

Finally, some conclusions regarding productivity can be drawn from this research. Row-crop yields may be greatly reduced in the first year after a borrow area has been restored. Yields were greatly reduced if row-crop production was initiated immediately after reclamation without the benefit of a winter freezing and thawing. After a period of one to several years, yields from these areas can equal or exceed county average yields. Certain sites, such as those developed on glacial till, will require the replacement of at least 6 in. of salvaged topsoil and may equal countywide yield in a period of 2 yr.

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Establishment and Growth of Shelterbelt Species and Grass Barriers on Windswept Wyoming Rangeland

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Survival and growth of six shelterbelt species and three rangeland shrubs were evaluated for 6 yr at a single windswept site adjacent to Interstate 80 in south-central Wyoming. Placing plants behind a snow fence to reduce wind speed did not influence their establishment success or their growth rate. Rodent depredation limited establishment and growth of some species more severely than the harsh climate. After 6 yr, survival of three deciduous species planted as bare-root stock ranged from 16 to 65 percent; survival of three conifers planted as container-grown stock ranged from 73 to 91 percent. A number of years would be required for a shelterbelt to become tall enough to effectively deposit drifting snow in locations where environmental conditions are similar to those of the study site. Such plantings would require extensive land areas to retain quantities of snow similar to those retained by snow-fence systems protecting I-80. Russian olive and white rabbitbrush were about 85 cm tall after six growing seasons, and Colorado blue spruce and ponderosa pine were about 65 cm tall. The ability of a stripping treatment imposed on sagebrush rangeland to increase on-site snow storage and reduce snow relocation was also evaluated. Sagebrush was fertilized with nitrogen at rates of 0, 22.4, and 44.8 kg/ha. The stripping treatment was only effective where livestock grazing was excluded and crested wheatgrass was planted on grass strips. The grass stand caused on-site snow retention to double. Winter snow accumulation behind a snow fence decreased about 20 percent because of reduced snow relocation.

Shelterbelts have been widely planted on the Great Plains to reduce wind speed and drifting snow around farms and ranches. Technical information is available about adapted species and techniques to establish a planting (1-4). Plantings have not been made on the high plains of south-central Wyoming where Interstate 80 is located. Environmental conditions are much more severe along I-80 than on the Great Plains, and snow relocation is common in winter months. At this time, about 52 km of snow fence protect 49 km of the highway between Laramie and Walcott Junction that has the most severe winter weather. The height of approximately 70 percent of these fences is 3.8 m (5). Possibly the severity of snow relocation might be reduced by shelterbelt plantings or through management of native rangeland vegetation.

The current study was conducted in cooperation with the Wyoming State Highway Department and was designed to evaluate survival and growth characteristics of six tree and shrub shelterbelt species and three rangeland shrubs planted in a location with and without snow-fence protection. In addition, the ability of grass strips to increase on-site snow

retention and reduce snow drifting on sagebrush rangeland was investigated.

STUDY SITES AND EXPERIMENTAL METHODS

Shelterbelt Study

The single shelterbelt planting site was located on the south side of I-80 about 8 km east of the town of Elk Mountain near mile 264. The site is 2300 m in elevation, and native vegetation is dominated by Wyoming big sagebrush (*Artemisia tridentata* sub. *wyomingensis*) about 10 cm tall. Soil has a sandy loam texture in the A and B horizons; the combined depth of these horizons is 30 cm. The study site was 35 by 155 m and it was enclosed by a snow fence 3.8 m tall across the downwind side and by a fence of woven wire on the remaining three sides so that livestock grazing was excluded. At study initiation, the site was plowed to kill native vegetation; 1 yr later the site was sprayed with herbicide to control weeds.

Three conifer species--Colorado blue spruce (*Picea pungens*), ponderosa pine (*Pinus ponderosa*), and white fir (*Abies concolor*)--were evaluated along with three deciduous species--Russian olive (*Elaeagnus angustifolia*), Siberian elm (*Ulmus pumila*), and Siberian peashrub (*Caragana arborescens*). Rocky mountain juniper (*Juniperus scopulorum*) is one of the most commonly planted shelterbelt species in the central Great Plains. However, at study initiation, planting stock of juniper was unavailable and this species was not evaluated.

Conifer species were grown in containers and were 10 to 15 cm tall when planted. Deciduous species were planted from bare-root stock that had been held in cold storage for about 6 weeks. Two slow-release fertilizer tablets (20 percent nitrogen, 10 percent phosphorus, 5 percent potassium) were placed in the soil adjacent to each plant as they were planted on June 27 and 28, 1975. The plants were placed in holes 61 cm in diameter in which soil was loosened to a 61-cm depth. To eliminate water stress as a survival factor, rainfall during the 1975 and 1976 growing season was supplemented by irregular waterings. Most plants that died in the first year of

study were replaced in June 1976. Study measurements for these individuals ended 1 yr later than those for individuals planted in 1975 to permit the expression of data on the basis of number of years since planting.

A planting of two common western shrubs and a sagebrush species native to Europe was also evaluated. Two sources of basin big sagebrush (A. t. sub. tridentata) collected in Colorado and Nevada, white rabbitbrush (Chrysothamnus nauseosus sub. albicaulis), and the exotic, oldman wormwood (A. abrotanum), were tested. The shrubs were selected because of rapid growth characteristics at a shrub garden maintained by the Intermountain Forest and Range Experiment Station in Ephraim, Utah. Big sagebrush and white rabbitbrush seedlings were dug from the garden May 11, 1976, and planted 2 to 3 days later at the shelterbelt site. Rooted and unrooted cuttings of oldman wormwood were also obtained from the shrub garden.

Each coniferous and deciduous species was planted in a single row 125 m long oriented perpendicular to prevailing winds, except for Siberian peashrub, which was planted in two rows (Figure 1). About 60 percent of each row was located downwind of a snow fence 3.2 m tall, whereas the remainder of the row was fully exposed to prevailing winds. Plant rows were between 38 and 65 m from the upwind snow fence. The location of snow fences 3.2 and 3.8 m tall with respect to the rows of plants, spacing between plants within a row, and spacing between rows are shown in Figure 1.

Rangeland shrubs were placed 0.5 m on either side of Colorado blue spruce and ponderosa pine. The

three shrub species were planted sequentially at 0.8-m intervals until 28 individuals of a species were placed on either side of the two conifers. Rooted oldman wormwood cuttings were adjacent to Colorado blue spruce, and unrooted cuttings were adjacent to ponderosa pine. Half the plants of the Colorado and Nevada selections of big sagebrush were placed in rows associated with spruce and pine. The shrub planting did not extend the full length of the conifer rows. Thus, the influence of fence protection on rangeland shrub establishment and growth could not be evaluated.

Plant survival was determined as growth commenced in the spring (June) and at the close of the growing season (early October). Differences in survival of each species between locations protected and unprotected by the upwind snow fence were tested for statistical significance by chi-square. An analysis was made for data collected 1 and 2 yr after planting, when most mortality occurred. Plant height was measured each fall beginning the third season after planting. Height differences between plants growing in locations protected and unprotected by the upwind snow fence were tested for statistical significance with a t-test based on data collected three to six growing seasons after planting. Statistical significance in this paper is based on a 0.05 level of probability.

Sagebrush-Grass Strips

The study involving sagebrush and grass strips was conducted on rangeland dominated by Wyoming big sagebrush and black sagebrush (*A. nova*) that was about 10 cm in height. Study sites were on the south side of I-80 at Dana Ridge (mile 246) and west of the town of Elk Mountain (mile 255). The Dana Ridge site was 2210 m in elevation, and Elk Mountain was 2220 m. Most snow is relocated by strong westerly winds following precipitation events. Treatment was based on the premise that sagebrush height could be increased by removing half of the sagebrush stand in alternate strips to provide additional soil water to residual sagebrush plants. To further stimulate height growth, the effects of fertilizing sagebrush vegetation with nitrogen at rates of 0, 22.4, and 44.8 kg/ha were also investigated. The study began in 1975 and ended after snow measurements in 1980.

Study sites were 120 m square. Strips 1-12 and 4-15 were used for the study at Elk Mountain and at Dana Ridge, respectively (Figure 2). A snow fence

Figure 1. Location of snow fences with respect to shelterbelt planting (top) and location of each row of species, spacing between plants, and spacing between rows (bottom).

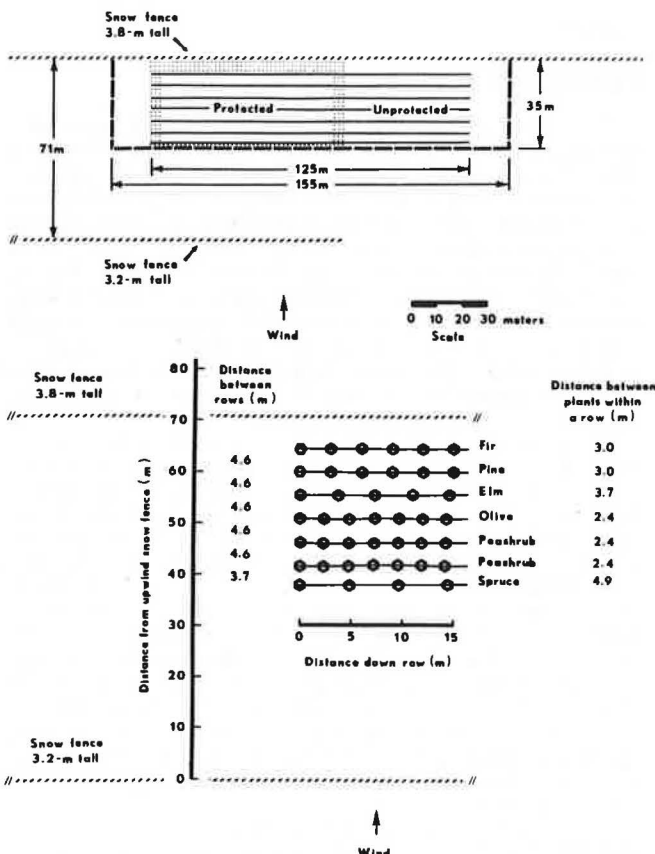
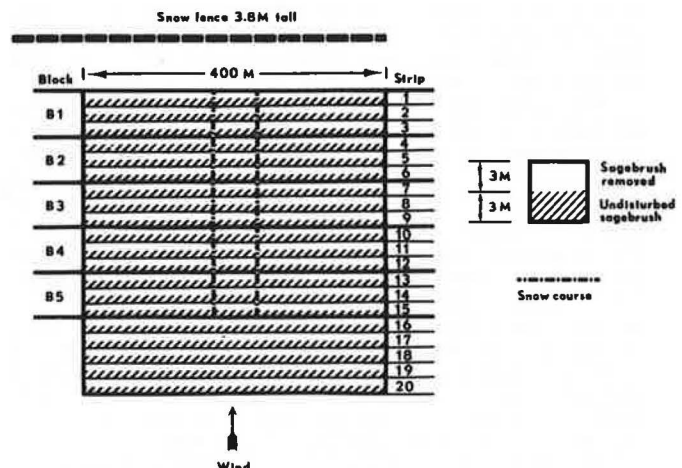


Figure 2. Sagebrush and grass stripping study sites.



3.8 m tall was located 70 m downwind from the Elk Mountain strips and 12 m downwind from the Dana Ridge strips. Sagebrush was controlled in strips 3 m wide that alternated with untreated strips of vegetation also 3 m wide. The long axis of strips was perpendicular to prevailing wind direction. The stripped-untreated sequence was repeated 20 times. Nitrogen was applied as ammonium nitrate or urea in late fall or spring; the first application was in June 1975. The Elk Mountain site was heavily grazed, but the Dana Ridge site was fenced to exclude grazing.

Sagebrush on treated strips was controlled by using a thermal procedure that heats plant tissue enough to cause death but not enough to cause ignition (6). Hot air, generated by burning propane, was used to control vegetation. Dana Ridge was treated June 9, 1975, and treatment at Elk Mountain followed 8 days later. The thermal technique was not effective against the diminutive sagebrush stand. Vegetation at Elk Mountain was retreated November 10, 1975, by mowing slightly above the soil surface. In May 1976, thermally treated strips at Dana Ridge were disked and planted with crested wheatgrass (*Agropyron cristatum*) at a seeding rate of 11.1 kg/ha.

Study measurements were confined to the 12 pairs of sagebrush and grass strips nearest the snow fence at Elk Mountain; at Dana Ridge strips 4-15 were used to avoid the upwind drift cast by the fence. The effects of stripping on sagebrush height growth and on snow accumulation were evaluated within a randomized block design; blocks were replicated four times at each study location. Each block consisted of three pairs of sagebrush and grass strips; the sagebrush strips were fertilized with nitrogen at 0, 22.4, or 44.8 kg/ha. Fertilization rates were randomly assigned within a block. An analysis of variance was performed for data collected on each snow-measurement date and for sagebrush height data collected in 1975 and 1979. Separate analyses were performed for data collected at Dana Ridge and Elk Mountain.

The height of six randomly selected sagebrush plants on the 12 measurement strips was determined at the beginning of study in 1975 and in 1979 after fertilization for five growing seasons. Sagebrush density was determined at the beginning of study by counting the number of plants rooted within six belt transects on measurement strips. Comparable sagebrush measurements were made in 1976 and in 1979 in front of snow fences at Dana Ridge and Elk Mountain on transects used to measure snow retention in undisturbed rangeland vegetation. Sagebrush in front of the Dana Ridge snow fence was twice as tall as that on the stripping study area. A second set of transects in vegetation comparable to that on the stripped area was placed 30 m south of the stripping site. Vegetation on transects outside of the stripped area was grazed at both study locations.

The influence of stripping on snow retention was evaluated by measuring the depth of snow remaining on sagebrush and grass strips on two transects located 8 m from the center of the stripping area after major drifting events (Figure 2). Snow was probed at distances of 0.3, 0.9, 1.8, and 2.7 m from the windward edge of a strip. The depth of snow retained by undisturbed sagebrush rangeland in front of the snow fence was measured at intervals of 3 m on two transects 120 m long. Average snow density on measurement dates was determined by weighing the water contained in individual cores collected with a Federal snow sampler. Five cores were usually collected on sagebrush strips, and five were collected on strips where sagebrush was controlled.

The effect of stripping on overwinter snow relo-

cation was evaluated in late March by measuring the volume of snow stored behind the snow fence. In addition, measurements of drift volume were usually taken when snow retention was measured on the stripped area. The drift behind the snow fence was cross-sectioned at three locations downwind of stripped and undisturbed rangeland vegetation. Snow density was measured on the center transect with a Federal snow sampler. The other two transects were probed at 3-m intervals with an aluminum rod to determine the depth of snow (7).

CLIMATIC CHARACTERISTICS

Temperature and precipitation records are available for the town of Elk Mountain at a National Oceanic and Atmospheric Administration Cooperator Station. Wind-speed data were collected by the Wyoming State Highway Department at the sagebrush stripping study site at Elk Mountain (8). Climatological data from these stations are believed indicative of general conditions at the three study locations.

Long-term annual precipitation in the town of Elk Mountain is 32.7 cm; 10.6 cm of the yearly total falls from November through March during the snow-drifting season and 11.4 cm is received between June and September in the growing season. Deciduous shelterbelt species leaf out in late May, and leaf fall is in September. Native plants begin growth earlier in the spring than shelterbelt species. July is the warmest month, with an average monthly maximum of about 27°C. Night-time temperatures are consistently above freezing only during July and August. Average annual temperature is 6°C. Wind speeds are greatest in winter, and average monthly speeds range from 6 to 9 m/sec between November and March. Thus, plants are subjected to severe desiccation stresses in winter because of the long period of subzero temperatures, frozen soils, and strong, persistent winds.

RESULTS

Shelterbelt Planting

Differences in survival between locations protected and unprotected by the upwind snow fence were not statistically significant for coniferous or deciduous species (Table 1). The heights of Siberian elm and Colorado blue spruce protected by the upwind snow fences were significantly greater than those for individuals in the unprotected location during the fifth and sixth growing season, respectively. However, browsing by white-tailed jackrabbits (*Lepus townsendii*) on the trunk and branches of elms in winter months, not fence protection, was the primary factor influencing elm height in later years of the study.

Data on the number of individuals of each species planted in 1975 and 1976 and average species survival are given in Table 2 for the 6 yr of study. Data from the two fence locations were combined because the upwind fence did not affect survival and had no consistent effect on growth rates. Colorado blue spruce had the highest survival rate of coniferous species at the end of 6 yr (91 percent), whereas Siberian elm, with a 65 percent survival rate, was the highest of the deciduous species. Only 16 percent of Russian olive plants lived as long as 2 yr, but there was no additional mortality. Russian olive died mainly during the winter, which suggests that planting stock was not sufficiently hardy for the severe winter conditions at the study site.

Rangeland shrub survival was poor (Table 2). Neither the Colorado nor the Nevada selections of

basin big sagebrush were adapted to severe winter conditions and died throughout the study. Initial survival of rooted oldman wormwood cuttings was much higher than that of unrooted cuttings because of browsing by Richardson's ground squirrels (*Spermophilus richardsonii*). Wire cages were placed around oldman wormwood plants about a month after planting, when it was discovered how palatable the herbage was to the squirrels. Survival of white rabbitbrush was also very low. At the end of the first growing season, 23 percent of the plants were alive and 20 percent were alive after 1 yr, but

there was no additional mortality. The method of handling the rabbitbrush seedlings before planting probably contributed to the high mortality rate.

Average height of species three to six growing seasons after planting is shown in Figure 3. The rate of growth for coniferous species was quite uniform. Colorado blue spruce and ponderosa pine were about 65 cm tall after six growing seasons, whereas white fir was 12 cm shorter. Russian olive was 84 cm tall at the end of the study. It had a densely branched growth form with a crown spread approximately equal to plant height. This species was damaged by herbicide drifting across the study site when roadside weeds were sprayed. Average height dropped sharply in the fifth growing season, but plants grew vigorously the following year. Siberian peashrub exhibited a very spindly growth form and would have to be closely planted to form an effective windbreak. Basin big sagebrush was taller than other species after six growing seasons but was not winter hardy. After establishment, white rabbitbrush was very hardy, and it was 81 cm tall at the close of the study.

Depredation by indigenous rodent species limited establishment and growth of some species. White-tailed jackrabbits girdled the trunks of Siberian elms in winter months and ate the twigs and smaller branches. The height of elms generally decreased after the third growing season because of rabbit damage. None of the plants regained a treelike form

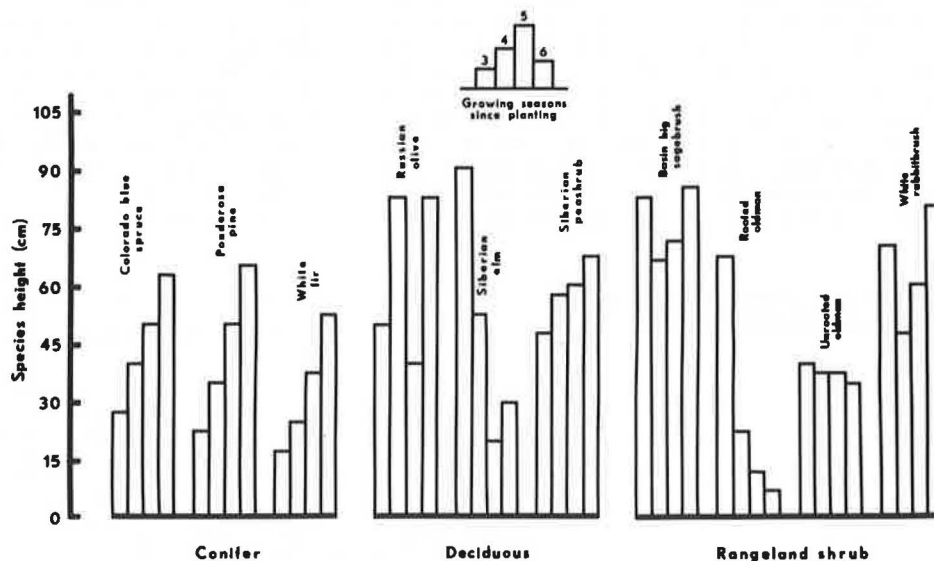
Table 1. Survival percentage for coniferous and deciduous species 1 and 2 yr after planting in locations protected and unprotected by upwind snow fence.

Group and Species	Survival Percentage by Year After Planting			
	One		Two	
	Unprotected	Protected	Unprotected	Protected
Coniferous				
Blue spruce	100	100	94	94
Ponderosa pine	75	80	65	80
White fir	79	97	79	88
Deciduous				
Russian olive	54	30	29	8
Siberian elm	77	76	77	67
Siberian peashrub	82	73	61	53

Table 2. Number of individuals planted and survival in first 6 yr after planting.

Group and Species	No. Planted			Survival Percentage by Year After Planting					
	1975	1976	Total	One	Two	Three	Four	Five	Six
Coniferous									
Blue spruce	25	10	35	100	94	94	94	94	91
Ponderosa pine	40	15	55	78	75	75	73	73	73
White fir	41	10	51	90	84	84	84	84	82
Deciduous									
Russian olive	51	10	61	39	16	16	16	16	16
Siberian elm	34	0	34	76	71	71	71	65	65
Siberian peashrub	101	11	112	76	55	54	54	54	54
Rangeland shrub									
Basin big sagebrush									
Colorado source	0	56	56	38	32	27	11	11	11
Nevada source	0	56	56	38	38	30	25	25	25
Oldman wormwood									
Rooted cutting	0	56	56	84	84	84	79	32	9
Unrooted cutting	0	56	56	32	32	32	32	32	30
White rabbitbrush	0	112	112	20	20	20	20	20	20

Figure 3. Average height of species.



once the trunk had been girdled. Rabbits also browsed twigs of white rabbitbrush and basin big sagebrush in winter, but plants were not irreparably harmed.

Richardson's ground squirrels devastated oldman wormwood. The squirrels were active from April until August and ate any foliage within reach. For protection, circular wire cages 46 cm long and 10 cm in diameter were placed around rooted and unrooted oldman cuttings the year of planting. The cages remained around plants that started as unrooted cuttings through the study, and the height of these plants was similar from year to year (Figure 3). The entire row containing oldman wormwood originating from rooted cuttings was fenced at the beginning of the second growing season to permit oldman to express its growth potential. Fencing was moderately successful the summer of installation. Plant height increased from 53 cm the previous summer to 69 cm. However, ground squirrels browsed oldman wormwood so severely in subsequent years that survival decreased from 84 percent in the third year after planting to 9 percent in the sixth year (Table 2). Richardson's ground squirrels also browsed white rabbitbrush during the summer but much less severely than oldman wormwood.

The configuration of snow fences at the planting site had a complicating effect on the shelterbelt study but should not have materially changed study results. The planting was not far enough downwind from the 3.2-m snow fence to be free of the drift cast by the fence in winters with high snow transport. Of course, plants were completely protected from wind when covered by snow and were in a uniform temperature regime at slightly below freezing until snowmelt started. The drift failed to reach the planting site in three winters of below-normal precipitation and completely covered the site at the end of two winters with above-average precipitation. About 2.5 m of snow covered the Colorado blue spruce row in these winters. Snow decreased in depth across the planting site and white fir was covered by 1 m of snow. Some breakage of blue spruce and Siberian peashrub did result from snow settlement.

Turbulence generated at the end of a snow fence acts to reduce snow accumulation near the end of the fence. The rows of plants extended across the boundary between the fenced and unfenced areas, so that plants near the boundary received somewhat less than full wind protection.

Wind speed is also reduced on the windward side of a snow fence, which causes an upwind drift to form. The upwind drift of a Wyoming Highway Department snow fence 3.8 m tall extends 47 m from the fence and has a maximum depth of 1.8 m when the fence is filled with snow (9). Thus, the drift in front of the snow fence could have extended across the entire planting site. However, actual snow storage by this fence was small in relation to its capacity. The upwind drift was shallow and barely reached the row of white fir that was closest to the

fence. It is assumed that the presence of the fence on the downwind side of the planting site had a negligible effect on wind speeds where shelterbelt species were located.

Sagebrush Height Growth

Sagebrush was 10.1 and 9.5 cm tall at the Elk Mountain and Dana Ridge study sites, respectively, at the beginning of the study (Table 3). Sagebrush density at Dana Ridge was 67,200 plants/ha and at Elk Mountain density was 41,500 plants/ha.

Sagebrush plants on Elk Mountain strips increased 2 cm in average height during study, a statistically significant increase but of no practical importance (Table 3). Fertilization had no influence on sagebrush height. The height of plants outside the stripped area did not change between 1976 and 1979. Data thus suggest that sagebrush responded to stripping but not to fertilization. Vegetation was heavily grazed by antelope, sheep, cows, and horses. Individual sagebrush plants were closely hedged and produced few or no seed heads, which indicates a low state of vigor.

The study site at Dana Ridge was not grazed by livestock, and sagebrush responded to stripping and fertilization with a significant increase in height (Table 3). Plants that received 44.8 kg/ha of nitrogen increased from 9.9 cm in 1975 to 15.2 cm in 1979, a 50 percent increase in height. Unfertilized plants increased 1 cm. Sagebrush located in front of the snow fence and 30 m south of the stripping site in undisturbed rangeland had similar heights in 1976 and 1979.

Snow Retention and Relocation

The stripping treatment at Elk Mountain had little effect on snow retention. Snow depths on sagebrush and mowed strips and on undisturbed rangeland were similar through the study. Snow storage behind the Elk Mountain snow fence downwind of stripped and undisturbed vegetation was similar in all of the years of the study.

The depth of snow retained on the Dana Ridge stripping site increased during the study but not in response to sagebrush growth (Table 4). Rather, crested wheatgrass became the dominant roughness agent, or factor, controlling snow retention. The grass stand was still quite open the winter after planting (1976-1977) (Figure 4), and grass strips retained significantly less snow than sagebrush strips on all measurement dates (Table 4). Crested wheatgrass grew vigorously the year after planting, and seed stalks were 40 to 50 cm in height. Snow accumulation on grass and sagebrush strips was similar beginning in the 1977-1978 winter, since each grass strip performed as a living snow fence and cast a drift across the adjacent downwind sagebrush strip. After crested wheatgrass had developed fully, snow was usually about twice as deep on the stripping study site as on undisturbed rangeland

Table 3. Sagebrush height at stripping sites and in undisturbed rangeland at beginning and end of study.

Site	Year	Height (cm) by Nitrogen Level (kg/ha)				Year	Height (cm) by Location in Nonstripped Rangeland	
		0	22.4	44.8	Avg		At Snow Fence	South of Stripping Site
Elk Mountain	1975	9.2	10.5	10.7	10.1 ^a	1976	10.0	
	1979	12.1	11.9	13.1	12.3	1979	9.1	
Dana Ridge	1975	9.4	9.3 ^a	9.9 ^a	9.5 ^a	1976	19.4	10.3
	1979	10.6	14.1	15.2	13.3	1979	18.7	8.7

^aSignificant difference between years at the 0.05 probability level. Duncan's multiple-range test was used to identify significant means for nitrogen fertilization levels.

Table 4. Snow density and depth at Dana Ridge study site.

Winter	Date	Snow Density (cm)	Snow Depth (cm)				
			By Nitrogen Level (kg/ha)			By Location in Rangeland Vegetation	
			0	22.4	44.8	At Snow Fence	South of Stripping Site
1975-1976	03/06	0.24	7.7	6.7	6.4	20.1	-
1976-1977	12/07 ^a	0.13	6.2	6.7	6.5	11.7	6.9
	01/05 ^a	0.12	9.4	10.7	10.3	-	10.7
	03/29 ^a	0.15	5.5	5.6	5.6	9.9	7.6
1977-1978	11/22	0.19	15.5	16.8	15.1	-	6.6
	12/02	0.23	6.7	8.5	7.1	13.2	3.6
	01/09	0.17	7.0	7.9	7.7	11.2	3.6
	01/17	0.14	23.5	25.1	24.5	26.9	14.2
	01/28	0.22	27.4	27.7	27.2	31.5	16.0
	02/21	0.25	38.2	39.5	39.9	43.7	26.4
1978-1979	11/13	0.19	6.0	7.2	5.8	4.6	4.1
	11/29	0.17	13.3	15.8	15.4	13.7	7.1
	12/12	0.24	18.2	20.6	20.4	18.5	7.9
	12/18	0.31	17.3	18.7	19.9	19.1	4.6
	01/09	0.27	28.1	28.8	29.3	30.0	15.5
	02/15	0.31	29.7	29.3	31.4	31.0	9.9

^aSnow depth significantly greater on one or more fertilized sagebrush strips than on adjacent crested wheatgrass strips at a 0.05 probability level.

Figure 4. Snow accumulation on sagebrush and crested wheatgrass strips at Dana Ridge, winter 1976-1977.

vegetation to the south (Table 4). Accumulation of snow by undisturbed sagebrush vegetation in front of the snow fence was initially much deeper than by vegetation on the stripping study site; however, accumulation on the two areas was similar beginning in the 1977-1978 winter.

Before establishment of crested wheatgrass, the volume of snow stored by the Dana Ridge snow fence downwind of the stripped area was about 43 percent greater than that stored by the fence downwind of untreated vegetation at the end of winter (Table 5). This disparity arose because of differences in vegetation height and because of differences in fetch upwind from the two segments of the fence. A ridge delineating the upwind fetch boundary was appreciably closer to that portion of the snow fence downwind of untreated vegetation than to the fence downwind of stripped vegetation. Consequently, the ratio comparing snow accumulation behind the fence downwind of stripped and untreated vegetation was the most meaningful parameter for assessing the effects of grass strips on snow transport.

The sagebrush stripping treatment at Dana Ridge increased on-site snow retention, thus reducing snow

Table 5. Snow storage by Dana Ridge snow fence.

Winter	Date	Snow Storage (m ³ /m)		
		Stripped Location	Undisturbed Location	Ratio Stripped/Undisturbed
1974-1975	04/22	94.7	65.5	1.45
1975-1976	10/30	6.3	3.0	2.10
	12/02	9.7	4.8	2.02
	01/22	60.8	42.5	1.43
1976-1977	03/06	81.2	55.9	1.45
	03/24	78.6	55.4	1.42
	12/07	4.6	2.6	1.77
1977-1978	03/24	28.1	15.5	1.81
	11/22	12.9	15.0	0.86
	01/09	12.4	12.8	0.97
	01/17	23.4	25.1	0.93
	01/28	53.6	45.5	1.18
	02/21	79.5	69.8	1.14
1978-1979	03/20	94.7	78.6	1.20
	11/29	4.5	5.6	0.80
	12/12	34.5	29.0	1.19
	01/09	52.5	44.1	1.19
	02/15	123.7	101.4	1.22
1979-1980	03/16	126.5	101.7	1.24
	03/21	146.6	122.2	1.20

relocation and snow storage behind the snow fence. In 1975 and 1976, the snow-accumulation ratios (stripped/untreated) were 1.45 and 1.42 (Table 5). The ratio increased to 1.81 in 1977, when snow was scoured from strips of newly planted crested wheatgrass. The ratio decreased after the grass stand thickened and was 1.19 in 1978, 1.24 in 1979, and 1.20 in 1980. Thus, the 20 strips of crested wheatgrass extending 120 m in a windward direction reduced winter snow transport approximately 20 percent.

Vegetation was most effective in reducing snow transport early in the winter before its storage capacity filled. The snow-accumulation ratio in the 1975-1976 winter (before planting crested wheatgrass) was about 2.0 during the time that snow storage downwind of untreated sagebrush vegetation was less than 15 m³/m of fence length (Table 5). The ratio was less than 1.0 at a similar stage of drift formation in later years, which suggests that the grass stand reduced snow transport about 50 percent. The snow-accumulation ratio increased to 1.2 when snow storage downwind of untreated sagebrush vegetation reached about 30 m³/m of fence length and remained at this value the rest of the winter.

DISCUSSION AND CONCLUSIONS

Three coniferous, three deciduous, and three rangeland shrubs were tested at a single shelterbelt planting site adjacent to I-80 to determine survival and growth characteristics under harsh environmental conditions. Placement of the planting behind a snow fence to provide protection from the wind did not improve survival or height growth in the 6-yr period after planting.

Growth of all species was slow; the tallest species--Russian olive, basin big sagebrush, and white rabbitbrush--were about 85 cm in height after six growing seasons. Colorado blue spruce and ponderosa pine increased in height from 10 to 65 cm in the 6 yr of study. Siberian peashrub was about 70 cm tall but had a very spindly growth form. The canopy of Russian olive was as wide as the plant was tall. This species would form an excellent wind-break. Russian olive survival was only 16 percent after 2 yr but probably could be enhanced by obtaining planting stock from plants adapted to the harsh environment. The selections of basin big sagebrush from Colorado and Nevada were not winter hardy, and mortality continued through the study period.

Wildlife depredation can limit survival and growth of plant species as much as the severe climate when shelterbelts are situated on rangeland. White-tailed jackrabbits girdled the trunks and browsed twigs and branches of Siberian elms in winter months and also ate stems and branches of white rabbitbrush and big sagebrush. The foliage of oldman wormwood was extremely palatable to Richardson's ground squirrels, and it is not a suitable shelterbelt species where these squirrels are present. A wildlife inventory should precede establishment of shelterbelts in rangeland situations so that species attractive to wildlife will not be planted.

Because of plant breakage caused by snow settlement, shelterbelts should not be placed behind a single row of snow fence. Rather, tandem snow fences are required. The first snow fence stores incoming snow, whereas the second fence provides wind protection. The planting should not extend more than 30 times fence height downwind from the protection fence to maximize wind protection (9). The height of snow fences required to store drifting snow at a specific site can be calculated by knowing precipitation during the drifting season and snow-retention characteristics of vegetation and terrain in the zone contributing snow to the fence (10).

The drift behind snow fences represents a potential source of irrigation water for shelterbelts. Snowmelt is slow enough that surface runoff seldom extends more than a few meters from a drift unless the site is underlain by relatively impermeable soil. A planting lying at a lower elevation than the drift might be subirrigated. Melt water could also be stored to supply a trickle irrigation system.

The shelterbelt study was not designed to determine snow-accumulation characteristics of planted species. However, it is possible to estimate the size of a planting required to store the same volume of snow as stored by snow fences currently protecting I-80. For example, snow fences 3.8 m tall retain up to 316 m³ of snow for each meter of length and the drift is 158 m long. A shelterbelt would have to be 632, 316, 211, and 158 m in width for each meter of length to store the same volume of snow as the 3.8-m fence, assuming plants retain snow in a uniform blanket 0.5, 1.0, 1.5, and 2.0 m deep, respectively. Clearly, in regions of high snow transport, the use of shelterbelts to control drifting snow will require substantial reservations of land. Plants are biological organisms with a finite

life span, as well as susceptible to damage from weather, disease, and insects. A strong maintenance program to keep the shelterbelt in a vigorous state of health would be essential to maximize retention of blowing snow.

The grass stripping treatment imposed on sagebrush rangeland shows that snow relocation can be reduced by increasing vegetation height to retain more of the winter's snowfall on site. Crested wheatgrass was much taller than native sagebrush and the drift cast by grass strips covered the adjacent strip of sagebrush vegetation. Thus, snow storage can be increased by only partly treating an area. The benefits of vegetation management are further enhanced in locations where appreciable melt occurs between storms because of a renewal of vegetation's storage capacity. Management of rangeland for snow retention does require that livestock grazing be closely regulated. Snow management will also benefit vegetation productivity by increasing water available for plant use.

The effects of vegetation management on snow transport can be determined for any location if winter precipitation, snow-retention characteristics of terrain, and snow-retention characteristics of treated and untreated vegetation are known (10). Retaining snow that falls on site would obviate the need for structural snow-control measures. In locations where precipitation exceeds the storage capacity of vegetation, vegetative treatments can reduce snow transport at a downwind location.

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Vegetation of Roadside Slopes in Massachusetts

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The achievements and conclusions of some of the research carried out on the establishment of roadside vegetation and sand-dune control from 1962-1977 are reviewed. Fall and early spring seedings of basic grasses—creeping red fescue (*Festuca rubra*), Kentucky-31 tall fescue (*Festuca elatior* var. *arundinacea*), ryegrass (*Lolium* spp.), redbud (*Agrostis alba*), and Kentucky bluegrass (*Poa pratensis*)—and a legume, white clover (*Trifolium repens*), are successful for erosion control and vegetative cover on roadsides properly limed and fertilized. Hay, excelsior mat, wood cellulose, and wood-chip mulches provided excellent erosion control and assistance in seedling establishment. For more permanent cover, low-maintenance leguminous species that can be substituted for grasses are crownvetch (*Coronilla varia*), flat pea (*Lathyrus sylvestris*), and lespedeza (*Lepedeza cuneata*), but they require more precise soil preparations of liming and fertilization for establishment. Methods were found of establishing woody species quickly and inexpensively through the use of root cuttings of sweet fern (*Comptonia peregrina*), bristly locust (*Robinia fertilis*), and sumac species (*Rhus* spp.); spot seeding of other woody species and even legumes is successful and inexpensive. Proper wood-chip depth is important. Moving sand dunes on Cape Cod initiated experiments that showed that American beachgrass (*Ammophila breviligulata*) can be successfully grown by machine planting with the use of a complete fertilizer; during the second season, the area was completely covered with beachgrass. Coastal panicgrass (*Panicum amarulum*), weeping lovegrass (*Eragrostis curvula*), and tall fescue provided good cover after having been seeded with a grain drill modified to plant the seeds 2 in. deep. Woody species such as pines (*Pinus* spp.) and bayberry (*Myrica pensylvanica*) can be planted on stabilized dunes as climax vegetation.

With the rapid expansion of the U.S. Interstate system of highways, the Highway Research Board in 1932 created a joint committee to help guide the practical application of roadside development. Some years later, another committee of the same organization was formed to consider the technical and research aspects. Roadside development, then, is concerned with the many facets of a progressive highway construction program, including the historical background of an area, aesthetics, conservation of natural resources, rest areas, scenic overlooks, erosion control, landscaping, safety considerations, right-of-way ramifications, and future development (1).

From 1962 to 1977, the University of Massachusetts was involved in a roadside development research program, the purpose of which was to test new methods and materials for practical and economic stabilization on roadsides in the state.

Field studies showed the value of fescue grass species for stabilizing sandy slopes. The seeds of some of these species were incorporated into the grass slope seed mixture and the per-acre rate of seeding was cut to 100 lb from the previously used 180-lb/acre rate. The value of lime and fertilizer for permanent slope cover, especially for legumes like crownvetch, was investigated and recommendations were accepted by the Department of Public Works. As wood-chip use increased for erosion control on slopes, investigations were directed to the seeding of legumes, shrubs, forbs, and trees into mulched areas. Root cuttings for shrub establishment in mulched areas were also studied. The re-

sults of these studies with the seeding methods mentioned above showed that both methods of vegetating slopes produced rapid cover at a minimum cost.

BACKGROUND INFORMATION

The soils in Massachusetts are classified as Brown Podzolic forest soils, which are formed under deciduous, mixed deciduous, and coniferous forests in a cool humid climate. So the challenge in Massachusetts initially was to grow grasses and legumes, which are the best species for rapid erosion control, in an ecological environment of climate and soil that is conducive to shrub and tree vegetation. Fortunately, the climate is favorable to grass growth.

Some of the problems one encounters when trying to establish grasses, legumes, and forbs along newly constructed highways in Massachusetts are listed below:

1. Shallow topsoil: More than 60 percent of Massachusetts land area is in forest cover, and in areas where tree removal is necessary during construction, a large portion of the topsoil is inevitably removed from the site along with the tree stumps.
2. Acid soils: The topsoil and subsoil are acid due to leaching losses of calcium and magnesium.
3. Sandy soils: The texture of many of the soils is sandy. Such soils have a very low organic-matter content, low percentage of water-holding capacity, and a low basic exchange capacity.
4. Low natural fertility: Most of the soil fertility is in the organic fraction of the soil. Soluble plant-food elements have been lost by leaching, and the original granitic parent material from which the soil was formed contains only low amounts of plant-food elements.
5. Rocks and boulders: Most areas in Massachusetts are glaciated and contain rocks and boulders that interfere with seed-bed preparation.

A typical analysis of an undisturbed sandy loam soil (Merrimac) showed a pH of 4.6; 0.85 percent organic carbon; a total exchange capacity of 6.1 meq of calcium, magnesium, potassium, sodium, and hydrogen; a 30 percent base saturation; and low phosphorus content. The above soil analysis illustrates the low availability of nutrients in the state, and if such soils are to be seeded to grasses and legumes, there is need for the addition of lime, nitrogen, phosphorus, and potassium.