Mounding as a Technique for Restoration of Prairie on a Capped Landfill in the Puget Sound Lowlands

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Abstract

Closed landfills create large open spaces that are often proposed as sites for restored or created ecosystems. Grasslands are probably prescribed most often because of the presumption that grass root systems will not breach the landfill cap. Capped landfills have a number of soil degradation problems, including compaction, decreased permeability, lack of organic material, diminished soil fauna, inappropriate texture, and lack of structure. In this study in the Puget Sound lowlands, Washington, U.S.A., mounding (low sandy-loam mounds, about 20 cm high and 2 m in diameter), addition of fertilizer, and mulching with yard-waste compost were applied to landfill sites as treatments in a factorial-design experiment. Prairie plants (1,344 individuals, 7 species) were planted into 4-m^2 plots (n = 48), and plant growth and survival and the increase in weed biomass were monitored for 3 years. Mulching had no effect on plant survival or growth. Fertilization had a negative effect on *Lupinus lepidus*, a nitrogen-fixing species. Mounding had a positive effect on growth and survival of *Eriophyllum lanatum, Festuca idahoensis*, and *Aster curtus*. *Potentilla pacifica* was indifferent to mounding, and *Carex inops* responded negatively. Mounds should probably be used as one element of a complex of habitats on restored landfills.

Key words: Idaho fescue, landfill, mounding, prairie vegetation, weeds.

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Introduction

Capped landfills have similar soil degradation problems and characteristics as closed strip mines (e.g., compaction, change in soil texture, loss of structure, decreased permeability), and they create problems for revegetation (Corbett et al. 1996). Landfills often have an unstable surface because of subsidence. If their surface is not flat, there may be erosion. To minimize the potential for erosion and breaching of the landfill cap, vegetation cover is usually mandated by regulatory agencies, and fast growth and stabilization of the cover is desirable. Their vegetation is often characterized by the immigration of weedy species (Robinson et al. 1992; Parker et al. 1993; Robinson & Handel 1993).

An impermeable cap, often composed of clay or a geomembrane, covers newer landfills; the cap prevents atmospheric water from entering the fill material and leaving as a toxic leachate. Soil generally covers the impermeable material, although it is often shallow and may create problems associated with low soil volume and low permeability (Moffat & Houston 1991; Handel et al. 1997; Parsons et al. 1998). There may be excessive soil or surface water during the wetter part of the year, and drought may occur during the dry season (Leone et al. 1983). This results in a stressful environment that may have few analogues in natural systems near the landfill (Gilman et al. 1989; Pastor et al. 1993; Kindscher & Tieszen 1998).

Freshly closed landfills have the additional problem of elevated methane and carbon dioxide levels in the soil and around vents, toxic substances working their way to the surface, and reduced rooting volume caused by construction material, old tires, and other non-soil items near the surface (Leone et al. 1977; Huang 1988). In urban areas, revegetation and restoration may be further hindered by mountain bikes, off-road vehicles, continued illegal dumping, illegal camps, and many urban weeds.

The Center for Urban Horticulture at the University of Washington manages a capped landfill adjacent to its Seattle campus as the Union Bay Natural Area. Attempts at prairie grassland establishment on the site have been hindered by three conditions: (1) dry soil in the summer (despite its reputation for rain, Seattle has little precipitation in the summer, and hot dry conditions can exist from August into October, as illustrated by Table 1), (2) flooding in the shallow soil above the impermeable cap in winter and spring, and (3) competition from non-native pasture grasses and weeds.

The objective of this study was to compare the effectiveness of three techniques that have been regionally used for prairie restoration projects on a site that exhibits both seasonal flooding and drought. A cue was taken from the naturally mounded prairies in south

Puget Sound, and mounding was selected as one of the treatments. Mimicry of natural mounds has been used in other restoration attempts (Reader & Buck 1991; Houle 1992; Kukert & Smith 1992; Tiszler et al. 1995; Zemke 1996; Dhillion 1999). Other treatments were the application of composted yard waste as a mulch and the application of a granular fertilizer. These treatments were designed to address the problems of flooding in the winter and spring (the mounds elevate the plants above saturated soil), dry soil in the summer (mulch application has been shown to extend the growth period of *Festuca idahoensis* in the summer), and weed growth. Fertilizer may have an initial benefit to prairie plants, but in the long term it has been shown to encourage weed growth (Ewing 2002).

Methods and Materials

This study took place in a Seattle urban landfill (47°30′ N, 122°13′W), now called the Union Bay Natural Area. The site was a municipal landfill closed by the City of Seattle in 1966, graded to a specified design elevation, and seeded with pasture grasses in 1971. The fill includes refuse and municipal garbage that was placed in a former wetland; the wetland was formed when Lake Washington was lowered by 3.5 m in 1917 to create navigation locks and a connection with Puget Sound. The site is underlain by deep peat. There has been differential settling of up to 6 m since landfill closure.

The 23 ha of the Union Bay Natural Area has a rich bird fauna that depends on open spaces. The site is managed, therefore, under a plan that mandates a large grassland component. Grasslands are a vegetation type commonly installed on landfills, partly because of the ease of planting and maintaining and partly because the conditions on a landfill can be tolerated by grassland species (Worthington & Helliwell 1987; Matsil & Feller 1996). The native grassland of western Washington is found on the prairies that inhabit the glacial outwash to the south of Puget Sound and on the shallow-soil headlands around the sound and on the San Juan Islands. This community was used as the reference for the establishment of a prairie grassland on the Natural Area.

Differential settling of both the fill material and peat that underlies it (the site was once a delta where a creek drained into Lake Washington) has resulted in a rolling topography. Densely compacted subsurface soil (a clayey loam used to seal the landfill cap) has created an edaphic environment that has low summer soil moisture in the marine/Mediterranean climate of Seattle (Table 1) but which is persistently saturated for about 6 months during Seattle's rainy fall and winter.

Forty-eight plots were established on a gently sloping area of the capped landfill on 5 May 1995. Each plot was circular, with an area of 4 m^2. Within each plot, four individuals of seven different prairie species (28 plants per plot) were planted in geometrically fixed locations, one in each compass quadrant of the circle. The species were all natives of the south Puget Sound prairies and were either grown from seeds collected on the prairies or were salvaged from construction sites. The species used were *Festuca idahoensis* var. *roemeri* (Idaho fescue), *Lupinus lepidus* (prairie lupine), *Camassia quamash* (camas), *Potentilla gracilis* (cinquefoil), *Aster curtus* (white-top aster), *Eriophyllum lanatum* (Oregon sunshine), and *Carex inops* (long-stoloned sedge). All species were grown in the nursery in 10-cm pots in non-soil medium (sand, peat moss, and vermiculite). After reaching a sufficient size for transplanting, individual plants were removed from pots, root systems were cut vertically along the sides of the rootmass, and the root system was opened up and placed into a soil hole and covered with native material.

Table 1. Monthly average rainfall (in mm.) for past 35 years at the University of Washington in Seattle. Western Regional Climate Center, National Weather Service.

Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Ann*
125	107	89	58	38	38	24	27	49	82	124	147	911

Festuca idahoensis is a bunchgrass found in the shrub-steppe and sagebrush desert, north into British Columbia and Alberta and south into California and Colorado. It is an important indicator of high-quality prairie in the south Puget Sound prairies and also occurs on open headlands in coastal areas north into the San Juan Islands. The western Washington variant has recently been characterized as *F. idahoensis* var. *roemeri*. *Lupinus lepidus* is one of several nitrogen-fixing lupines of the western Washington prairies. A low woody perennial semishrub, it is characteristic of open prairie environments. *Camassia quamash* is perhaps the species most thought of in conjunction with the prairies because it blooms in profusion, and its starchy bulbs may be the reason that much of the prairie exists; the land was burned by native Americans so that camas bulbs could be harvested. Unfortunately, camas plants do not produce flowers for several (four to five) seasons after their seeds have germinated. They were not found and identified with enough regularity to include them in the analysis. *Potentilla gracilis* is a yellow-flowering cinquefoil 4 to 8 dm tall, usually found widely distributed in western Washington prairies but not in large populations. *Aster curtus* is a "species of concern" under the Endangered Species Act and is listed in Washington state as "sensitive" (Giblin 1997). It is diminutive and rhizomatous and is a hardy plant whose status comes primarily from habitat destruction. It is quite often found growing out of a dense turf of prairie grasses and forbs. *Eriophyllum lanatum* is a low mat-forming composite on the prairies but can also be robust and tall (to 6 dm) in more mesic environments. It is often found colonizing burned or disturbed sites, as is *C. inops*. *Carex inops* is a small sedge, a few centimeters tall on the prairie, often dispersed among the grasses and forbs and with only a few achenes on each plant reaching maturity.

A factorial design was used in this experiment, so that plots were either mounded or not, fertilized or not, and mulched or not. This resulted in eight unique treatment combinations. The plots were placed into six blocks so that all eight combinations were randomly assigned to a block and grouped together in repeated units from the top to bottom of the slope.

Mounds were 20 cm deep at their center and were created with a nutrient-poor sandy gravelly loam trucked to the site. This material was very similar to the landfill cover material brought to the site to cover the impermeable landfill cap. On those plots that had no mounds, vegetation was treated with the herbicide glyphosate, and the plots were tilled after existing vegetation had died. The fertilizer application on the fertilized plots was accomplished with a granular 27-3-4 NPK turf–grass mixture, at the recommended rate of 226 kg/ha. Mulched plots were covered with 10 cm of a locally produced composted yard waste (Cedar Grove Compost, Seattle, WA, U.S.A.). Although the soil had an average of 11 ppm of extractable nitrate and ammonium, the compost had an average concentration of 136 ppm. The soil N level is considered insufficient to support fast-growing plants. The N level in the compost was high, but compost was not incorporated into the soil, reducing nutrient availability from this source.

Soil moisture was determined gravimetrically at the time of planting in May 1995. Moisture for mounded sites was measured in soil adjacent to the mounds to determine the general moisture condition of the area around each mound. The following spring, the presence of standing water in plots was noted and recorded. By 15 June 1995, grasses had stopped growing and were beginning to senesce. The first growth measurement was made at that time. The measurements for each species were as follows: *F. idahoensis*, height, bunch diameter, inflorescence height, and diameter; *L. lepidus*, bunch diameter; *P. gracilis*, height; *A. curtus*, total branch and stem length; *E. lanatum*, length $\times$ width of the mat-forming plant; and *C. inops*, spread, longest axis of clone. *Camassia quamash* was not found. Subsequent measurements were made on 24 September 1995, 10 July 1996, and 31 July 1997. Biomass of mostly non-native invasive weeds in plots was sampled and weighed in August 1997. For this measurement, a right triangle sampling frame was designed to attach to a pin in the center of each circular plot; the sides of the triangle were the length of the radius of the plot and the area harvested within the frame was 0.64 m^2.

Data were analyzed using SAS (SAS Institute Inc., Cary, NC, U.S.A.). Analysis of variance was carried out using the general linear models procedure. Normality of distribution for each variable was checked using the univariate procedure in SAS. Equality of variances was analyzed by plotting residuals using the general linear models procedure. Log or reciprocal transformations, where appropriate, were applied according to Neter et al. (1985). Block effects were included in the models; this resulted in the removal of one source of variation from experimental error (Petersen 1985). For the purpose of the analysis, the mean growth value per plot for each species was calculated using a value of zero for missing plants. For the tabular presentation of growth, zero values for missing plants were not included in the calculation of the mean.

Results

The most important finding based on the measurement of growth of six prairie species was that mounding resulted in significantly greater growth or reproductive output, after the first growing season, for *Festuca idahoensis, Aster curtus*, and *Eriophyllum lanatum* (Table 2). *Potentilla gracilis* did not show a trend in response to mounding. Mulching and soil amendment produced no significant response in any of the species, other than a decrease in growth of *Lupinus lepidus*, a nitrogen fixer, in fertilized plots at the end of the first year of measurements.

Soil moisture was measured in May 1995 and was found to vary significantly among treatment blocks (p = 0.0001). The mean percentages of soil moisture, from blocks 1 through 6, respectively, were 18.5, 20.6, 21.3, 24.4, 23.3, and 28.6. The numbers of plots found with standing surface water in March 1996, for blocks 1 to 6, respectively, were 0, 0, 0, 3, 3, and 7. For several species, there was a significant block effect in plant responses that developed most fully in 1997. For *F. idahoensis*, *E. lanatum*, *A. curtus*, and *P. gracilis* the lowest values for plant growth were measured in the wettest blocks.

The number of surviving individual plants diminished over the four measurement periods. Mortality was slight during the first growing season but increased markedly after the first, and especially the second, winter. After 3 years, 70% of the *F. idahoensis* survived, as well as about 60% of the *A. curtus* and *P. gracilis* (Table 3). Over half of the *E. lanatum* plants had died by the final measurement. All *L. lepidus* plants died of a viral disease during the fall of the first year. *Carex inops* survival could not be enumerated in 1997. Mounding resulted in significantly greater survival for both *E. lanatum* and *A. curtus* in 1996 and 1997. There was no significant difference in survival among any treatments for *F. idahoensis*, *P. gracilis*, or *C. inops.*

Table 2. Mean values for main effects in experimental design, for surviving plants.

	Base		*Amendment*		*Mulch*	
	M	*H*	*F*	*N*	*C*	*B*
15 June 1995						
Festuca idahoensis ht. (cm)	19.69	19.29	19.14	19.84	19.97	19.01
Eriophyllum lanatum length × width (cm^2)	178.23	140.03	149.61	168.65	164.27	153.99
Lupinus lepidus diameter (cm)	11.81	9.69	11.93	9.58	11.61	9.90
Aster curtus total stem length (cm)	17.73	14.95	15.54	17.14	16.20	16.42
Potentilla gracilis height (cm)	3.66	3.22	3.64	3.34	3.72	3.26
Carex inops spread (cm)[a]	3.91	4.26	3.82	4.33	4.15	4.01
24 Sep 1995						
Eriophyllum lanatum length × width (cm^2)	1264.6	2002.6	1541.0	1726.2	1528.7	1738.4
	***					
Lupinus lepidus diameter (cm)	35.22	39.65	34.53	40.34	37.80	37.04
			*			
			*block**			
Aster curtus total stem length (cm)	29.69	25.50	25.85	29.35	29.11	26.08
Potentilla gracilis height (cm)	6.41	7.11	6.86	6.65	6.44	7.07
Carex inops spread (cm)	9.07	12.74	10.18	11.50	10.65	11.05
	*					
	*block**					
10 Jul 1996						
Festuca idahoensis height (cm)	24.24	20.21	21.95	22.50	22.01	22.44
	***					
Festuca idahoensis bunch diameter (cm)	7.31	7.66	7.52	7.45	8.08	6.89
Festuca idahoensis inflorescence height (cm)	102.4	98.1	99.6	100.9	99.3	101.2
	*					
Festuca idahoensis inflorescence number	56.1	51.7	54.6	53.2	52.0	55.8
Eriophyllum lanatum length × width (cm^2)	4703	3961	4126	4614	3941	4830
Aster curtus total stem length (cm)	193.9	106.6	148.3	157.7	137.6	168.0
	***					
Potentilla gracilis height (cm)	55.5	60.5	59.5	56.6	53.8	62.3
	*block***					
Carex inops spread (cm)	19.9	23.8	20.9	22.6	22.6	21.0
31 Jul 1997						
Festuca idahoensis height (cm)	24.42	20.14	22.57	21.88	22.81	21.68
	*block**					
Festuca idahoensis bunch diameter (cm)	3.07	2.02	2.68	2.37	2.46	2.60
Festuca idahoensis inflorescence height (cm)	98.0	100.0	99.8	98.0	97.8	99.9
Festuca idahoensis inflorescence number	48.0	29.1	37.3	39.5	45.4	31.6
Eriophyllum lanatum length × width (cm^2)	3102	2407	2373	3243	2710	2969
	*					
	*block****					
Aster curtus total stem length (cm)	246.3	200.6	213.6	245.2	202.8	259.0
	***					
	*block***					
Potentilla gracilis height (cm)	118.6	116.3	120.7	114.0	134.7	101.0
	*block**					
19 Aug 1997						
Weed biomass, grams dry wt per m^2	527.2	445.9	452.2	520.9	486.0	487.0
	*					

Factorial experiment used three treatments: Base (mounded, M, or not mounded but herbicided, H), Amendment (fertilized or not, F or N), and Mulch (compost mulch or bare surface, C or B). Significant results are shown for main effects, blocking, and interaction terms (* <0.05, ** <0.01, *** <0.001).

[a]There was an interaction ($p < 0.05$) between amendment and mulch for *C. inops*.

Table 3. Percent of individuals surviving for each treatment at each measurement period, and percent of *Festuca idahoensis* plants with inflorescences.

	15Jun95		*24Sep95*		*10Jul96*		*31Jul97*	
Festuca idahoensis	Base		Base		Base		Base	
	M	H	M	H	M	H	M	H
	100	100	100	100	94	82	72	71
	Amend		Amend		Amend		Amend	
	F	N	F	N	F	N	F	N
	100	100	100	100	86	90	75	68
	Mulch		Mulch		Mulch		Mulch	
	C	B	C	B	C	B	C	B
	100	100	100	100	84	92	67	76
Festuca idahoensis with inflorescences	Base		Base		Base		Base	
	M	H	M	H	M	H	M	H
	—	—	—	—	85	72	64	74
	Amend		Amend		Amend		Amend	
	F	N	F	N	F	N	F	N
	—	—	—	—	78	79	70	68
	Mulch		Mulch		Mulch		Mulch	
	C	B	C	B	C	B	C	B
	—	—	—	—	74	83	64	74
Eriophyllum lanatum	Base		Base		Base**		Base**	
	M	H	M	H	M	H	M	H
	98	97	98	97	98	72	64	32
	Amend		Amend		Amend		Amend	
	F	N	F	N	F	N	F	N
	99	96	99	96	82	88	46	51
	Mulch		Mulch		Mulch		Mulch	
	C	B	C	B	C	B	C	B
	97	98	97	98	90	80	51	46
Lupinus lepidus	Base		Base		Base		Base	
	M	H	M	H	M	H	M	H
	100	100	100	100	—	—	—	—
	Amend		Amend		Amend		Amend	
	F	N	F	N	F	N	F	N
	100	100	100	100	—	—	—	—
	Mulch		Mulch		Mulch		Mulch	
	C	B	C	B	C	B	C	B
	100	100	100	100	—	—	—	—
Aster curtus	Base		Base		Base		Base***	
	M	H	M	H	M	H	M	H
	100	96	100	96	94	60	80	39
	Amend		Amend		Amend		Amend	
	F	N	F	N	F	N	F	N
	97	99	97	99	76	78	59	59
	Mulch		Mulch		Mulch		Mulch	
	C	B	C	B	C	B	C	B
	99	97	99	97	73	81	56	63
Potentilla gracilis	Base		Base		Base		Base	
	M	H	M	H	M	H	M	H
	96	97	96	97	72	75	55	61

(*continued*)

Table 3. Continued.

	15Jun95		24Sep95		10Jul96		31Jul97	
	Amend		Amend		Amend		Amend	
	F	N	F	N	F	N	F	N
	97	96	97	96	72	75	63	54
	Mulch		Mulch		Mulch		Mulch	
	C	B	C	B	C	B	C	B
	98	95	98	95	74	73	59	57
Carex inops	Base		Base		Base		Base	
	M	H	M	H	M	H	M	H
	100	100	100	100	82	88	—	—
	Amend		Amend		Amend		Amend	
	F	N	F	N	F	N	F	N
	100	100	100	100	80	91	—	—
	Mulch		Mulch		Mulch		Mulch	
	C	B	C	B	C	B	C	B
	100	100	100	100	82	88	—	—

The number planted was 96 in each treatment level, except for *Carex inops*, for which 74 individuals were planted in each treatment level. A factorial experiment used three treatments: Base (mounded, M, or not mounded but herbicided, H), Amendment (fertilized or not, F or N), and Mulch (compost mulch or bare surface, C or B). Significant differences are shown for main effects (** <0.01, *** < 0.001).

Individual Species Response

The keystone prairie species *F. idahoensis* was fairly indifferent to any block effects until the final measurement period. At that time there was a decrease in both the mean height (27.8–17.8 cm) and surviving number proceeding along a gradient from blocks 1 to 6 (from drier to wetter areas). Of the treatments, mounding resulted in significantly greater plant and inflorescence heights in 1996 and in a greater inflorescence number in 1997. Mean plant height in 1997 was 24.4 cm in mounded treatments and 20.1 cm in unmounded treatments.

The mean area of the mat-forming *E. lanatum* was greater in mounded treatments than unmounded treatments in June 1995, July 1996, and July 1997. The difference was significant in 1997. In 1996 and 1997, survival of clones was substantially greater on mounded plots (98% survival on mounds vs. 72% on unmounded plots in 1996; 64% survival on mounds vs. 32% on unmounded plots in 1997).

The low woody perennial semishrub *L. lepidus* survived for 1 year at the site but then was completely eliminated by a viral die-back that also impacted other populations in the region. During the first year, the species did not respond to mounding but was inhibited by fertilization. By the end of the year, plants in fertilized plots had significantly smaller diameters than those in plots that were not fertilized.

Aster curtus responded to mounding by developing a greater total stem and branch length on mounded plots on every occasion that it was measured. The difference was significant in 1996 and 1997. Survival of individuals was substantially greater on mounded than unmounded plots in 1996 (94% survival on mounds vs. 60% on unmounded plots) and in 1997 (80% survival on mounds vs. 39% on unmounded plots).

The herbaceous perennial *P. gracilis* appeared to be the most environmentally adaptable of the species used in this project. It showed no significant treatment effects. There was a block effect; *P. gracilis* showed persistence in both very dry sites and flooded sites, but survival rates were lower in the wetter more consistently saturated plots.

C. inops plants produced more clonal growth on unmounded sites. This difference was statistically significant in September 1995, at the end of the first summer of growth, but not at end of the following growing season. Measurements in the third year could not be made because *C. inops* was completely obscured by weed growth. Differentiating it from weedy grass species was very difficult, and the resultant data were not dependable.

Aboveground weed biomass (all plant material in plots except those individuals that were planted) was harvested from plots in August 1997, just after the final measurements of native prairie plant growth. The mean value for weed biomass was significantly greater on mounded than unmounded plots (527 vs. 446 g/m^2 dry mass).

Discussion

A surprising aspect of the results of this work was that creating mounds had a measurable effect on plant performance, whereas applying fertilizer or mulching had very little effect. In a previous study using Idaho fescue (Ewing 2002), both fertilizer and mulch had a significant positive effect early but a negative effect over time.

Zemke (1996), on the other hand, found that mounded topsoil plots without compost or fertilizer yielded higher biomass of Idaho fescue and lower weed biomass than composted and fertilized plots after one year.

In the siting of this project, plots were placed along a gradient from well-drained soil to soil that became saturated in the winter. Both summer drought and winter saturation impeded restoration with native plants on the site. Unfortunately, the non-native pasture grasses that were used to seed the landfill when it was capped are quite well adapted to the environment, but natural populations of native prairie species are found on well-drained droughty soils, and they suffer when exposed to winter and spring flooding.

Mounding

During the first year of measurement (1995) few positive effects of mounding could be seen. *Carex inops* displayed significantly less spread on mounded sites than on unmounded ones by the end of 1995. This may be the result of the preference of *C. inops* for moist habitats; the mounds were quite hot and dry the first summer of their installation. Past experience with plantings at this site has shown that saturated soil conditions in the spring caused considerable mortality. For this reason it might be expected that any significant positive effects of mounding would develop after the first winter, and that proved to be the case. *Festuca idahoensis* height and inflorescence production were greater on mounded sites in both 1996 and 1997. *Eriophyllum lanatum* and *Aster curtus* both had their greater growth on mounds in 1996 and 1997. Mortality was always less in mounded (compared with unmounded) plots for *F. idahoensis*, *E. lanatum*, *L. lepidus*, and *A. curtus.*

Mounded grasslands are encountered on most continents, and the existence of the mounds is attributed to fire ants, termites, rodents, fossorial rodents, and various fluvial or seismic events. In Argentina they have been built in seasonally flooded areas by ants (Cox et al. 1992). On the seasonally flooded Okavango alluvial fan in Africa they are created by termites (McCarthy et al. 1998). These works have shown that mounds provide local safe sites for organisms in temporally wet and dry environments.

In the Puget Sound lowlands, theories attribute the existence of mounds to fossorial rodents, earthquakes, floods, and prehistoric agriculture (Kruckeberg 1991). It has been observed that where they exist, mounds result in microsites that are colonized by different species than those that dominate the surrounding flat matrix (McCarthy et al. 1998; Grace et al. 2000). The slight increase in elevation afforded by mounds has been found to induce a host of correlated differences, including soil organic content and soil cation concentrations. Plant groups within Texas coastal prairie were found to be separated by environmental conditions associated with mounded topography; it has been suggested that restoration and conservation efforts will need to consider local topographic influences at such sites to be successful (Grace et al. 2000).

Artificial or created mounds have been constructed in a surprising diversity of environments. Artificial mounds were found to have an impact on the development of *Schizachyrium scoparium* (little bluestem) in *Quercus havardii* (shin oak) communities in west Texas (Dhillion 1999). Mounds that mimic those produced by marine megafauna were found to produce increased benthic diversity over time on the deep-sea floor (Kukert & Smith 1992). Seedling establishment on created mounds similar to those produced by burrowing mammals was found to exceed establishment in adjacent old-field sites (Reader & Buck 1991). *Betula* (birch) seedlings established preferentially on created mounds or in pits in deciduous forest in Quebec; initial survival was greater on mounds because of differences in soil moisture, organic matter, and temperature (Houle 1992). Accretion mounds, which are important habitat for animals and create successional sites for plants, were created in the California desert (Tiszler et al. 1995).

Amendments and Mulching

Mulching had no significant effect on plant responses in this experiment. Its effect would have been expected during the first year, when it could have provided improved moisture conditions (especially on the freshly constructed mounds) by acting as a vapor barrier and by dissipating heat. Nevertheless, no strong pattern emerged, and there were no significant differences between mulched and unmulched plots.

Fertilization had a negative effect on the nitrogen-fixing legume *L. lepidus.* By the second measurement period in 1995, fertilized plots had smaller *L. lepidus* plants. Unfertilized plots had greater survival than fertilized ones for every species in September 1995 and July 1996. Fertilization may suppress nitrogen fixers, as appears to be the case here, but it also encourages fast-growing weedy species (Zemke 1996; Ewing 2002). Often the failure of restoration is a failure to adequately control weeds or to provide an environment in which they do not have a competitive advantage. Survival was more evenly distributed between fertilized and unfertilized plots in July 1997, but by that time any effects of fertilization done in 1995 had probably disappeared.

Conclusions

Mounding had a positive effect on growth and survival of several species. Mulching had no effect in this study, though it has shown to improve summer soil moisture availability in other work (Ewing 2002). Fertilization had a negative effect on the nitrogen-fixing lupine and was associated with its lower survival. Mounding is a good restoration technique on landfills, but some species either did not respond to it or responded negatively. Mounds should probably be used as one element of a complex of habitats, especially to support species that are sensitive to flooding.

After 3 years of growth, weedy species, some of them the pasture grasses planted on the site decades before, were choking out the prairie species that were planted in 1995. This emphasizes the fact that strategies like mounding and mulching will provide microhabitats in which prairie species will survive but they do not eliminate the problem created by the presence of invasive species. Soil impoverishment by removal of organic material has been tried at the site and appears to be effective as part of an integrated treatment (Ewing 2002).

A suggested strategy for prairie introduction on capped landfills might include early control of the site so that weedy or competitive species are not introduced or quick removal if they immigrate onto a site. A complementary strategy is impoverishment of the soil. One way of accomplishing impoverishment is the addition of a surface layer of sand or gravel. Mounds and other microsites may be created to increase habitat diversity. Finally, an invasive species control strategy must be put into effect. Weedy species must be manually or chemically removed, or burning, grazing, or some other technique for preferentially giving native prairie plants an advantage must be used. Initial attention to removal of invaders as they appear will result in a much lower presence of these weedy species in the soil seed bank.

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