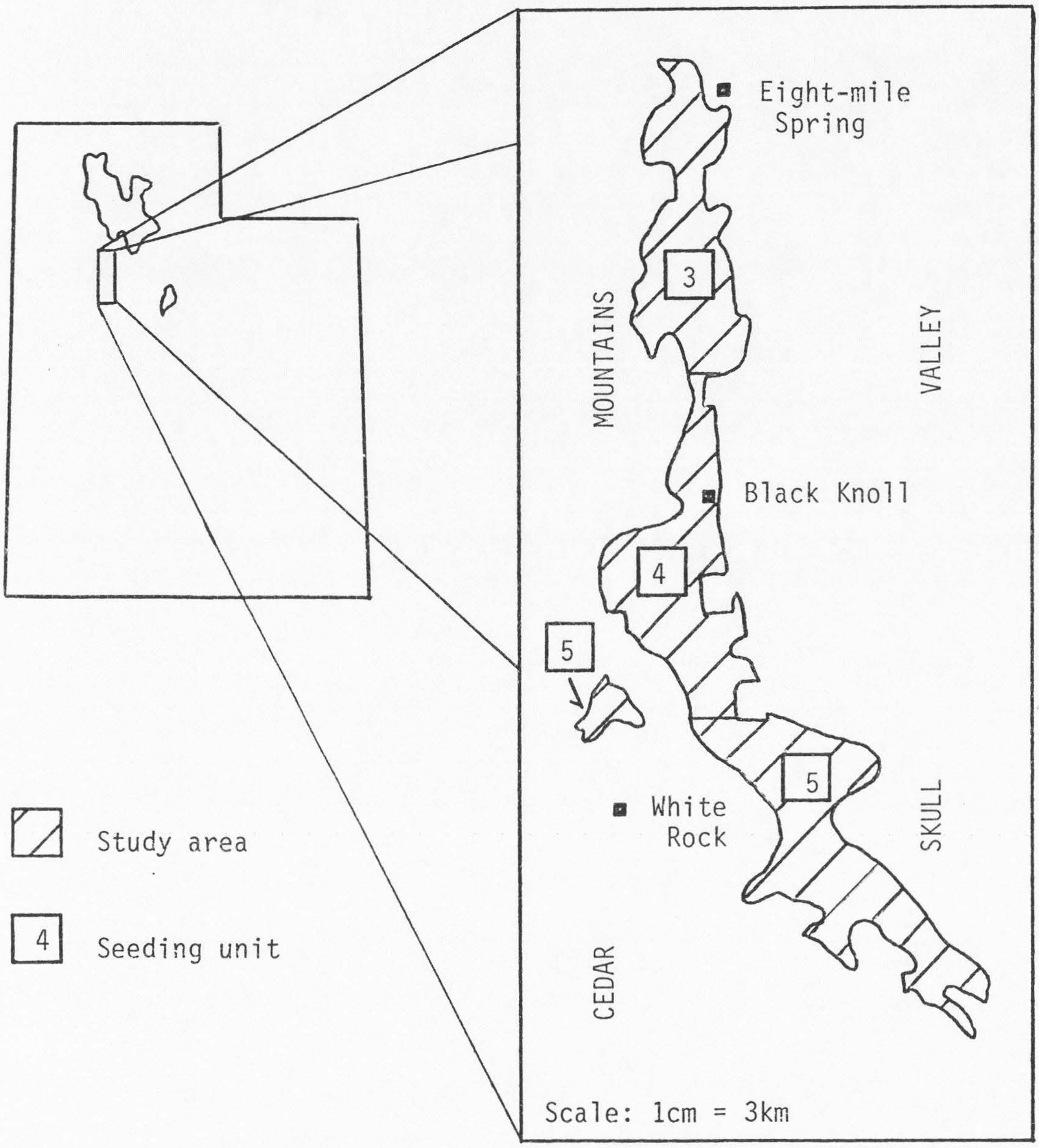

Figure 1.--Study area location including the three seeding units within the Tooele Fire Rehabilitation Project.

Table 1.--Physical and vegetal characteristics (prior to burning) of the six ecological sites within the Tooele Fire Rehabilitation Project study area.

Ecological site	Elevation (m)	Precip. zone (cm)	Dominant plant species (overstory/understory)
Desert flat	1280-1460	12-20	Atriplex confertifolia/ Elymus elymoides
Desert loam	1280-1981	12-20	A. confertifolia/ Oryzopsis hymenoides
Desert gravelly loam	1500-1600	12-20	A. confertifolia/ Hilaria jamesii
Desert shallow loam	1525-1830	12-20	A. confertifolia/ Hilaria jamesii
Semidesert gravelly loam	1300-1830	20-30	Artemisia tridentata ssp. wyomingensis/ Psuedoroegneria spicata
Semidesert loam	1340-1730	20-30	A. tridentata ssp. wyomingensis/ Psuedoroegneria spicata

soluble salt and sodium percentages increase and coarse fragments disappear from the soil profiles.

Plant community composition within the study area was influenced most by precipitation zone. Shadscale was the dominant shrub on desert precipitation zone sites near the Skull Valley floor. Wyoming big sagebrush (Artemisia tridentata subsp. wyomingensis Beetle and Young) dominated semi-desert sites at the base of the Cedar Mountains. Major understory species varied by site (Appendix). Cheatgrass was present in dense stands prior to the Tooele wildfire, but the stands were largely confined to areas near the valley floor.

Seeding Detail

Seeding within the study area was done during fall 1983 and spring 1984. Four seeding methods were used and four independent private contractors participated in the project. Three of these contractors participated in the actual seeding operation; the fourth was employed only to broadcast seed by plane. The planting methods included aerial broadcasting followed by chaining or sheep trampling to cover the seed, and drilling with standard and deep furrow single offset disk drills. Row spacing was 30.5cm on standard drill treatments and 45.7cm on deep furrow seedings. A mixture of 'Alkar' tall wheatgrass, 'Nordan' crested wheatgrass and 'Luna' pubescent wheatgrass was used to seed all sites. The seeding rate for all drill treatments was 6.7kg/ha composed of equal amounts of the three seeded species. For broadcast treatments, the seeding rate was 11.2kg/ha composed of 4.5kg of crested wheatgrass and 3.4kg each for both tall and pubescent wheatgrasses.

The BLM divided the entire burned area into five units to facilitate the seeding work. Units Three, Four and Five were located within the study area (Figure 1). These units varied in size, contained different ecological sites and were seeded by different contractors with various combinations of the methods outlined above.

Unit Three was located in the northernmost portion of the study area on a semidesert gravelly loam ecological site. Its total size was approximately 3040ha, but only about one-half of this area was located within the study area.

Unit Three was seeded with standard drills in fall 1983 and spring 1984 by the K and B Excavating Company. Fall seeding with a single tractor pulling tandem drills began on November 11 and was finished by November 17, covering 225ha. Spring seeding began on April 18 the following year and continued until May 15, again by a single tractor with tandem drills. The total area seeded in spring was 1360ha.

Unit Four was located in the central portion of the study area and covered approximately 2540ha. Two ecological sites were identified within this unit. A desert gravelly loam site covered the eastern portion of the unit between about 1460 and 1615m in elevation. A desert loam site occurred on the western part of the unit between approximately 1380 and 1460m.

Approximately 285ha of the westernmost portion of the desert gravelly loam site were broadcast-seeded in fall 1983. The seed mixture was broadcast by plane on October 17. Beginning November 8, two tractors dragged an anchor chain over the area to cover the seed. This work was completed by November 14.

The remaining portion of the desert gravelly loam site and the entire area of the desert loam site, approximately 2230ha in total combined size, were seeded by Graham Brothers contractors with standard drills in fall 1983 and spring 1984. Beginning on October 15 and ending November 21, about 1515ha of the southernmost portion, covering both desert gravelly loam and desert loam ecological sites, were seeded by two tractors each pulling tandem drills. Between April 25 and May 13 of the following spring, the remaining 715ha of the desert gravelly loam site were seeded, again using two tractors pulling tandem standard drills.

Unit Five was located in the southern portion of the study area. It was the largest of the three units, approximately 5040ha, and contained four ecological sites. The desert flat site was the lowest in elevation, ranging from 1420 to 1450m, followed by desert gravelly loam (1430 to 1495m) and semi-desert gravelly loam (1480 to 1525m). The desert shallow loam ecological site, largely confined to steep hillsides with rock outcrops, was between 1490 and 1575m.

Several seeding methods were used in fall 1983 and spring 1984 to seed Unit Five. On October 19 and 22, seed was aerially broadcast on 315ha of the desert shallow loam site within the northwestern corner of the unit. On November 17 and 18, two tractors operated by employees of James Buffham dragged an anchor chain over the area to cover the seed. Seed was aerially broadcast on October 27 on a second desert shallow loam site, approximately 390ha in size, located in the southwestern corner of the study area. After broadcasting, the BLM asked grazing permittees to herd their sheep over the seeded area in an effort to cover the seed.

The largest portion of Unit Five was seeded with drills by K and B Excavating. Between October 20 and November 16, approximately 1660ha of the southern portion of this unit were seeded by three tractors each pulling tandem standard drills. The ecological sites within this area were desert flat and semidesert loam. In addition, between Novemeber 4 and 16, approximately 260ha of the semidesert loam site along the base of the Cedar Mountains were seeded with a single tractor and deep furrow drill. The remaining 1650ha within the northern part of Unit Five were seeded the following spring between April 18 and May 15. The desert loam and a portion of the desert gravelly loam sites were seeded with standard drills pulled in tandem. During the same period, areas of the desert gravelly loam site along the base of the mountains were seeded with a single tractor pulling one deep furrow drill.

METHODS

Six ecological sites were seeded within the TFRP study area (Table 1). Four methods were used to seed the sites including: 1) standard rangeland drill with single offset disks; 2) rangeland drill with deep furrow single offset disks; 3) aerial broadcast followed by chaining; and 4) aerial broadcasting followed by sheep trampling. Depth bands and packer wheels were not used on any of the drills. Drilling operations were conducted in fall 1983 and spring 1984. All broadcast seedings were done during fall 1983.

All possible combinations of sites, seeding methods and planting seasons were not represented within the study area. The basic sampling units therefore consisted of existing combinations of ecological sites, seeding methods and planting seasons. Thirteen such combinations (hereafter referred to as treatment combinations or TC) were identified within the study area. Table 2 lists the 13 TC and their respective approximate sizes.

Three permanently established transect clusters were randomly located within each of the 13 TC. Each of the 39 total transect clusters consisted of a 50m baseline and five 1 x 15m belt transects (Figure 2). These belt transects were spaced at 10m intervals perpendicular to the baseline and alternated sides along the baseline length. Transects were oriented parallel to furrows on drill seeded

Table 2.--Approximate sizes of treatment combinations (sites, planting seasons and seeding methods) located within the Tooele Fire Rehabilitation Project study area.

Treatment combination	Approx. size (ha)
Semidesert gravelly loam/fall/standard drill	220
Semidesert gravelly loam/spring/standard drill	1360
Semidesert loam/fall/deep furrow drill	260
Semidesert loam/fall/standard drill	1160
Desert gravelly loam/fall/standard drill	470
Desert gravelly loam/fall/broadcast-chained	280
Desert gravelly loam/spring/standard drill	710
Desert gravelly loam/spring/deep furrow drill	900
Desert loam/fall/standard drill	1050
Desert loam/spring/standard drill	1475
Desert flat/fall/standard drill	500
Desert shallow loam/fall/broadcast-chained	320
Desert shallow loam/fall/broadcast-sheep trampled	390
Total estimated ha seeded	9095

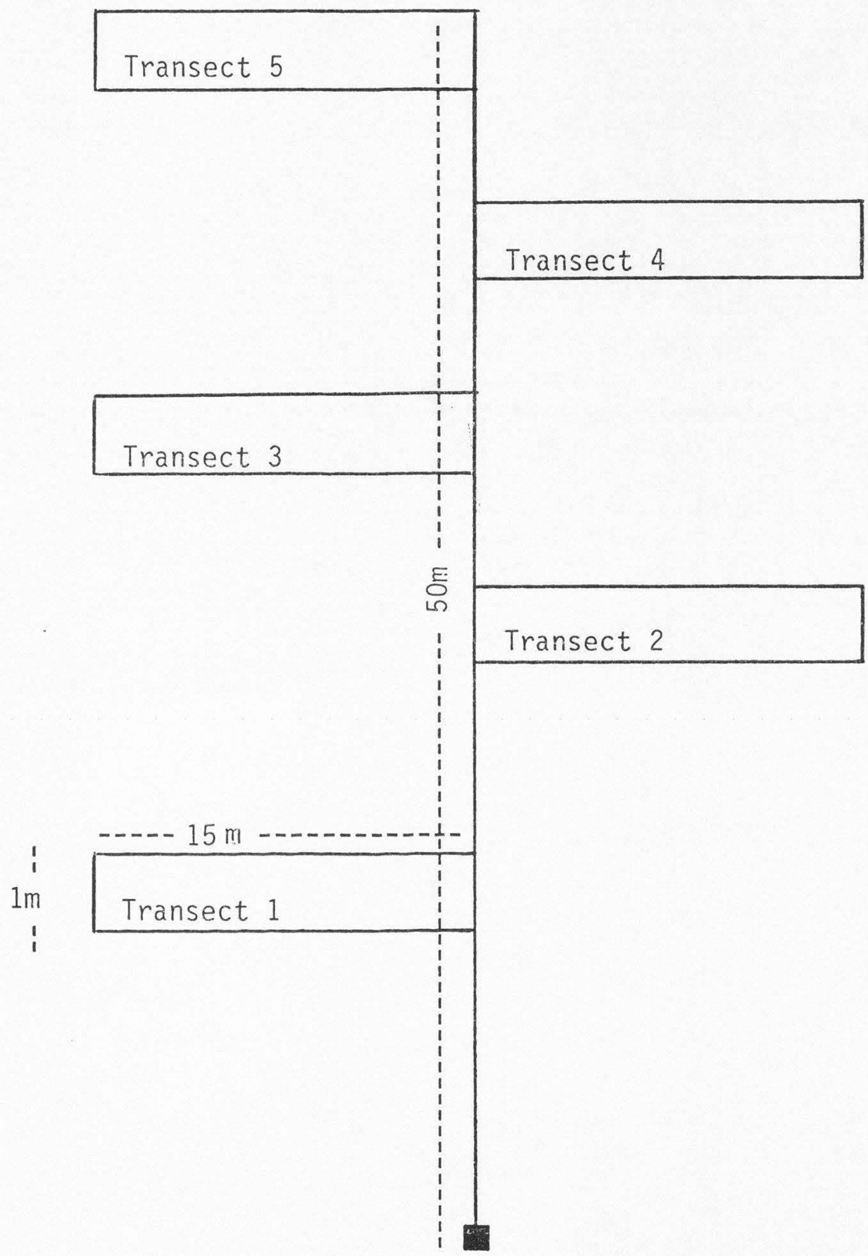

Figure 2.--Schematic representation of transect cluster design used to sample seedling density within the Tooele Fire Rehabilitation Project.

treatments. The first belt transect was always placed on the left side of the baseline 10m from the baseline starting point.

Data were collected during three time periods, beginning the first week of September in 1984 and 1985 and the second week of June in 1985. The combined number of crested wheatgrass, tall wheatgrass and pubescent wheatgrass seedlings were counted in each of the 195 permanently established transects. During the first data collection period, I attempted to count grass seedlings by species, but this proved too difficult to accomplish with a reasonable degree of certainty. All count data were converted to seedlings/m2 so that drilled and broadcast seeded treatments could be directly compared.

Data analysis was planned as a two-step process. First, all seedling density data were tested for significant differences between collection periods using analysis of variance (ANOVA) in a repeated measures design. In this model, TC and data collection periods were considered main effects. Transect clusters were treated as a nested term within TC; transects were a nested subsampling term within transect clusters. I was most interested in the collection period x TC interaction in this model. If this interaction was not significant, then the result would be interpreted to mean that there had been no changes in seedling numbers, and therefore survival, within TC among the three data collection periods. The ANOVA could then be reduced to a completely nested design and one time period's data used for all further analyses. All seedling density data cannot be pooled and used in this simplified analysis as counts obtained on permanently established transects between time periods are not independent of each other. If the nested model was used, I decided a priori to use count data collected during the last collection period as it best represented conditions at the conclusion of study.

The second step in the statistical analysis was to use one degree of freedom comparisons to test preconceived hypotheses about seeding success gained from literature review.

These hypotheses and their predicted outcomes are:

1) Semidesert versus desert precipitation zones. If the amount of precipitation is an important factor controlling seeding success, then semidesert precipitation zones should be more successful in terms of seedling density than desert precipitation zones;
2) Gravelly versus non-gravelly ecological sites. Rock-free soils are considered better adapted to seeding than those with rock. If this is true, gravelly ecological sites (>35% rock by volume) should be less successful than non-gravelly ecological sites (<35% rock);
3) Fall versus spring planting seasons. Fall plantings are generally considered to be more successful than spring plantings. This hypothesis tests this idea using several sites and seeding methods;
4) Fall versus spring planting seasons when both are seeded with a standard drill. A test of hypothesis three except using one seeding method across several sites;
5) Fall versus spring planting seasons within the desert precipitation zone and seeded with a standard drill. A second test of hypothesis three for one precpitation zone and one seeding method;

6) Broadcast versus drill seeding methods when both are used to seed during fall. Broadcast seeding is generally considered inferior to drill seeding. This hypothesis tests this idea across several sites;

7) Deep furrow drill versus standard drill when both are used during fall planting season. Deep furrow disks are considered more successful for seeding drier sites (<30cm average annual precipitation) than are standard disks. This hypothesis tests this idea over a variety of sites with under 30cm of average annual precipitation.

Hypothesis test results cannot be extrapolated beyond the study area boundaries, the specific years of this study and the specific sites, seeding methods and planting seasons examined.

RESULTS

While weather parameters were not monitored within the study area, monthly precipitation and temperature data for 1983 and 1984 were available from the Dugway weather station, approximately 10 km south (Table 3). Monthly temperatures over the study period were about equal to long term means. January and Febuary 1984 were exceptions; temperatures were 6.7 and 9.2C lower than respective normals during these two months. Precipitation was 197% of the 30-year normal in 1983 and 162% of normal in 1984. Between September 1983, one month before seeding began, and November 1984, the end of the first growing season after seeding, precipitation was 176% of the long term mean.

Within the total 195 permanent transects, there were only two crested wheatgrass plants and pubescent wheatgrass appeared to be totally absent. Therefore, reported seedling densities are composed almost entirely of tall wheatgrass.

No significant differences ($P \leq 0.05$) where found in mean seedling densities between the three data collection periods (Appendix, Table 9). Both the TC and cluster by collection period interactions were not significant ($P \leq 0.05$). This was interpreted to mean there were no significant changes in mean seedling densities counted on permanent transects between fall 1984 and fall 1985 (Appendix, Table 10).

Table 3.--Monthly precipitation and temperature data recorded in 1983 and 1984 at the Dugway weather station.

Precipitation (cm)

Month	1983	1984	30-year mean	1983 % of normal	1984 % of normal
January	2.5	1.3	1.3	192	100
February	3.0	1.0	1.5	200	67
March	5.0	2.2	1.6	313	138
April	2.7	4.7	1.9	126	247
May	1.2	0.8[1]	2.1	57	38
June	0.0	2.7	1.5	0	180
July	4.8	4.5	1.1	436	409
August	4.8	4.7	1.2	400	392
September	1.2	1.2	1.2	100	100
October	1.5	3.0	1.4	107	214
November	1.8	1.2	1.3	138	92
December	5.9	1.2	1.4	421	86
Totals	34.4	28.5	17.5	197	162

Temperature (C)

Month	1983 high	1983 low	1984 high	1984 low	30-year means high	30-year means low
January	4.6	-4.2	-4.2	-14.9	3.5	-8.2
February	8.2	-1.3	-1.5	-13.8	7.3	-4.6
March	11.1	1.4	8.7	-3.3	11.3	-2.3
April	12.7	0.6	14.3	1.4	16.7	2.1
May	20.6	4.9	--[2]	--[2]	22.9	7.0
June	27.8	11.5	27.0	10.0	29.0	11.9
July	33.2	16.4	33.1	15.9	34.7	16.9
August	31.6	17.3	31.9	15.9	32.9	15.6
September	26.9	11.2	27.3	10.4	27.1	9.3
October	19.2	3.9	14.7	1.1	19.3	2.7
November	9.5	-1.7	10.1	-2.5	10.1	-3.3
December	1.9	-5.4	1.8	-10.6	3.8	-7.4

[1]May 1984 precipitation was estimated using the normal-ratio method (Paulhus and Kohler 1952).

[2]Data not available.

Seedling density data collected during fall 1985 was used for all further analyses. The data collected during all three periods were not pooled because seedling counts were not independent between data collection periods. Such pooling would violate the independence assumption of the analysis of variance procedure (Glass et al. 1972). Fall 1985 data was used because it best represented seedling densities at the conclusion of the study. With the main effect of time removed, the analysis model was reduced to a nested design. Transects were considered to be nested within clusters and clusters were nested within TC.

Nested analysis of variance (Appendix, Table 11) indicated there were no significant differences ($P \leq 0.05$) between the 13 TC. Treatment means ranged from 1.9 to 0 seedlings/m2 (Table 4). There was significant variation ($P \leq 0.05$) between transect clusters within TC.

Only two of seven one-degree-of-freedom tests were significant (Table 5). Fall plantings were significantly better ($P \leq 0.05$) than spring on the desert gravelly loam, desert flat and desert loam sites seeded with a standard drill. On all fall plantings regardless of site, the combination of deep furrow and standard drill seeding methods was significantly better ($P \leq 0.05$) than the combination of chained and sheep-trampled broadcast seedings.

Table 4.--Treatment combination and transect cluster mean seedling densities for the Tooele Fire Rehabilitation Project study area.

Trt. no.	Ecological site/planting season/seeding method treatment combination	Cluster no. 1	2	3	Overall mean	CV[1]
		-----seedlings/m2-----				
1	Semidesert gravelly loam/ fall/standard drill	0.0	2.4	3.4	1.9	88%
2	Semidesert gravelly loam/ spring/standard drill	0.2	4.5	0.0	1.6	158%
3	Desert gravelly loam/fall/ standard drill	2.2	1.3	0.6	1.4	56%
4	Semidesert loam/fall/deep furrow drill	3.0	0.8	0.2	1.3	114%
5	Desert flat/fall/standard drill	1.7	1.4	0.0	1.0	89%
6	Desert loam/fall/standard drill	0.9	1.3	0.6	0.9	37%
7	Desert gravelly loam/fall/ broadcast-chained	0.7	0.0	0.0	0.2	133%
8	Semidesert loam/fall/ standard drill	0.0	0.1	0.5	0.2	125%
9	Desert shallow loam/fall/ broadcast-chained	0.1	0.3	0.0	0.1	100%
10	Desert gravelly loam/spring/ standard drill	0.0	0.0	0.0	0.0	--
11	Desert loam/spring/standard drill	0.0	0.0	0.0	0.0	--
12	Desert gravelly loam/spring/ deep furrow drill	0.0	0.0	0.0	0.0	--
13	Desert shallow loam/fall/ broadcast-sheep trampled	0.0	0.0	0.0	0.0	--

[1]Coefficient of variation between transect clusters.

Table 5.--Summary of one degree of freedom comparisons.

Comparison[1]	Mean density (seedlings/m^2)	Standard error of mean	Coefficient of variation (%)
Semidesert vs	1.1	0.30	147
Desert	1.1	0.17	101
Gravelly vs	1.7	0.27	145
Non-Gravelly	0.7	0.15	89
Fall vs	0.8	0.11	155
Spring	0.4	0.17	335
Fall (SD) vs	1.1	0.15	119
Spring (SD)	0.5	0.23	287
Fall (SD, D) vs	1.1*	0.16	100
Spring (SD, D)	0.0	0.01	300
Broadcast (F) vs	0.1*	0.15	120
Drill (F)	1.2	0.05	246
Deep Furrow (F) vs	1.3	0.42	124
Standard Drill (F)	1.1	0.15	120

[1]Comparisons were as follows:

Semidesert vs desert= Semidesert vs Desert precipitation zones seeded in fall with standard drill

Gravelly vs Non-gravelly= Gravelly vs Non-gravelly sites irrespective of precipitation zone seeded in fall with standard drill

Fall vs Spring= Fall vs Spring planting seasons across all sites and seeding methods

Fall (SD) vs Spring (SD)= Fall vs Spring planting seasons seeded with standard drill irrespective of precipitation zone

Fall (SD, D) vs Spring (SD, D)= Fall vs Spring planting seasons within desert precipitation zone seeded with standard drill

Broadcast (F) vs Drill (F)= Broadcast vs Drill seedings across all sites planted during fall

Deep Furrow (F) vs Standard Drill (F)= Deep Furrow Drill vs Standard Drill fall seedings across all sites

*Significant at $P \leq 0.05$

DISCUSSION

Evidence and Possible Causes of Seeding Failure

The results strongly suggest seedings within the Tooele Fire Rehabilitation Project (TFRP) study area were failures. Cook et al. (1967) considered range seedings with less than 2.7 seedlings/m2 as poor. The best ecological site/planting season/seeding method combination within the study area averaged only 1.9 seedlings/m2 and this was not significantly different ($P \leq 0.05$) from treatment combinations averaging 0 seedlings/m2.

Seedling density, however, is only one measure of seeding success. Uniformity of the seeded stand must also be considered (Hull 1954, Hyder and Sneva 1954). The significant variation ($P \leq 0.05$) between transect clusters suggests non-uniform seedling establishment within TC (Appendix, Table 11). Only three of 13 TC had seedlings in all three transect clusters and coefficients of variation between transect clusters within TC were also large (Table 4). Although the statistical analysis did not address variation between and within transects within clusters, my observations during data collection suggest this was large as well. Not all transects within clusters contained seedlings, even within clusters where mean seedling densities were high. Often, only one drill row within a transect would contain seedlings. These observations provide additional evidence of non-uniform seedling establishment within the study area and, therefore, seeding failure.

If the seedings are considered failures as seedling density and stand uniformity data suggest, then it is not possible to address the original objectives of this study. A determination of which ecological sites, planting seasons and seeding methods were most successful cannot be made using data from the seedings alone. The next best alternative is to examine possible causes for seeding failure.

Identifying the exact cause(s) for seeding failure within the TFRP is difficult. Vallentine (1971) listed 26 possible causes, alone or in combination, for seeding failures. The relative importance of each undoubtedly varies in time and place. Therefore, the discussion that follows is an appraisal based on the data collected during the study, the literature review, conversations with BLM personnel, entries in the TFRP logbooks, background information from BLM project files and my field observations.

Plummer et al. (1968) identified 10 principles and procedures necessary for successful range seeding. For the purpose of determining the causes of seeding failure within the TFRP, I have condensed these into six relevant questions based on my observations within the study area. First, were weather patterns over the study period conducive to seeding success? Second, could the ecological sites within the study area be seeded with a reasonable expectation of success? Third, were seeding methods adequate? Fourth, were these methods correctly applied during the proper season? Fifth, were the seeded species adapted to the area and was the seed of acceptable viability? Last, were there other factors present that could have contributed to seeding failure?

An appropriate starting point in addressing these questions is to compare the TC ranking in Table 4 with one based on the results of previous studies and experience. In other words, if I were asked to predict the relative order of success of the TC within the study area prior to seeding, how closely would this ranking resemble the actual results in Table 4? If the two rankings are highly correlated, then seeding failure may have been related to site and weather influences. The seeding results achieved would have been the best that could have been expected given the site and weather parameters at the time of seeding within the study area. If there is a low correlation between rankings, then other factors such as planting season, seeding method, seeding technique and/or low seed viability, may have been more important than site and weather influences in causing failure.

Several assumptions were made to construct this ranking. First, precipitation is the most critical factor determining seeding success (Cornelius and Talbot 1955, Plummer et al. 1955, Plummer et al. 1968). Therefore, seeding on semidesert sites should be more successful than desert sites. Second, planting season was considered the next most critical factor (Monsen and McArthur 1985). Fall plantings should be more successful than spring (Douglas et al. 1960, Hull et al. 1950, Klomp and Hull 1972, Parker 1961, Plummer et al. 1955, Plummer et al. 1968, Rummell and Holscher 1955, Stark et al. 1946, Stewart et al. 1939, Vallentine et al. 1963, Walker and Bracken 1938). Third, sites with deep soils should be more promising to seed than those with shallow soils (Plummer et al. 1955, Rummell and Holscher 1955, Vallentine et al. 1963, Stewart et al. 1939). Therefore, the shallow loam sites within the study area should be the least successful. Fourth, gravelly soils were considered less adapted to seeding than those without rock when soil texture and depth were equal (Vallentine et al. 1963). Last, drill seeding should be more successful than broadcasting (Douglas et al. 1960, Drawe et al. 1975, Hull and Holmgren 1964, Hull and Klomp 1967, Keller 1979, Klomp and Hull 1972, Nelson et al. 1970, Plummer et al. 1955). Deep furrow drills should produce more seedlings than standard drills, all other conditions being equal (Vallentine 1971, Vallentine et al. 1963). I was unable to find a comparison in the literature of chaining versus sheep trampling to cover broadcast seed, but I assumed that chaining would be the more successful method because this treatment could be applied more uniformly over a seedbed.

To construct the proposed TC ranking, I first split the TC into two groups based on precipitation zone. Next, I separated the TC within each precipitation zone into "most successful" and "least successful" catagories. This procedure yielded a total of four treatment groups. Generally, fall plantings with the drill were considered the most successful treatments. Spring plantings and broadcast seedings were considered the least successful. The TC were then arranged from best to worst on the basis of soil depth and rockiness within each group. Loam soils were considered to have a higher potential for seeding success than gravelly loams. Shallow loam sites had the least chance of success.

The one exception to this ranking procedure was the desert flat/fall/standard drill TC. I considered this TC to have a low potential for seeding success for two main reasons. First, the desert flat ecological site is found at the lowest elevation and landscape position of any of the sites within the study area (Appendix). Average annual precipitation on this site, therefore, is also the lowest of any of the sites considered in the study. Second, soil texture on this site ranges from moderately fine to fine and permeability is moderately slow to very slow. This suggests that the limited amount of precipitation that does fall on this site is easily lost to evaporation (Blackburn 1975). Evaporation loss would be highest when air temperatures are warm enough for seed germination and seedling growth. In addition, these fine texture soils have a high potential to form surface crusts (Hugie and Passey 1964) that would reduce seedling emergence (Wood et al. 1978, Wood et al. 1982). For these reasons, I ranked the desert flat/fall/standard drill TC lower in terms of potential seeding success than would be expected based on the above assumptions alone.

The expected ranking was compared with the actual TC ranking based on mean seedling densities using Spearman's rank correlation procedure (Table 6). The correlation (r_s=0.6) between rankings suggests a weak positive relationship. If it is reasonable to assume that a perfect correlation indicates seeding failure resulted from site and weather limitations, and that no correlation suggests failure attributable to other factors, then the intermediary value of r_s suggests both factors are possible causes for seeding failure. The ranking comparison does not clearly eliminate any of the possible causes for seeding failure.

Table 6.--Comparison of actual treatment combination ranking obtained from seedling density data collected during fall 1985 and expected ranking based on literature review.

Treatment Combination	Actual Rank	Expected Rank[1]
Semidesert loam/fall/deep furrow drill	4	1
Semidesert loam/fall/ standard drill	7	2
Semidesert gravelly loam/ fall/standard drill	1	3
Desert loam/fall/standard drill	6	4
Desert gravelly loam/fall/ standard drill	3	5
Semidesert gravelly loam/ spring/standard drill	2	6
Desert gravelly loam/ spring/deep furrow drill	9	7
Desert gravelly loam/ spring/standard drill	9	8
Desert loam/spring/ standard drill	9	9
Desert gravelly loam/ fall/broadcast-chained	7	10
Desert flat/fall/ standard drill	5	11
Desert shallow loam/fall/ broadcast-chained	8	12
Desert shallow loam/fall/ broadcast-sheep trampled	9	13

[1]Spearman's rank correlation coefficient of actual and expected ranking is $r_s = 0.60$.

The only remaining procedure to identify why the TFRP seedings were failures was to systematically examine the six questions posed at the beginning of this discussion.

Planting Season

Spring seedings within the study area probably had little chance of being successful. Spring is an unreliable time to seed rangelands in the Intermountain area (Hull et al. 1950, Plummer et al. 1968, Vallentine 1971, Vallentine et al. 1963).

Notations in BLM logbooks suggested wet soil conditions when spring seeding began in April 1984. Table 3 shows April 1984 precipitation was 247% of normal. This would indicate that conditions were too wet in April for seeding. Seed tubes could easily become plugged and fail to deliver seed under these conditions. Soil sloughing from furrow berms could have buried many seeds too deep to emerge. On May 4, 1984, BLM log entries indicated the soil surface had dried and drill disks were not cutting well-formed furrows. Spring seeding continued until May 13.

Stark et al. (1946) concluded spring seeding was successful when rainfall was received after planting. Precipitation during June, July and August of 1984 was 180, 300 and 391% of normal, respectively (Table 3). Even so, spring seedings within the study area were among the poorest treatments (Table 4).

Seeding Method

Choices of seeding methods were a minor cause of failure. Broadcast seedings ranked among the poorest treatments within the study area (Table 4). This was because the desert shallow loam site, where most of the broadcast seeding was done, was not a high potential site and should not have been seeded. Portions of the desert gravelly loam site were also broadcast seeded. I saw no restrictions that would have precluded using a drill on this site. Drill seeding would have increased the chances of seeding success.

Site Suitability

There is evidence that most ecological sites within the study area were suitable for seeding. Three seedings existed in the study area prior to the burn. The first was established by the BLM prior to the Tooele wildfire near Post Hollow on a semidesert loam site. This site probably has as high a potential for seeding as any other within the study area. Precipitation averages between 25 and 30cm annually. Soils are deep (approximately 60cm) and surface texture is loam to silty loam. In addition, this site is located within a long, moderately narrow valley and probably receives run-off moisture from hills on either side. The seeding covered approximately 350ha and was planted in the fall of 1982 with a rangeland drill (BLM, pers. comm.[2]). Crested wheatgrass, intermediate wheatgrass and pubescent wheatgrass (varieties unknown) were the dominant species within the seeding, but Russian wildrye and tall wheatgrass plants were present as scattered individuals.

I counted established plants within 10 randomly located 1 x 15m transects oriented parallel to drill rows to obtain an estimate of

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[2]Information provided by USDI Bureau of Land Management personnel, Salt Lake City District Office.

seeded plant density. Mean density was 7.4 plants/m2 (S.E.= 0.4). Cook et al. (1967) considered seeded stands with 5.4 seedlings/m2 as good and 8.1 seedlings/m2 as excellent.

The two other seedings within the burn were established on October 7, 1983 by the Agricultural Research Service (ARS). Both were small scale plantings of approximately 0.5ha, and were planted using four methods of seedbed preparation and seeding (Horton and Asay, unpublished data3). Nine perennial grass cultivars were planted including 'Hycrest', 'I-28 Synthetic' and 'Nordan' crested wheatgrasses, 'Alkar' tall wheatgrass, 'Vinall' and 'Bozoisky-select' Russian wildrye, 'Luna' and 'Mandan' pubescent wheatgrasses, 'Piute' orchardgrass (*Dactylis glomerata* L.) and the RS-2 hybrid of quackgrass [*Elytrigia repens* (L.) Nevski X bluebunch wheatgrass *Pseudoroegneria spicata* (Nevski) A. Löve].

Ten randomly placed 1 x 15m transects oriented parallel to drill rows were located in each seeding plot to obtain an estimate of seeded species density. The first seeded plot was located within TFRP Unit Three on a semidesert gravelly loam ecological site. Seedling density within this plot averaged 7.1 seedlings/m2 (S.E.= 0.3). The area immediately surrounding this plot was seeded in spring and fall as part of the TFRP. Fall TFRP plantings averaged 1.9 seedlings/m2 and the spring seeding averaged 1.6 seedlings/m2. The second seeded plot was located to the east of Unit Three on a desert flat ecological site. This plot averaged 5.3 seedlings/m2 (S.E.= 0.3) while TFRP seedings on

[3]W. H. Horton and K. H. Asay. Methods of seeding perennial range grasses on cheatgrass dominated burn areas. Unpublished manuscript.

the same ecological site averaged only 1.0 seedlings/m2.

The three existing seedings within the study area ranged from lowest seeding potential (desert flat site) to highest (semidesert gravelly loam). The composite mean density of these seedings was 6.6 seedlings/m^2 compared to 0.6 seedlings/m^2, the mean of all TC considered in this study. This suggests limited site potential was generally not a major cause of seeding failure.

The desert shallow loam site was an exception, however. This site would be difficult to successfully seed. Soils are shallow (20-50cm) and of medium to moderately coarse texture. Pebbles and small stones cover about 40-70% of the soil surface. Because of the steep site topography, drilling is not practical. This site was broadcast seeded and chained or sheep-trampled but seedings were not successful (Table 4).

Seeded Species

I found only two crested wheatgrass plants over a 1-1/2 year period of data collection in a total of 195 permanently established transects. Crested wheatgrass was well established in the two ARS seeded plots and on the existing BLM seeding near Post Hollow. Of the three perennial grass species seeded within the TFRP, crested wheatgrass was the best adapted to the study area precipitation and soil conditions and is easy to establish (Forsberg 1953, Jordan 1981, Plummer et al. 1955, Plummer et al. 1968, Rogler and Lorenz 1983, Stevens 1983, Thornburg 1982, Vallentine 1961, Weintraub 1953).

It is difficult to explain the absence of crested wheatgrass throughout the study area. Enough site variation exists within the study area to indicate that even if conditions were unsuitable in one area, other areas should have supported crested wheatgrass. Seeding methods and planting seasons were used in enough combinations that crested wheatgrass should have been present on several TC, if not in well established stands then at least as scattered individual plants. Even though the rangeland drill may have buried some seeds too deeply and left others uncovered, some crested wheatgrass seed should have been placed between these two extremes just through random chance. Some of this seed should have germinated and some of those seedlings should have become established.

Neither seed viability nor seed age appear to be causative factors. Tests conducted just prior to seeding by the Division of Plant Industry, Utah State Department of Agriculture indicated the crested wheatgrass seed was 97% pure and germination was 90% (Table 7). Although the seed was not certified, I doubt the lack of certification contributed to seeding failure in light of these germination tests. There is a possibility that much of the seed did germinate after planting, but seedlings perished for some reason. Still, I saw no evidence of large (or small) numbers of dead seedlings while collecting data, so I dismissed this possibility. Therefore, I have no explanation for why crested wheatgrass was not present in the study area, but must conclude its absence was a major cause of seeding failure.

Seeding Technique

Four points of evidence suggest seeding technique was the major cause of seeding failure within the TFRP study area. First,

Table 7.--Summary of seed inspection reports completed by the Utah Department of Agriculture, Division of Plant Industry for perennial grass species seeded on the Tooele Fire Rehabilitation Project study area.

Cultivar and Common Name	Seed Origin	Certified	Pure live Seed (%)	Germ. (%)	Date Sampled
'Nordan' CWG[1]	Montana	No	97	90	9/28/83
Nordan CWG	Montana	No	97	90	10/10/83
Nordan CWG	Montana	No	97	90	10/23/83
Nordan CWG	Montana	No	97	90	11/16/83
PWG[2]	Colorado	No	95	88	10/13/83
'Luna' PWG	Colorado	No	95	85	10/20/83
'Alkar' TWG	Utah	No	95	88	10/05/83
Alkar TWG	Utah	No	97	90	11/16/83

[1]CWG=crested wheatgrass, PWG=pubescent wheatgrass, TWG=tall wheatgrass.

[2]Lab report did not specify whether this seed lot was a named variety.

contractors and work crew members involved in drilling operations had little or no rangeland seeding experience (BLM pers. comm.). In addition, BLM log entries stated at least one-work crew member resigned during seeding operations and was replaced with an equally inexperienced employee. As such, these workers could not calibrate drills to plant seed at desired rates. They also lacked the experience to ensure that drills were scalping furrows adequately and that equipment was otherwise functioning properly. In addition, the workers probably could not recognize unsuitable ground conditions for seeding. As a result, one drill was stuck in mud for two days and could not be removed until the soil dried (BLM, pers. comm.).

Second, the speed at which drills are operated during seeding can affect seeding success (Horton, pers. comm.[4]). If drills are pulled too fast, they tend to bounce and skip across the soil surface and furrows appear discontinuous, especially on areas with uneven microtopography. I found no references in the literature addressing drill speed as a variable in seeding success, but BLM contracts specified 6.5km/hr as a maximum allowable speed. Common sense would suggest proper drill speed is affected by temporal and physical site conditions and best determined during actual seeding operations.

Workers inexperienced with seeding equipment may not know when or how to adjust drill speed to site conditions. I noticed several areas within the study area where furrows were discontinuous. This was especially common on shadscale sites with coppice dune and interspace

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[4]W. H. Horton, Support Scientist, Agricultural Research Service, Forage and Range Research Laboratory, Logan, Utah.

microtopography. Furrows were well-formed on coppice dunes but not in the dune interspaces. This could have been caused by operating drills at high speeds. BLM logbooks also indicated that drill operators may have been moving too fast to effectively seed.

I attempted to estimate the average drill speeds for seeding units within the study area. Estimates (Table 8) were based on hectares seeded per unit, the number of drills used to seed each unit, total days spent seeding and an estimate obtained from the BLM logbooks of the average number of hours each drill was operated during the day. These numbers underestimate actual average speeds because time spent to refuel and load seed was not subtracted from the number of hours worked/drill/day. These estimates do not suggest that drills were operated in excess of contract specifications or at speeds too high for successful seeding, but considering the other evidence, this cannot be discounted as a possibility.

Third, drills were inadequately equipped to properly seed. All drill seeding was done with single offset disk rangeland drills, but no depth bands were used to ensure seed was planted at correct depths (BLM, pers. comm). Horton and Asay (unpublished data) found that drills without some positive means of depth control buried some seed too deeply and allowed others to remain uncovered.

Double disk drills form better furrows on uncultivated seedbeds, such as those in the TFRP (Horton, pers. comm.). Furrows within spring planted, single offset disk, deep furrow drill treatments were discontinuous along their length in many areas. In these treatments however, the disks did cut through the surface layer but the soil did

Table 8.--Estimated average operating speeds of rangelands drills used to seed the three units of the Tooele Fire Rehabilitation Project study area.

Seeding Unit	Drill Type	Planting Season	Estimated Speed[1]
			--km/hr--
3	standard disks	fall	3.4
3	standard disks	spring	1.3
4	standard disks	fall	2.2
4	standard disks	spring	3.2
5	standard disks	fall	2.0
5	standard disks	spring	2.0
5	deep furrow disks	fall	2.5

[1]Calculations of estimated speeds are based on total hectares seeded by each method, number of drills used, drill width, total days spent seeding and an estimate of the number of hours each drill was operated per day.

not pile into berms on either side of the furrow. It appeared that cheatgrass had established in dense stands on these treatments prior to seeding. The cheatgrass bound the soil into a thick sod. As the drill passed, the offset disks cut through the sod, lifted it up and attempted to form a berm but then the bound sod sprang back and resealed the furrow after the disks passed. This could have been avoided by using a double disk drill.

Last, there were abrupt changes in seedling density within furrows and between adjacent furrows on many areas. This was expressed more as an all or nothing appearance than a simple reduction or increase in seedling numbers. For example, a row of seedlings would be present along some length of a single drill row but then abruptly stop leaving a long section of the same row without seedlings. In other cases, only one or two of three adjacent drill rows within a transect would contain seedlings, even though all were made with the same pass of the same drill.

Three possibilities, alone or in combination, might explain the abrupt changes in seedling density. First, during wet conditions drill seed tubes became plugged with mud and failed to deliver seed. BLM logbooks noted that this did indeed happen on several occasions. Second, operators could have been drilling when drill seed bins were empty. Last, BLM logbook entries stated that after seed was delivered to the work site it was often left uncovered, even during rainstorms. If this seed became wet and was then placed in the drill seed bins, it would not feed smoothly into seed tubes. Seed would not be dropped onto the seedbed as a result.

Weather

Weather data (Table 3) indicate precipitation over the study period was 197% of normal in 1983 and 162% of normal in 1984. Precipitation was 179% of the long term mean for the period between December 1983 and March 1984 and 223% of normal for the period April through August 1984. Monthly high and low temperatures within these same periods were approximately normal. January and February temperatures in 1984 were below normal (Table 3), but probably not enough to cause high seedling mortality (Rogler and Lorenz 1983). Overall, these weather data suggest inadequate precipitation or extreme temperatures were not a cause of seeding failure.

It is possible that excessive precipitation could have reduced seeding success. Wood et al. (1982) found, under conditions of above average spring rainfall in Nevada, seedling emergence was reduced on soils with a massive surface horizon when seeded with a deep furrow drill. Saturated soil along furrow berms flowed into furrow bottoms and buried seeds too deeply to emerge. There was little visual evidence that soil movement of this type occurred uniformly over the study area, but some smaller areas did appear as though the berms created by the disks had been eroded. This soil would have accumulated in the furrow bottoms deeply burying some seeds.

Grasshopper Damage

The potential for rangeland forage and seedling destruction by grasshoppers is well recognized. In 1983, 1984 and 1985, estimates of grasshopper densities in Skull Valley were 10-25, 25-45 and 60-119/m2, respectively (W. Bitner, pers. comm.[5]). These densities represent extremely high population levels. Hewitt and Onsager (1983) stated grasshopper densities on western rangeland of 30-40/m^2 were not uncommon yet some areas seldom exceed 1/m^2.

The continued productivity of the two ARS seeding plots provides evidence that grasshopper damage was not a principal cause of seeding failure, even though grasshopper populations were extremely high. These plots were seeded October 7, 1983; contractors working on the TFRP began seeding one week later in the same area. Averaging over the four seeding methods and nine grass species planted on the semidesert gravelly loam ARS plot, forage production was 491kg/ha (S.E.= 196 kg/ha) in 1984 and 779kg/ha (S.E.= 315kg/ha) in 1986. The second plot on the desert flat site averaged 441kg/ha (S.E.= 274kg/ha) in 1984 and 442kg/ha (S.E.= 279kg/ha) in 1986 (Horton and Asay, unpublished data). If grasshoppers were responsible for destroying the 9,000ha TFRP seeding, then why were ARS seeding plots, about 1ha in combined size, not destroyed as well?

The evidence suggests spring planting, broadcast seeding and seeding technique were inadequate to produce successful seedling germination and establishment within the study area. If this is correct, then seeding failure already occurred before grasshoppers hatched and reached growth stages harmful to the seedlings. In addition, if newly germinated seedlings had been destroyed by grasshoppers, the bases of grazed seedlings would have been present and easily observed in the seedbed. Yet, no visual evidence suggested

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[5]Telephone conversation on April 7, 1987 with W. Bitner, County Agricultural Extension Agent, Tooele, Utah.

seedlings were ever present. Therefore, grasshopper damage was associated with or possibly additive to seeding failure, but was not a principal cause.

Cheatgrass Competition

Cheatgrass was present in the study area prior to the Tooele wildfire and after burning became the dominant species on the site. Cheatgrass competition is considered a major factor leading to seeding failure on western rangelands (Evans 1961, Harris 1967, Harris and Wilson 1970, Hull 1964, Klemmedson and Smith 1964, Shown et al. 1969, Stewart and Hull 1949).

The evidence for dismissing cheatgrass competition as a cause of failure is neither clear nor strong. However, if cheatgrass did cause seeding failure, then its effects would have been most strongly expressed after perennial grass seeds germinated. The lack of dead seedlings within transects suggests competition did not occur. In addition, during the first period of data collection in fall 1984, cheatgrass was not established in or near furrow bottoms, even though sufficient rainfall for cheatgrass germination had fallen prior to this time (Table 3). Cheatgrass established instead on furrow berms. This establishment pattern should have given the seeded species an opportunity to grow, for at least a portion of one growing season, without any major competition from cheatgrass. Therefore, cheatgrass competition must be considered, at best, additive to seeding failure, but not a principal cause.

SUMMARY AND CONCLUSIONS

Seedings within the Tooele Fire Rehabilitation Project study area were failures. As a result, meaningful conclusions concerning the most successful ecological sites, planting seasons and seeding methods within the TFRP cannot be given. Seeding success cannot be determined on the basis of evidence provided from seeding failure alone.

Study effort was redirected to determine possible causes for seeding failure within the TFRP. Planting seasons, seeding methods, site suitability, seeded species, seeding technique, weather, seedling mortality caused by grasshoppers and cheatgrass competition were identified as possible causes. Each factor was examined using information provided by seeding density data collected during the study, literature review, conversations with BLM personnel involved in the TFRP, entries in TFRP logbooks, TFRP background files and my field observations.

Seeding methods and planting seasons contributed to seeding failure. Broadcast seeding was the method most associated with failure. This seeding method is not often successful. Portions of the desert gravelly loam site that were broadcast seeded could have been planted with a drill, greatly increasing the chances of seeding success on this site. If the desert shallow loam site was excluded from seeding consideration, it would not have been necessary to broadcast seed within the TFRP at all. Spring plantings probably had little chance of being successful. Soil conditions were too wet when seeding began in April and were too dry one month later when operations ceased. The period suitable for seeding between these extremes was too short to successfully seed any appreciable amount of ground.

Most ecological sites within the study area were suitable for seeding. A BLM seeding, planted prior to the TFRP seedings, was successful. In addition, two small experimental seedings, established by the ARS one week prior to the beginning of seeding work on the TFRP, were successful. One plot was located on a semidesert gravelly loam site and the other on a desert flat site. These two sites approximate the end points of a site suitability spectrum from high (semidesert gravelly loam site) to low (desert flat site) seeding potential. Most other seeded sites within the TFRP fall between these two extremes and therefore had the potential to be successfully seeded.

The desert shallow loam ecological site was an exception, however. This site is steep and has a very shallow, rocky soil. Broadcast planting was the only method suitable for seeding this site. The desert shallow loam site has very low potential and should not have been seeded.

Planting season, seeding method and site suitability explain only localized seeding failure. They do not explain the ubiquitous failure indicated by seedling density and stand uniformity data and therefore were not considered principal causes.

The absence of seeded crested wheatgrass plants in the study area was a major factor causing seeding failure. Only two crested wheatgrass plants were found on 195 permanently established transects in the study area. I have no reasonable explanation for the absence of crested wheatgrass. Seed germination tests performed by the Utah Department of Agriculture indicated seed viability was not a factor. Crested wheatgrass is easy to establish and was the best adapted grass to existing site conditions of the three species planted.

Seeding technique was considered the most important factor causing failure within the study area. Contract workers had no prior rangeland seeding experience. They may have pulled the drills too fast at times and otherwise seeded during periods when soil conditions were not suitable. Abrupt changes in seedling numbers within furrows and between adjacent furrows suggest that seed tubes may have been plugged with mud at times and failed to deliver seed to the seedbed. It is also possible that drill seed bins could have been empty or that wet seed was placed in these bins.

Drills used on the TFRP were inadequately equipped to properly place seed in the soil. No depth bands were used to ensure seed was uniformly planted at correct depths. Some seed could have been buried too deeply and some would have been left uncovered. The single offset disks on these drills were ineffective in cutting well-formed furrows. This was especially true on deep furrow treatments planted in the spring.

I found no evidence to suggest precipitation was inadequate or temperatures too extreme over the study period to cause seeding failure. Precipitation was far above normal and temperatures were about equal to 30-year means. It is possible excessive overland flow during some storms could have caused furrow berms on drill seedings to erode and bury some seedlings too deeply, but I saw little physical evidence that this occurred over a large enough area to be a major factor.

Cheatgrass competition with grass seedlings and grasshopper-caused seedling mortality were factors that might have further reduced seeding success, but they were not the main factors that caused failure. Seeding failure occurred long before either cheatgrass or grasshoppers could have been influential.

RECOMMENDATIONS

Rangeland seeding failure can occur for a variety of reasons. Some factors are within the control of land managers, others are not. The TFRP seedings failed for reasons within the control of project managers. The purpose of this section is to provide some suggestions that may be valuable in planning future seeding operations.

Planting Season

In areas such as Skull Valley, seeding should be done only in fall. If there is a choice, late fall (late October to late November) is preferred. Late fall planting will prevent seedlings from germinating until spring when moisture and temperature conditions are most favorable for survival. Early fall (September to mid-October) seedings are the next best alternative, although inadequate fall moisture and loss of seedlings to winter-kill present formidable obstacles to success.

Spring planting should be avoided. Because of adverse site conditions, seeding often must be delayed until after the optimum period for seed germination and seedling growth. When seeds germinate, seedlings have only a short time to become established before the dry summer period. This is not to say that spring seeding cannot be successful. If moisture and temperature conditions are favorable, seedlings may be able to grow rapidly enough to withstand summer drought. The problem is that managers cannot control spring weather patterns and therefore the risk of spring seeding failure will always be great.

Seeding Method

When topography and soil conditions permit, rangeland seedings should always be done with a drill. Drill seeding is preferred to broadcasting because drills use less seed, better control planting depth and more uniformly distribute and cover seed. Depth bands should, almost without exception, be used on drills. Seed bins should be equipped with an agitator to ensure that seed feeds smoothly into seed tubes. Drills should also have packer wheels to firm the seedbed. These wheels improve soil-seed moisture relations and help cover seed. On burned areas where seedbeds are free of debris, a double disk grain drill with depth bands forms excellent furrows and accurately places seed at the desired depth.

Deep furrow disks have certain advantages over standard disks. The deep furrows made by these disks can collect water and remove shallow rooted weedy plant species from the area around the seed. Deep furrows also moderate extreme temperatures. On the other hand, the berms around deep furrows can erode easily and bury seedlings. Because of this, deep furrow disks should not be used in coarse-textured soil. Deep furrow disks can remove the thin organic and A horizons common on rangeland soils, reducing the chances of seedling establishment. In addition, these deep furrows act as seed depositories in areas where cheatgrass is common. The advantages and disadvantages of deep furrow disks should be weighed with respect to site conditions before they are used in seeding operations.

Broadcast seeding may not be the preferred method, but there are times when it can or must be used. Steep topography can make drill seeding impossible on some sites, for example. The most important factor in the appraisal of broadcast seeding is whether adequate seed coverage with soil can be obtained. Seed must be covered or the seeding will fail. To accomplish this, seeded areas may need to be small, especially if livestock are used to trample seed into the ground.

The best broadcast seeding method may be the disk-chain currently used in Texas and being tested in the Intermountain West. Not only does this method provide for seed converge by the soil, but it has weighted chain spreaders which firm the seedbed during the same pass. The one disadvantage of the disk-chain, like all broadcast methods, is it requires more seed than drilling methods to be successful. This adds to seeding costs, at least under present conditions of relatively expensive seed.

Site Suitability

Determining the most suitable sites to seed is difficult. The ideal site has often been described as having deep, fertile soil with medium to fine texture and high organic matter content. It is rare that a manager finds such a site on an area that needs revegetation. To compound matters, researchers have not identified the relative importance of seedbed characteristics for seeding success. Until this is accomplished, site evaluation will have to be made by professional judgement backed with considerable rangeland seeding experience.

There are some principles helpful in selecting suitable seeding sites. Given a particular area, only the best sites should be seeded. This makes sense both biologically and economically. Managers with seeding experience can use site characteristics they feel are most important to success to form a relative site ranking. Managers must also be cautious when gauging site suitability by existing seedings. Seedings can be established in years of above normal precipitation giving the false impression of success as the site may not support a long-lived stand.

Seeded Species

Only plant species adapted to the site should be used in seeding operations. If possible, a mixture of adapted species and growth forms should be used. Of course, management objectives, cost, seed availability and other factors play roles in determining what can be seeded as well. For example, tall wheatgrass was readily available at the time the TFRP work began, but this species is not well adapted to Skull Valley climate and soil conditions. If precipitation patterns become drier over the next few years, tall wheatgrass plants in the TFRP seeding may die.

One factor rarely discussed or given thought when buying seed is the origin of that seed. In an area as dry and hot as Skull Valley, this factor may be extremely important in terms of not only seeding success but stand longevity. There is considerable variation in drought tolerance even within plant cultivars. Crested wheatgrass strains that have been produced for several generations in Montana, for example, may not be as drought tolerant as the same cultivars grown in southern Utah or northern Arizona. If it is possible to take origin into account, seed should be puchased from areas that are as similar to the area to be seeded as possible. If a choice between seed sources produced on a wetter site or sources from drier sites must be made, seed produced on the drier site should be used. Some yield may be sacrificed, but the seeding will have a greater chance of success.

Other Considerations

Contracting government work may be cost effective, but this is only true if product quality is identical among potential contractors. It is clear from the evidence presented in this study that seeding technique was largely responsible for the seeding failure within the TFRP study area. This happened largely because contractors had little experience with rangeland seeding. In the future, more care should be used in selecting who is awarded government bids. Part of the criteria used to make such decisions must include work experience relevant to the task at hand. It would also be beneficial if contractors were either constantly supervised or held responsible for project quality in some fashion.

Several sources of assistance are available and can be used during each step of a seeding project. The SCS, ARS, Intermountain Research Station and Cooperative Extension Service are some examples. Bureau of Land Management personnel should not be excluded from consideration. Personnel with considerable seeding experience can be found within each of these agencies and can provide assistance in planning, conducting and evaluating seeding projects. Several of these sources, not just one, should be consulted if for no other reason than to provide an independent constructive evaluation of seeding plans and operations.

Time is of the essence in rehabilitation work, but other factors may dictate the pace. Perhaps the TFRP seedings within the study area would have been successful if more time had been alloted to complete the project. It might have been unrealistic to expect an area the size of the TFRP to be successfully seeded in the fall of 1983 and spring of 1984.

In future projects, I would recommend one of two courses of action be taken. The first is to space the seeding work within projects over a short period of years. This will allow time to properly plan the project, obtain the materials and equipment required to successfully complete the work and evaluate each step. While such a procedure may create additional costs for seedings planned near the end of the project time frame and increase the risk of site damage, success would be more certain. The alternative is to award bids to a larger number of contractors. In this way, each would be responsible for seeding a smaller area. Delays because of equipment failure or weather would not be as critical and the seeding work could be completed in minimal time. In addition, actual planting operations could be conducted within a short time period that would best assure seeding success.

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APPENDIX

DESERT FLAT

Classification

Site name: desert flat
Site number: D28X119U
Habitat type: Atriplex confertifolia/Ceratoides lanata/Elymus elymoides
Associated sites: desert loam, alkali flat and desert salt flat.

Physical Characteristics

Physiographic features:

This site occurs on lake plains. Slopes are mostly 0-3%. Elevations range from 1280 to 1460m on all aspects.

Soils:

Characteristic soils on this site are 25 to 50cm deep and are somewhat poorly to well drained. Parent materials are lacustrine and alluvial sediments derived mainly from limestone and quartzite. Textures are moderately fine throughout the profiles. Soils are nonsaline to moderately saline and moderately alkaline through very strongly alkaline in subsoil horizons. Soils on this site are sodium-affected and calcareous throughout. Permeabilities are moderately slow through very slow. Runoff is slow and erosion hazard is slight. The available water capacities are between 8 and 15cm. Representative soil taxonomic units given for this site are fine-silty, mixed, mesic Typic Natrargids and fine, mixed, mesic Typic Natrargids.

Climatic features:

Mean annual precipitation is 12 to 20cm. Approximately 70 percent falls as rain between March and October. On the average, July, September, January and February are the driest months and April, May and June are the wettest months. The mean annual air temperature is between 7.7 and 11.6C. The average frost-free period is 100 to 160 days.

Potential natural plant community:

The dominant aspect of the climax plant community is shadscale (Atriplex confertifolia). The composition of this community by air-dry weight is approximately:

Plant species	Common name	Percent by weight
Total Grasses		(10-15)
Elymus elymoides	bottlebrush squirreltail	5-10
Oryzopsis hymenoides	Indian ricegrass	3-5

Hilaria jamesii	Galleta	1-2
Poa nevadensis	Nevada bluegrass	0-1
Total Forbs		(3-5)
Total Shrubs		(80-90)
Atriplex confertifolia	shadscale	50-60
Ceratoides lanata	winterfat	10-15
Artemisia spinescens	bud sage	5-10
Kochia americana	gray molly	3-5
Other shrubs		2-3
Sarcobatus vermiculatus	black greasewood	
Chrysothamnus viscidiflorus	Douglas rabbitbrush	
Tetradymia glabrata	littleleaf horsebrush	
Ephedra sp.	Morman tea	

DESERT LOAM

Classification

Site name: desert loam
Site number: D28-124U
Habitattype: Oryzopsis hymenoides/Atriplex confertifolia/ Artemisia spinescens/Ceratoides lanata
Associated sites: desert flat, desert alkali bench, alkali flats and desert silt flats.

Physical Characteristic

Physiographic features:

This site occurs on gently sloping desert mesas, benches, flood plains, low lake terraces and alluvial fans. Slopes are mostly 0 to 20 percent. Elevations range from 1280 to 1981m.

Soils:

Characteristic soils on this site are over 150cm deep and well drained. Parent materials are alluvial and lacrustrine sediments derived from limestone and basalt. Soils are medium-textured and moderately through strongly calcareous. Soil surface layers with a platy structure and numerous closed pores are common. Rock fragments may cover the soil surface forming a "desert pavement". The underlying materials are often medium-textured or moderately fine-textured and may be slightly or moderately saline. Reactions are mildly alkaline through very strongly alkaline. Available water capacities are 5 to 15 cm. Representative soil taxonomic units given for this site are fine-loamy, mixed, mesic Typic Calciorthids and coarse-loamy, mixed, mesic Typic Calciorthids.

Climatic features:

Mean annual precipitation is 12 to 20cm. Approximately 70 percent falls as rain from March through October. On the average, July, September, January and Feruary are the driest months and April May and June are the wettest months. The mean annual air temperature is 7.7 and 11.6C. The average frost-free period is 100 to 160 days.

The climate of this site is characterized by hot, dry summers and cold, dry winters. Usually, enough moisture occurs during the summer to support warm season plants such as galleta (Hilaria jamesii). There are some years that are so dry during the summer, however, that little or no growth is made by these plants. Most of the plant production is a result of winter moisture that is stored in the soil.

Potential native plant community:

The dominant aspect of the climax plant community is Indian ricegrass (Oryzopsis hymenoides) and shadscale (Atriplex confertifolia). The composition of this plant community by air-dry weight is approximately:

Plant species	Common name	Percent by weight
Total Grasses		(30-40)
Oryzopsis hymenoides	Indian ricegrass	20-25
Elymus elymoides	bottlebrush squirreltail	5-10
Hilaria jamesii	Galleta	3-5
Stipa comata	needle and thread	1-2
Pascopyrum smithii	western wheatgrass	1-2
Bromus tectorum	cheatgrass	1-2
Poa nevadensis	Nevada bluegrass	1-2
Bouteloua gracilis	blue grama	T-1
Total Forbs		(5-15)
Sphaeralcea coccinea	scarlet globemallow	
Eriogonum sp.	buckwheat	
Astragalus sp.	locoweed	
Erigeron sp.	daisy	
Total Shrubs		(50-60)
Atriplex confertifolia	shadscale	20-25
Artemisia spinescens	bud sage	5-10
Ceratoides lanata	winterfat	5-10
Ephedra nevadensis	Nevada Morman tea	2-3
Chrysothamnus viscidiflorus	Douglas rabbitbrush	2-3
Other shrubs		5-10
Artemisia nova	black sagebrush	
Atriplex canescens	fourwing saltbush	
Kochia americana	gray molly	
Tetradymia sp.	horsebrush	

DESERT GRAVELLY LOAM

Classification

Site name: desert gravelly loam
Site number: D28X120U
Habitat type: Hilaria jamesii/Atriplex confertifolia/ Oryzopsis hymenoides/Tetradymia sp.
Associated sites: semidesert shallow loam, semidesert gravelly loam (Wyoming big sagebrush) North

Physical Characteristics

Physiographic features:

This site occurs on broad, nearly level hilltops. Slopes are mostly 1 to 5 percent. Elevations range from 1500 to 1600m on all aspects.

Soils:

Characteristic soils on this site are 150cm or more deep and well drained. Parent materials are alluvium underlain by coarser sediments derived mainly from limestone and calcareous sandstone and deposited by the waves of ancient lakes. Particle-size control sections have more than 35 percent, and frequently more than 60 percent, gravel by volume. Soils are medium-textured or moderately coarse-textured to a depth of about 60 or 80cm. They are coarse-textured below that depth. Soils are calcareous throughout and have moderate permeability. Available water capacities are 8 to 13cm. Taxonomic units associated with this site are loamy-skeletal, mixed, mesic Typic Calciorthids and loamy-skeletal, mixed (calcareous), mesic Typic Torriorthents.

Climatic features:

Mean annual precipitation is 12 to 20cm. Approximately 70 percent occurs as rain from March through October. On the average, July, September, January and February are the driest months and April, May and June are the wettest months. The mean annual air temperature is 7.7 to 11.6C. The frost-free period is 100 to 160 days.

Potential natural plant community:

The dominant aspect of the climax plant community is galleta (Hilaria jamesii). The composition of this community by air-dry weight is approximately:

Plant species	Common name	Percent by weight
Total Grasses		(35-45)
Hilaria jamesii	galleta	15-20

Oryzopsis hymenoides	Indian ricegrass	10-15
Elymus elymoides	bottlebrush squirreltail	3-5
Other perennial grasses		3-5
Stipa comata	needle and thread	
Poa secunda	Sandberg bluegrass	
Leymus salinus ssp. *salmonis*	salmon wildrye	
Total Forbs		(5-10)
Sphaeralcea coccinea	scarlet globemallow	
Astragalus sp.	locoweed	
Erigeron sp.	daisy	
Total shrubs		(50-60)
Atriplex confertifolia	shadscale	15-20
Artemisia spinescens	bud sage	5-10
Tetradymia sp.	horsebrush	5-10
Ephedra sp.	Mormon tea	3-5
Chrysothamnus viscidiflorus	Douglas rabbitbrush	3-5
Ceratoides lanata	winterfat	3-5
Atriplex canescens	fourwing saltbush	2-3
Xanthocephalum sarothrae	broom snakeweed	1-2
Chrysothamnus nauseosus	rubber rabbitbrush	1-2

DESERT SHALLOW LOAM

Classification

Site name: desert shallow loam
Site number: D28-138U
Habitat type: *Atriplex confertifolia/Hilaria jamesii*
Associatedsites: desert loam, desert flat and desert gravelly loam.

Physical Characteristics

Physiographic features:

This site occurs on benches, small hills and ridges, mesas and broad desert expanses over bedrock. Slopes are mostly 1 to 50 percent. Elevations range from 1524 to 1829m on all aspects.

Soils:

Characteristic soils on this site are 20 to 50cm deep over basalt and are well drained. Parent materials are colluvium and residuum derived mainly from basalt. These soils are typically shallow and are moderately coarse or medium-textured. Rock fragments average less than 35 percent by volume in the particle-size control section. Pebbles and stones cover approximately 40 to 70 percent of the soil surface. Both soils are moderately or strongly calcareous and moderately to very strongly alkaline. Available water capacities are 3.8 to 10.1cm. This site also contains some moderately deep soils with more than 35 percent rock fragments in the particle-size control section. Taxonomic units representative of this site include loamy, mixed, mesic Lithic Calciorthids and loamy-skeletal, mixed, mesic Typic Calciorthids.

Climatic features:

Mean annual precipitation is 12 to 20cm. Approximately 70 percent occurs as rain from March through October. On the average, July, September, January and February are the driest months and April, May and June are the wettest months. The mean annual air temperature is 7.7 to 11.6C. The frost-free period is 100 to 160 days.

The climate of this site is characterized by hot, dry summers and cold, dry winters. Usually, enough moisture falls during the summer to support warm season plants such as galleta (*Hilaria jamesii*). There are some years that are so dry during the summer, however, that very little or no growth is made by these plants. Most of the plant production is a result of winter moisture stored in the soil.

Potential native plant community:

The dominant aspect of the climax plant community is Indian ricegrass (Oryzopsis hymenoides) and shadscale (Atriplex confertifolia). The composition of this community in air-dry weight is approximately:

Plant species	Common name	Percent by weight
Total Grasses		(30-40)
Oryzopsis hymenoides	Indian ricegrass	20-25
Elymus elymoides	bottlebrush squirreltail	5-10
Hilaria jamesii	galleta	3-5
Stipa comata	needle and thread	1-2
Pascopyrum smithii	western wheatgrass	1-2
Bromus tectorum	cheatgrass	1-2
Poa nevadensis	Nevada bluegrass	1-2
Bouteloua gracilis	blue grama	T-1
Total Forbs		(5-15)
Sphaeralcea coccinea	scarlet globemallow	
Eriogonum sp.	buckwheat	
Astragalus sp.	locoweed	
Erigeron sp.	daisy	
Total Shrubs		(50-60)
Atriplex confertifolia	shadscale	20-25
Artemisia spinescens	bud sage	5-10
Ceratoides lanata	winterfat	5-10
Ephedra nevadensis	Nevada Morman tea	2-3
Chrysothamnus viscidiflorus	Douglas rabbitbrush	2-3
Other shrubs		5-10
Artemisia nova	black sagebrush	
Atriplex canescens	fourwing saltbush	
Kochia americana	gray molly	
Tetradymia sp.	horsebrush	

SEMIDESERT LOAM

Classification

Site name: semidesert loam (Wyoming big sagebrush)
Site number: D28X220U
Habitat type: *Psuedoroegneria spicata/Artemisia tridentata* ssp. *wyomingensis/Oryzopsis hymenoides*
Associated sites: semidesert gravelly loam (Wyoming big sagebrush--north), semidesert shallow hardpan.

Physical Characteristics

Physiographic features:

This site occurs on drainage bottoms, flood plains, alluvial plains and bajadas. Slopes are mostly 1 to 8 percent. Elevations range from 1340 to 1737m on all aspects.

Soils:

Characteristic soils on this site are 50 to 100cm deep and well drained. Parent materials are alluvium and lucustrine sediments from mixed parent rock sources. These soils have moderately fine textures throughout the profile. Generally, they have a root restricting zone, such as a duripan, petrocalcic horizon, strong calcic horizon or bedrock, between 50 and 100cm in depth. Soils are moderately or strongly calcareous throughout and moderately or strongly alkaline. Permeability is moderately slow. Taxonomic units representative of this site are fine-loamy, mixed, mesic Xerollic Durargids; fine-silty, mixed, mesic Xerollic Calciorthids; coarse-silty, mixed, mesic Xerollic Calciorhtids and fine-silty, carbonatic, mixed, mesic Xerollic Calciorhtids.

Climatic features:

Mean annual precipitation is 20 to 30cm. Approximately 70 percent occurs as rain from March through October. On the average, July, September, January and February are the driest months and April, May and June are the wettest months. The mean annual air temperature is 7.2 to 12.7C. The average frost-free period is 90-150 days.

Potential natural plant community:

The dominant aspect of the climax plant community on this site is Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and bluebunch wheatgrass (*Psuedoroegneria spicatum*). The composition of the community in air-dry weight is approximately:

Total Grasses		(50-60)
Oryzopsis hymenoides	Indian ricegrass	15-20
Pseudoroegneria spicata	bluebunch wheatgrass	20-25
Elymus elymoides	bottlebrush squirreltail	3-5
Poa nevadensis	Nevada bluegrass	3-5
Stipa comata	needle and thread	3-5
Other perennial grasses		3-5
Hilaria jamesii	galleta	
Poa secunda	Sandberg bluegrass	
Pascopyrum smithii	western wheatgrass	
Aristida sp.	threeawn	
Bouteloua gracilis	blue grama	
Other annual grasses		2-3
Total Forbs		(5-10)
Sphaeralcea sp.	globemallow	2-3
Astragalus sp.	locoweed	1-2
Phlox sp.	phlox	1-2
Eriogonum sp.	buckwheat	1-2
Other annual forbs		2-3
Total Shrubs		(35-45)
Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	15-25
Chrysothamnus viscidiflorus	Douglas rabbitbrush	3-5
Ephedra nevadensis	Nevada Mormon tea	3-5
Other shrubs		5-10
Atremisia spinescens	bud sage	
Atriplex confertifolia	shadscale	
Opuntia polycantha	plains pricklypear	
Atriplex canescens	fourwing saltbush	
Artemisia nova	black sagebrush	
Ceratoides lanata	winterfat	
Grayia spinosa	spiny hopsage	

SEMIDESERT GRAVELLY LOAM

Classification

Site name: semidesert gravelly loam (Wyoming big sagebrush) North
Site number: D28A215U
Habitat type: *Artemisia tridentata* ssp. *wyomingensis*/ *Psuedoroegneria spicata*
Associated sites: semidesert stony loam (black sagebrush) and semidesert loam (Wyoming big sagebrush).

Physical Characteristics

Physiographic features:

This site occurs on terraced bajadas. Slopes are mostly 3 to 15 percent. Elevations range from 1310 to 1830m on all aspects.

Soils:

Characteristic soils on this site are 150cm deep and well drained. Parent material is alluvium derived from mixed parent rock sources. These soils have moderately coarse to medium textures throughout the profile. Rock fragment content is 35 to 70 percent by volume. Above 50cm in depth, there is a layer of carbonate accumulation. The main edaphic factors limiting plant growth are the high rock content and carbonate layer. Available water capacities are 7.6 and 15cm. The taxonomic unit representative of this site is loamy-skeletal, mixed, mesic Xerollic Calciorthid.

Climatic features:

Mean annual precipitation is 20 to 30cm. Approximately 70 percent falls as rain from March through October. On the average, July, September, January and February are the driest months and April, May and June are the wettest months. The mean annual temperature is 7.2 to 12.7C. The average frost-free period is 90 to 150 days.

Potential natural plant community:

The dominant aspect of the climax plant community is Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*). The composition of this community by air-dry weight is approximately:

Plant species	Common name	Percent by weight
Total Grasses		(45-55)
Pseudoroegneria spicata	bluebunch wheatgrass	20-30
Elymus elymoides	bottlebrush squirreltail	5-10
Bromus tectorum	cheatgrass	1-2
Oryzopsis hymenoides	Indian ricegrass	5-10

Poa secunda	Sandberg bluegrass	5-10
Stipa comata	needle and thread	1-3
Pascopyrum smithii	western wheatgrass	1-2
Total Forbs		(10-15)
Balsamorhiza sagittata	arrowleaf balsamroot	1-2
Aster sp.	aster	1-2
Eriogonum sp.	buckwheat	1-2
Astragalus sp.	locoweed	1-2
Lomatium sp.	lomatium	1-2
Crepis acuminata	tapertip hawksbeard	3-5
Phlox hoodii	Hood's phlox	1-2
Total Shrubs		(35-40)
Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	20-30
Atriplex confertifolia	shadscale	5-10
Chrysothamnus viscidiflorus	Douglas rabbitbrush	1-3
Artemisia spinescens	bud sage	1-2
Other shrubs		2-5
Artemisia nova	black sage	
Ceratoides lanata	winterfat	
Opuntia polycantha	plains pricklypear	
Xanthocephalum sarothrae	broom snakeweed	
Tetradymia sp.	horsebrush	

Table 9.--Repeated measures design analysis of variance for seedling density data collected between fall 1984 and fall 1985 on the Tooele Fire Rehabilitation Project study area.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F-ratio
Treatment combination (R)	12	394.73	32.89	1.14
Cluster w/in R (C)	26	755.81	29.07	12.86*
Transect w/in C (S)	156	352.01	2.26	--
Time periods (T)	2	13.30	6.65	3.11
R X T	24	39.94	1.66	0.78
C X T	52	111.30	2.14	--
Residual	313	171.73	0.55	--
Total	585	1838.82		

*Significant at $P \leq 0.05$

Table 10.--Mean estimates and standard errors of seedling densities on the Tooele Fire Rehabilitation Project study area by treatment combination and data collection period.

Treatment combination	Collection period		
	fall 1984	spring 1985	fall 1985
	--------------seedlings/m2------------		
Semidesert gravelly loam/ fall/standard drill	2.6 ±0.8	1.9 ±0.5	1.9 ±0.5
Semidesert gravelly loam/ spring/standard drill	2.6 ±1.2	1.6 ±0.7	1.6 ±0.6
Desert gravelly loam/fall/ standard drill	0.8 ±0.2	1.1 ±0.2	1.4 ±0.2
Semidesert loam/fall/deep furrow drill	3.4 ±1.3	2.6 ±0.7	1.3 ±0.4
Desert flat/fall/standard drill	1.0 ±0.4	1.1 ±0.4	1.0 ±0.4
Desert loam/fall/standard drill	1.6 ±0.4	1.1 ±0.3	0.9 ±0.3
Desert gravelly loam/fall/ broadcast-chained	0.4 ±0.1	0.3 ±0.1	0.2 ±0.1
Semidesert loam/fall/ standard drill	0.5 ±0.2	0.3 ±0.1	0.2 ±0.1
Desert shallow loam/fall/ broadcast-chained	0.1 ±0.1	0.1 ±0.1	0.1 ±0.1
Desert gravelly loam/ spring/standard drill	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0
Desert loam/spring/ standard drill	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0
Desert gravelly loam/ spring/deep furrow drill	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0
Desert shallow loam/fall/ broadcast-sheep trampled	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0
Collection period means	1.0 ±0.2	0.7 ±0.1	0.7 ±0.1

Table 11.--Nested analysis of variance and one degree of freedom tests of seedling counts taken during fall 1985 on the Tooele Fire Rehabilitation Project study area.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F-ratio
Treatment combinations (TC)1	12	91.17	7.60	1.47
SD versus D	1	0.0	0.0	0
G versus NG	1	16.1	16.1	3.11
F versus S	1	7.1	7.1	1.37
F versus S (SD)	1	9.6	9.6	1.86
F versus S (SD on D)	1	22.1	22.1	4.27*
B versus D (F)	1	31.1	31.1	6.02*
DFD versus SD (F)	1	0.6	0.6	0.11
Residual	5	4.57	--	--
Clusters w/in TC (C)	26	134.30	5.17	8.62*
Transects w/in C	156	92.90	0.60	
Total	194	318.37		

1Treatment combinations: SD versus D= semidesert versus desert precipitation zones; G versus NG= gravelly versus nongravelly ecological sites; F versus S= all fall seedings versus all spring seedings; F versus S (SD)= all fall versus all spring plantings with standard drill; F versus S (SD on D)= within the desert precipitation zone, standard drill fall seedings versus standard drill spring seedings; B versus D (F)= all broadcast seedings versus all fall drilled seedings; DFD versus SD (F)= fall seedings planted with the deep furrow drill versus fall seedings planted with the standard drill.

*Significant at $P \leq 0.05$.